BMC Zoology

RESEARCH Open Access

Distribution range and human-hippopotamus (*Hippopotamus amphibious*) conflict in the Lake Tana biosphere reserve, Ethiopia

Getasew Mulu[1] and Dessalegn Ejigu[1*]

Abstract

Background Hippopotamus (*Hippopotamus amphibious)* is a semi-aquatic mammal that is considered the third largest living land mammal still alive on earth. The main objective of this study was to determine the distribution range and human-hippopotamus conflicts in the Lake Tana Biosphere Reserve, Ethiopia. Data were collected from June 2022 to January 2023. Total count methods were used to estimate the hippopotamus population, and Arc GIS was used to determine the distribution range and habitat suitability of hippopotamus. Structured questionnaire and focus group discussions were used to collect data on human-hippopotamus conflict. Data were analysed using One-way ANOVA, independent t-test, and chi-sqaure test.

Results The mean population estimation of hippopotamus in in the study area showed 252.67 ± 15.9 with a density of 0.072 individuals per km^2. The suitable slope analysis of hippopotamus along the the Lake Tana Biosphere Reserve's shoreline revealed that 4.7% of the shoreline was most suitable, 48.4% moderately suitable, and 46.9% not suitable. Variations in the hippopotamus' habitat suitability within the study area have been associated with a number of factors including availability of water, food, elevation, and vegetation cover. Crop raiding and overgrazing were the primary causes for conflict.

Conclusion In order to conserve hippopotamus in the in the Lake Tana Biosphere Reserve, appropriate conservation measures including habitat protection and restoration, and community engagement and education need to be developed. Moreover, further research on the ecological aspects of the Lake's ecosystem is required to ensure the conservation of hippopotamus.

Keywords Aquatic habitat, Coexistence, Conservation, Distribution, Human perception

*Correspondence:
Dessalegn Ejigu
dessalegn_ejigu@yahoo.com
[1]Department of Biology, College of Science, Bahir Dar University, Bahir Dar, Ethiopia

Background

Hippopotamus is a semi-aquatic animal that is considered as the third largest living land mammal on earth next to rhinoceros and elephant. It is a common name for the two species of Artiodactyl that constitute the family *Hippopotamidae* including the common hippopotamus (*Hippopotamus amphibius*) and the pygmy hippopotamus (*Hexaprotodon liberiensis)*, respectively Vulenrable and Endangered species under the IUCN redlist [1–3]. Hippopotamuses have two essential ecological requirements; water in which to submerge and spend majority of the day, and at night they use the nearby grassland for foraging [1, 4]. Thus, they need a supply of permanent water and adequate grazing land [5]. Water is required for their thermoregulation, and hippopotamus is thus never found far from water [6]. Hippopotamus is regarded a keystone species in the river and lake habitats and categorized as an iconic African mega-herbivore [7].

The life span of hippopotamus in the wild ranges from 35 to 50 years [1]. Females reach sexual maturity from nine to ten years, while males become sexually matured at eight years [8]. Mating in hippopotamus mainly takes place in water and breeding is not strictly seasonal [9], but most conceptions occur during the dry season and birth peaks during the wet season. Gestation period in hippopotamus is eight months [10], and normally a single calf is born [1]. Humans are its major predators, while lions, hyaenas, and crocodiles predate the young [9].

Hippopotamuses are highly gregarious and are territorial only when they are in the water [9]. Males defend territories against other males and territories are established to defend mating rights rather than food. Females are non-territorial and are not necessarily confined to a specific place. In hippopotamus, there are no social bonds between the adults within a group though they lie in close contact with each other. The social bonds are between the mothers and daughters, while males form separate bachelor groups [11].

Historically *Hippopotamus amphibius* occupied an extensive range in Africa [3] and were considered abundant. However, at present, its distribution is patchy and uneven and the recent overall population estimation is ranged between 115,000 and 130,000 individuals [3]. They spread over 19 African countries but they are relatively more abundant in Cameroon and Burkina Faso [12]. Permanent river systems or water-rich environments such as dams or wetlands can be considered suitable habitat for hippopotamus. There must be deep pools with gradually declined bottom slopes, dry sandbanks, and at least a 5 km radius supply of suitable land for grazing [13]. Hippopotamus population distribution was found to be influenced by grass species diversity and amount of biomass produced [14]. The distribution pattern and population size of the common hippopotamus is currently assessed as vulnerable by IUCN due to population decline across its ranges, and habitat loss and poaching are the major causes of such decline [3].

In East Africa, Tanzania has the highest number of hippopotamuses [3], and in Ethiopia, recent surveys suggest that the species is found from the Djibouti border across the highlands to the south and southwest, with the Setit River marking its northernmost range [15]. The hippopotamus population in Ethiopia is estimated to be around 2,500 individuals [3].

In studies of habitat distribution range of animals, vegetation indices derived from satellite based remote sensing data, such as the Normalized Difference Vegetation Index (NDVI) are being used more and more as indirect measures of forage abundance and habitat quality. As reviewed in [16], NDVI has been used to analyze animal habitat relationships in a variety of species. Animals choose their habitats based on a strategy that increases their chances of surviving and reproducing successfully [17]. Basic requirements such as food, cover, space, and water must be met by an organism in sufficient amounts and of suitable quality in order for an organism to reproduce and sustain a viable population. Thus, determining the limiting factors and optimal values for food, cover, space, and water are the requirements for habitat management [18].

Human-hippopotamus conflict is one of the current challenges facing its conservation. Hippopotamuses differ from other mega-herbivores in having a dual requirement of daily living space in water and an open grazing range often visited at night [1]. This requirement affects the manner in which hippopotamuses utilize resources and survive in areas dominated by high human population densities and continuous land use changes. Conversion of hippopotamus' terrestrial habitat and diversion of water for agriculture and human settlements largely contribute to the loss, degradation, and fragmentation of suitable habitats.

Hippopotamus-human conflicts are reported from several countries in Africa including Ethiopia [19]. According to [20] human-hippopothamus conflict poses a serious problem for both local farmers' livelihoods and hippopothamus conservation in the LTBR. Most records refer to crop damage, attacks on fishermen by destroying fishermen's nets or attacking their boats, and loss of human life [11, 19]. The damage caused by hippopotamus is often far greater than the other common agricultural pests. This is because their raids are unpredictable, more damage per raid, trampling and destroying certain areas of the field [11]. This growing conflict threatens both the economic stability of residents and the survival of hippopotamus, highlighting an urgent need for sustainable conflict mitigation and conservation strategies. We hypothesized that no interference between hippopotamus' home range and local communities' farmlands along the shorelines of the LTBR. In this regard, quantitative and qualitative data on hippopotamus' ecology and their population distribution in the LTBR landscape would be of great importance to provide essential information to decision makers for their management and their conservation strategy. The main objective of this research is to determine population estimate, distribution range, and human-hippopotamus conflicts Thus, the findings will inform the development of effective management strategies focused on habitat protection and restoration, along with community engagement and education to support hippopotamus conservation in the LTBR.

Materials and methods

Description of the study area

Lake Tana is one of the largest lake in Ethiopia and the source of the Blue Nile River. It is located in Amhara Region, northwestern Ethiopia, 565 km from the capital Addis Ababa. The Lake is 84 km long and 66 km wide and its maximum depth is 14 m with the mean depth of 9 m. Its surface area ranges from 3,000 to 3,500 km^2 depending on the season and amount of rainfall. Geographically, the lake is situated between 11° 41' 5.3" N latitude and 37° 20' 27.1" E longitude with average elevation of 1788 m a.s.l. It is bordered by Dembia Woreda in the north, Gondar Zuria Woreda in the north and northeast, Libokemkem Woreda, Fogera Woreda, and Dera Woreda in the east, Bahir Dar Zuria Woreda in the south east, south, and southwest, North-Achefer Woreda and Alefa and Takusa Woreda in the west (Fig. 1). It is surrounded by different wetlands and has more than 40 tributaries [21]. There are only a few remnants of the LTBR's original mountain ecosystem and forest vegetation, which boasts a high level of globally significant plant species. Native trees that can be found in the LTBR include *Albizia gummifera*, *Millettia ferryginea*, and *Cordia africana.*

Lake Tana Biosphere Reserve is home to a diverse range of wildlife, both aquatic and terrestrial, making it an important habitats of biodiversity conservation. Some of the wildlife species of the Lake include Nile tilapia, catfish, frogs, Nile crocodile, Nile monitor, different bird species including the White Pelican, Marabou Stork,

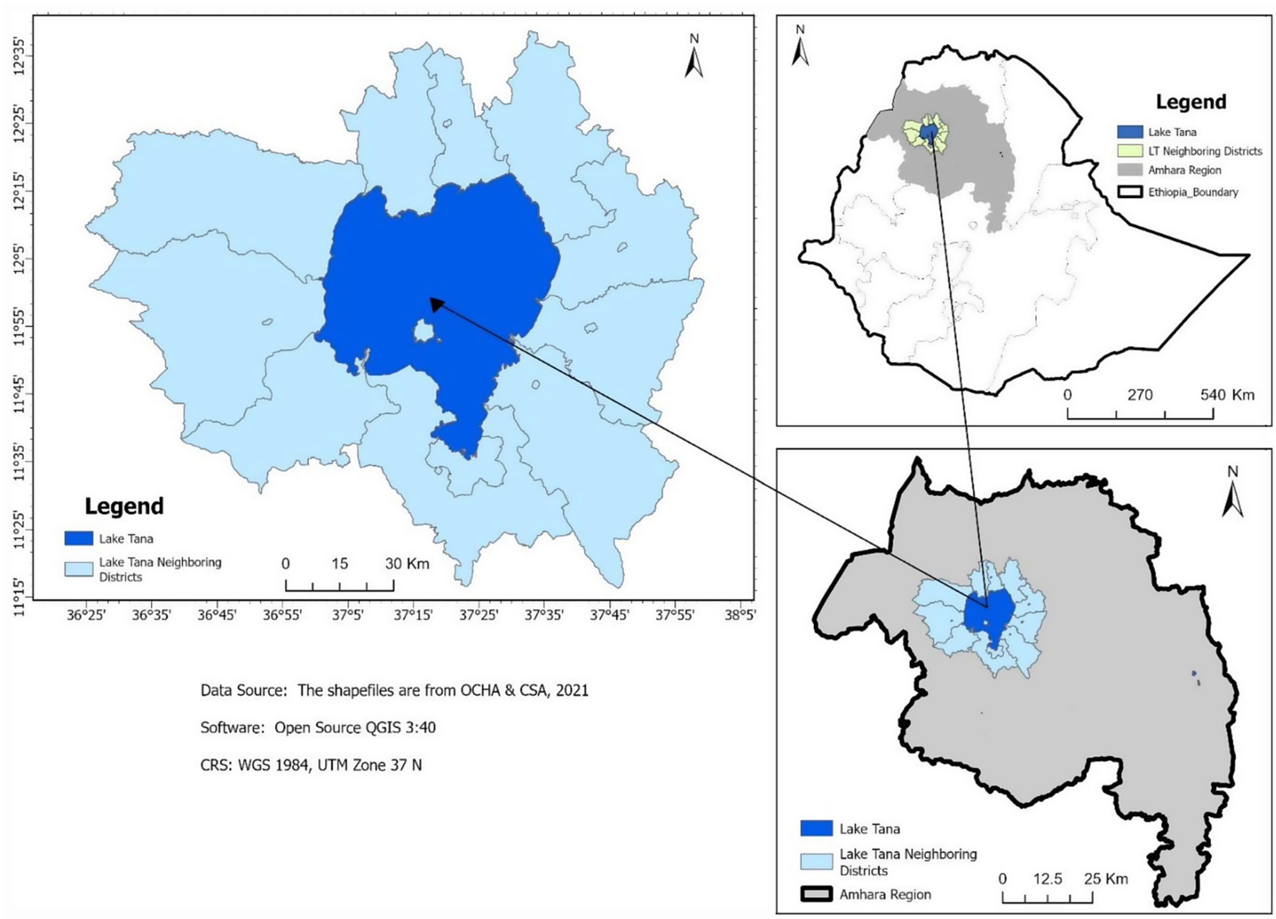

Fig. 1 Location map of the study area

Saddle-billed Stork, African Fish Eagle, Blue-winged Goose and Tana Weaver, and different species of mammals including grivet monkey, Anubis baboon, colobus monkeys, and antelopes.

Methods

Data for population estimate, distribution range, and human-hippopotamus conflict were collected in LTBR from June 2022 to January 2023. Major wetlands suitable for hipopotamus were identified and mapped using Arc GIS 10.71. We used the total count method [22, 23]) to determine population estimation of hippopotamus in the LTBR. Presumed hippos' habitats were divided clearly into defined and nonoverlapping sections. Two groups of researchers with five individuals each walked simultaneously using a straightline transect along the shore of the Lake on its opposite sides. Each group of researchers was assigned to specific locations of the lake where hippopotamous inhabits, and population counts were conducted at the same time to prevent hippopotamus from moving between habitats and being counted twice. Moreover, researchers also communicated among themselves using phones to check hippopotamus movements. Population estimates were performed twice a day in the morning from 08:00 to 12:00 and in the afternoon from 14:00 to 18:00 when hippopotamuses were most active and visible [24]. Population counts were carried out twice per month for six months, and then the average number of hippopotamus per count was calculated and monthly population means were obtained to determine population estimation of hippopotamus in the LTBR.

Data for distribution range and habitat suitablity of hippopotamus were adopted from [25]. Distribution and habitat use of hippopotamus depend on the suitability of the nearby buffer zone, which depends on three major factors including the lake shore elevation, grazing ground proximity, and human settlement and livestock disturbances (Table 1). Grazing ground suitability on the basis of proximity to resting water, and settlement and livestock disturbance were classified and reclassified using multiple rings buffer analysis on Arc GIS 10.7.1. The elevation classes which helped hippopotamus' movement to the land were identified as adopted from [26] and field observations.

The variety of habitat types surrounding the LTBR determine the availability of forage for hippopotamuses and was used to assess their spatial distribution. Thus, habitat suitability of hippopotamus was determined on the basis of its density in different habitats. Some habitats consisted of larger density of hippoptamus compared to others indicating habitat suitability [27].

Data for human-hippoptamus conflict were collected from five villages selected on the basis of their proximity from hippopotamus sighting areas [28], using structured questionnaire, focus group discussions, and observations. A total of 200 individuals (males = 107 and females = 93) were purposively selected and participated for data collection using questionnaire survey. Villages located from 0 to 5 km apart from the Lake boundary were used during data collection. The five villages were selected from five Woredas namely; Dembia, Fogera, Dera, Bahir Dar Zuria, and North Achefer. Thus, perception of the local community towards hippopotamus was assessed. Moreover, five focus group discussions, one from each Woreda, were carried out to collect additional information on human-hippopotamus conflict by participating elders, Kebele Administrative leaders, and other knowledgeable individuals, and six to nine individiuals participated in each focus group discussions.

Questionnaire survey participants and focus group discusants were purposively selected based on individuals whose cultivated land is near the lakeshores, wetlands, or hippopotamus habitats; fishermen who use the Lake for their livelihoods and may encounter hippopotamus during fishing; other local residents who live where hippopotamus are commonly observed; and community leaders who can provide insights on collective experiences and responses to conflicts.

Data analysis

One-way ANOVA was used to compute population estimate of hippopotamus among the different months. Independent samples t-test was used to compare the highest and the lowest hippopotamus' population estimates, and between female and male population estimates. Arc GIS 10.7.1's multiple rings buffer analysis was used to determine the distribution range and habitat suitability of hippopotamus. The habitats in the LTBR were classified from most suitable to not suitable areas for hippopotamus. Getis-Ord Gi* statistic (Z) [29] was computed using algorithms in ArcGIS 10.7.1 [30] to evaluate the hippopotamus' spatial distribution and to indentify its distribution hot spots. Chi-square test was used to compare perception of people towards conservation of

Table 1 Habitat suitability analysis for hippopotamus in the LTBR

Criteria	Suitability class			Source
	Highly suitable	Moderately suitable	Not suitable	
Elevation	1634–1900 m	1900–2000 m	> 2000 m	Dietz et al. (2000)
Grazing land proximity	2–5 km	5–10 km	> 10 km	Wengström (2009)
Settlement and disturbance	5.5 km	3 km	0.5 km	Tracy (1996)

Table 2 Mean monthly population estimations of hippopotamuses after six months survey (June–December 2022) in the LTBR

Months	Population structures			Population size
	Male	Female	Young	
July	100.1±12.0	108.3±9.16	52.1±4.5	260±12.4
August	98.6±8.1	104.8±7.45	61.3±4.1	263±8.9
September	107.2±9.5	102.4±5.03	53.3±7.5	262±10.3
October	95.2±6.3	105.1±7.64	49.0±4.4	249±9.5
November	98.4±8.5	103.0±5.91	46.5±4.0	247±11.2
December	93.8±10.3	99.5±10.33	44.2±6.7	235±10.6
Average	**98.5±4.9**	**103.5±3.2**	**50.8±6.1**	**252.7±15.9**

Table 3 Sex and age ratio of hippopotamus after six months survey (June 2022 - January 2023) in the LTBR

Months	Sex and age ratio		
	Male: Female	Young: Adult	Young: Female
July	1:1.08	1:4	1:2
August	1:1.06	1:3	1:1.7
September	1:0.95	1:4	1:1.9
October	1:1.10	1:4	1:2.1
November	1:1.05	1:4	1:2.2
December	1:1.06	1:2	1:2.3
	1:1.06	**1:4**	**1:2.03**

hippopotamus in the LTBR. Statistical Package for Social Sciences (SPSS) version 26.0 at 0.05 level of significance was used to run the analysis.

Results

Population estimatations of hippopotamus

The total mean population size of hippopotamus estimated in the LTBR was 252.7 ± 15.9. There was a significant difference in population size counts among the different months ($F = 38.5$, $df = 5$, $p < 0.05$). The mean population density estimated for hippopotamus was 0.07 individuals/km^2. The highest population estimate recorded was 263±8.9 individuals during August and the lowest was 235±10.6 individuals during December, and there was a significant difference between the highest and the lowest population estimates of hippopotamus ($t = 4.4$, $df = 2$, $p < 0.05$) (Table 2).

There were more females compared to males, and the difference showed statistically significant ($t = 4.14$, $df = 1$, $p < 0.05$). The adults constituted 79.9% ($n = 202$) and the youngs were 20.1% ($n = 51$) of the total hippopotamus population. Males and females represent 39% ($n = 99$) and 40% ($n = 101$), respectively. The sex ratio of male to female was 1:1.06. Young to adult was 1:4, and young to female was 1:2.03 (Table 3).

Table 4 Factors affecting habitat suitability for hippopotamus in the LTBR

Parameters	Parameters' classes	Degree of significance
	1781–1800	Most suitable
Elevation (in m)	1800–1830	Suitable
	1830–1900	Moderately suitable
	1900–1970	Less suitable
	1970–2080	Least suitable
	-0.22–0	Water body
NDVI	0.0–0.15	Very low vegetation
	0.15–0.30	Less vegetation
	0.30–0.4	Moderately vegetation
	0.4–0.58	High vegetation
	0–2	Most suitable
Slope (in %)	2–5	Suitable
	5–8	Moderately suitable
	8–15	Less suitable
	> 15	Least suitable

Distribution and habitat suitability of hippopotamus in the LTBR

The three main variables that affect habitat suitability for hippopotamus; elevation, vegetation index, and slope were analyzed. Thus, based on each factor's ecological significance for hippopotamus, five suitability classes were created (Table 4).

The elevation range of the LTBR as displayed by the digital elevation model is from a very low altitude of 1646 m to 2394 m a.s.l. According to [1] hippopotamus occurs between 200 and 2000 m a.s.l. We estimated the highest elevation limit of LTBR to be about 2000 m. Hence, based on this evidence the elevation classes from 1646 to 1900 m were considered more suitable, from 1900.1 to 2000 m moderately suitable, and above 2000 m not suitable. Therefore, the GIS spatial elevation suitability analysis showed that majority of the study area's altitudes fell into a class that was less suitable for hippopotamus. The NDVI suitability criteria showed that about 2.1% of the LTBR is most suitable, 30.5% moderately suitable, and the remaining 67.4% not suitable. The hippopotamus's form and size made difficult for it to ascend steep slopes. Therefore, the suitable slope values were those that indicate hippopotamus-friendly travel. The suitable location was determined to be within an estimated 5 km buffer zone of the Lake. Hence, just 4.7% of the LTBR shorelines were deemed to be most suitable, 48.4% moderately suitable, and 46.9% not suitable (Fig. 2).

The weighted overlay of each criterion is calculated using the pairwise comparison matrix of ArcGIS software 10.8, which compares the relative relevance of two criteria. As a result, the pairwise comparison matrix was created by taking into account the relative importance of each criterion and comparing them one-to-one using a pairwise scale. The criteria were weighted using 1–5

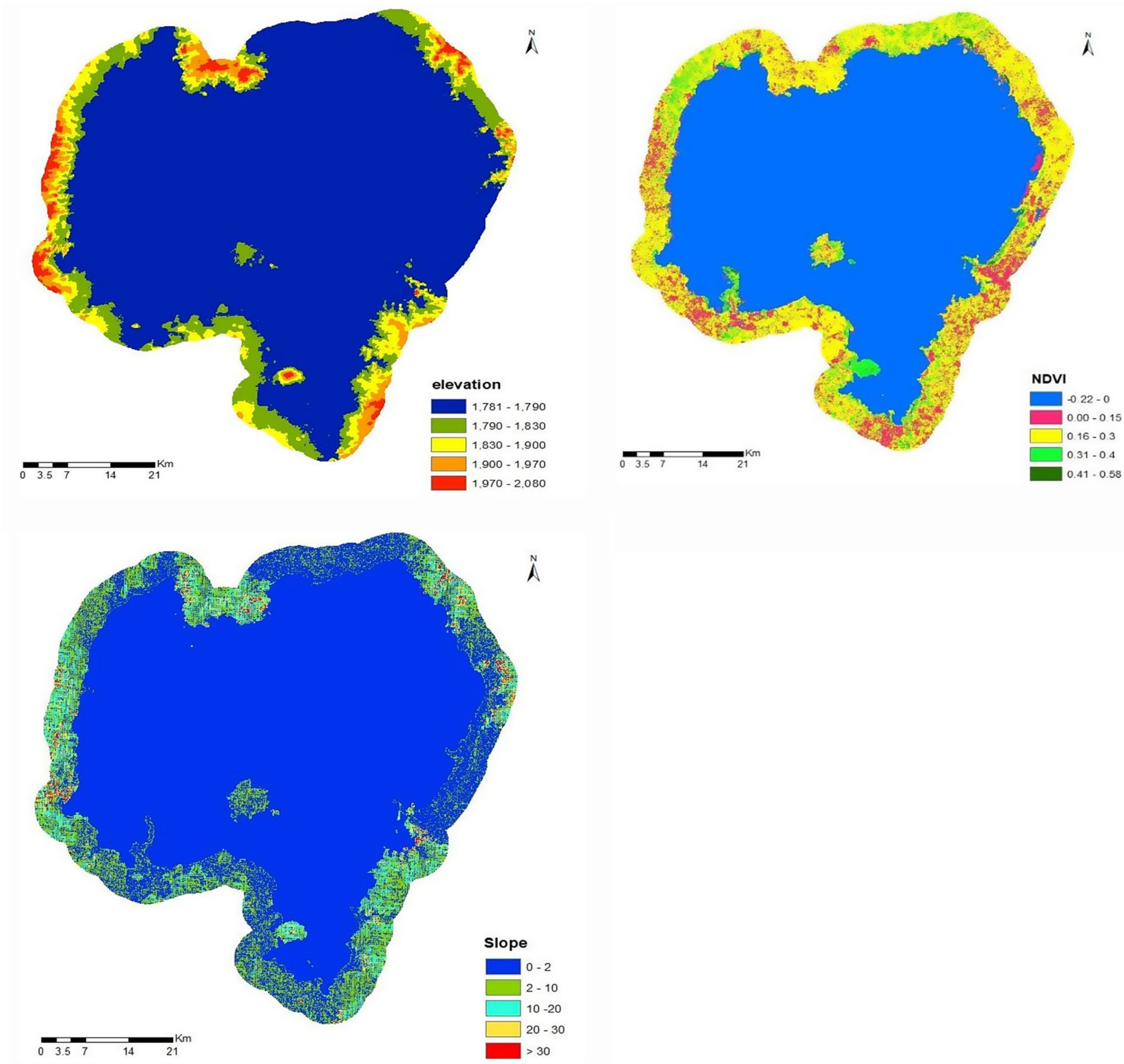

Fig. 2 Habitat suitability of hippopotamus in the LTBR based on elevation, NDVI index, and slope

scale, with the highest value (5) and the lowest value 1 representing the "most suitable" and the "least suitable", respectively. The weights of each sub-criterion were determined using the logic for elevation, NDVI, and slope with a value of 30%, 40%, and 30%, respectively. The final weighted overlay result was categorized into three classes as highly suitable, moderately suitable, and less suitable (Fig. 3).

The distribution range of hippopotamus was also disrupted by the dispersion of grazing territory and competition with domestic animals in the same area. Our field study revealed that people who lived near the lake built different types of fences to keep hippopotamus from entering their territories. The man-made obstacles that hanged the hippopotamus were the gravestone barricades and the holes built especially for this purpose. Majority of hippopotamus suitable habitats were located behind settlements. As a result, because of natural or man made obstacles, 78.8% of the lakeshores were not suitable for hippopotamus grazing (Fig. 4). The highest levels of livestock and human disturbances on the hippopotamus habitat in the LTBR environs showed that only 1.8% of the projected terrestrial habitat was free from human interference, 47.3% was moderately disturbed, and 50.9% was severely disturbed, and making it difficult for hippopotamuses to survive.

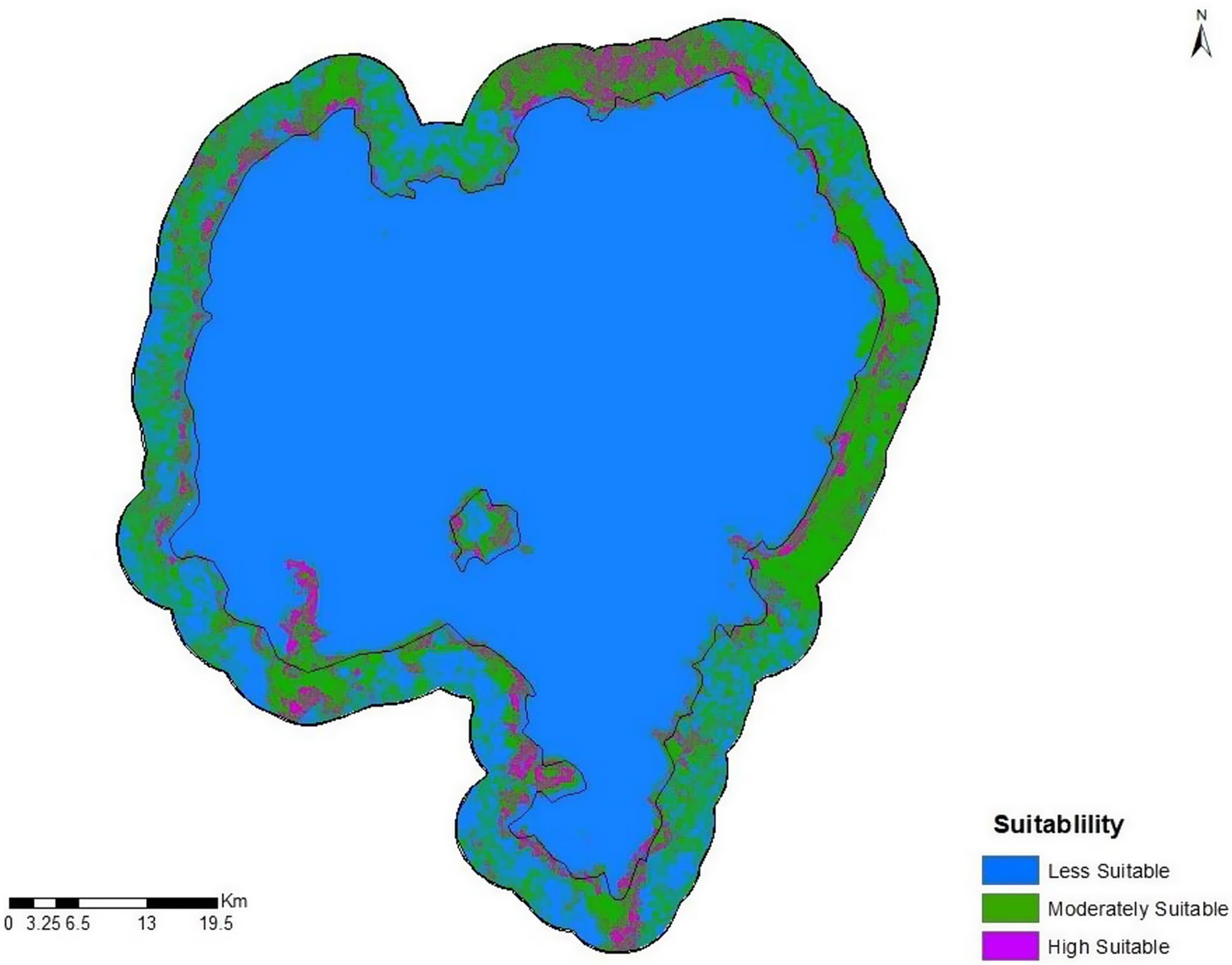

Fig. 3 Habitat suitability of hippopotamus in the LTBR based on the weighted overlay of elevation, NDVI and slope

Local communities' opinion on human- hippopotamus conflict in the LTBR

A total of 200 individuals were participated of which 53.5% ($n = 107$) were males and 46.5% ($n = 93$) females. The age category of respondents ranged from 18 to 75 years. Majority of the respondents (62%, $n = 124$) were from 35 to 54 years. When perception of the local people towards hippopotamus was assessed, 39.5% ($n = 79$) of them showed positive attitude, 36.5% ($n = 73$) negative attitude, and 24% ($n = 48$) remained neutral (Table 5).

When the educational level of the respondents was assessed, 64% ($n = 128$) of them did not attend conventional school, 20.5% ($n = 41$) informal education, 8% ($n = 16$) primary education, and 7.5% ($n = 15$) attended secondary education. Relatively more respondents 43.5% ($n = 87$) showed positive attitude towards the conservation of hippopotamus compared to those who showed negative attitude 32.5% ($n = 65$), and the difference was statistically significant ($\chi^2 = 152.00$, df = 1, $p < 0.05$).

When the main causes of human-hippopotamus conflict were assessed, 68.5% ($n = 137$) of the respondents replied that crop raiding was the primary cause, 19% ($n = 38$) described the cause was due to overgrazing, and 12.5% ($n = 25$) claimed that the cause of conflict was due to human and livestock injuries. The local people's responses to the factors that lead to conflict between humans and hippopotamus varied, and these differences revealed a significant difference ($\chi 2 = 386$, df = 2, $p < 0.05$). Crop damage assessement in Ethiopian Birr (USD) per housedhold within the hippopotamus habitats in the LTBR revealed that maize was the first crop damaged by hippopotamus, followed by sorghum, teff, and wheat (Table 6).

The local communities in the study area have been used different techniques or strategies including fences, digging ditches around crops, group vigilance, and planting less palatable crops to minimize crop damage by hippopotamus and then to mitigate human-hippopotamus conflict. Our results showed that about 79.5% ($n = 159$) of the respondents claimed that farmers should be compensated by the government for the crops damaged by hippopotamus. About 6.5% ($n = 13$) of them replied that to

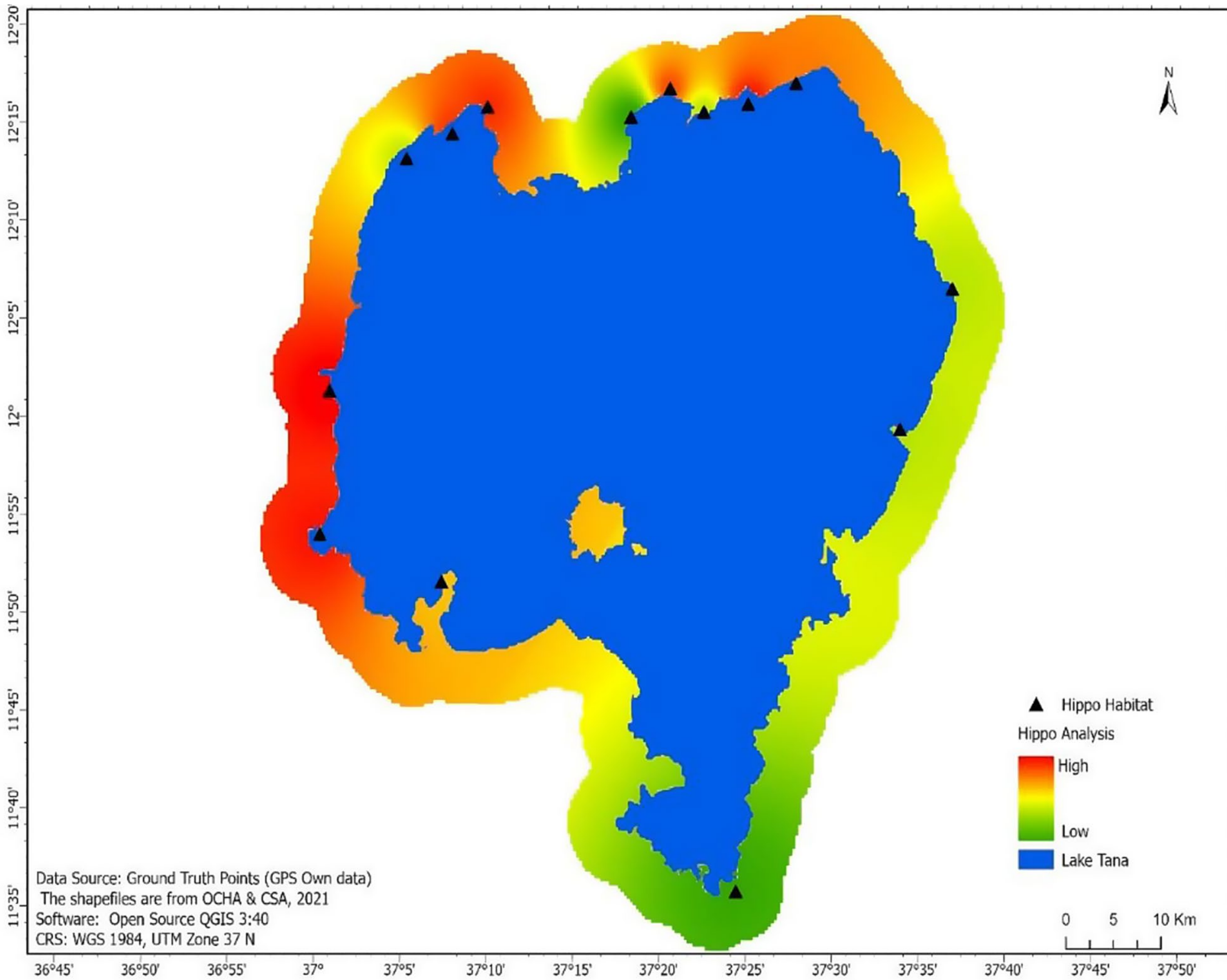

Fig. 4 Settlements and livestock disturbance in the hippopotamus habitats of the LTBR

Table 5 Age groups and perception of the local people towards hippopotamus in the LTBR

Age groups	*N*	Perception of the local people		
		Positive	Negative	Neutral
18–24 year old	20 (10%)	30% (*n* = 6)	5% (*n* = 1)	65% (*n* = 13)
25–34 year old	15 (7.5%)	46.6% (*n* = 7)	46.6% (*n* = 7)	6.6% (*n* = 1)
35–44 year old	75 (37.5%)	38.6% (*n* = 29)	44% (*n* = 33)	17.3% (*n* = 13)
45–54 year old	49 (24.5%)	57.1% (*n* = 28)	30.6% (*n* = 15)	12.2% (*n* = 6)
> 55 year old	41 (20.5%)	21.9% (*n* = 9)	41.5% (*n* = 17)	36.6% (*n* = 15)
Total (%)	**200 (100%)**	**39.5**% (*n = 79*)	**36.5**% (*n = 73*)	**24**% (*n = 48*)

minimize crop damage, hippopotamus should be killed, and about 5.5% ($n = 11$) of the respondents suggested that it is better to use different traditional control methods to minimize the damage caused by hippopotamus.

Table 6 Annual crop loss due hippopotamus around the LTBR

Type of crop	Loss of crop in (kg/household)	Cost estimation (in Ethiopian Birr/household)	Rank of damage
Maize	278	6,116 (46.58 USD)	1st
Sorghum	195	5,460 (41.58 USD)	2nd
Teff	26	1,040 (7.92 USD)	3rd
Wheat	15	420 (3.20 USD)	4th

Moreover, 7.5% ($n = 15$) of them have proposed that translocate hippopotamus to other areas would be ideal solutions to minimize crop damage in the area.

Generally, majority of the respondents claimed that hippopotamus cause severe crop damage directly by foraging. Since the community around the LTBR are farmers, crop raiding by hippopotamus could affect their survival. As a result, they have negative attitude towards conservation of hippopotamus in the area.

Discussion

Population estimations of hippopotamus

Population estimations of hippopotamus in the LTBR have revealed spatial and temporal variations. A higher population estimates of hippopotamuses was recorded in August, likely due to their increased activity and visibility during the rainy season compared to the dry season. The findings of the present study are consistent with those of [31] who found that cloudy skies and mild temperatures seemed to make hippopotamus more active than they were during the dry season. Rainfall promotes the growth of vegetation and creates the ideal environment for hippopotamus to be more visible near the shorelines during the rainy season. As a result, during the wet season, hippopotamuses congregate along the shorelines to feed, making them easier to observe during the time of population surveys and this results the highest population estimate during August.

The sex ratio of hippopotamus in the LTBR showed that there are relatively more females than males as it is typical of other mammalian species [32]. Studies have shown that males are more likely to die in violent interaction with other males such as in territorial disputes during mating [33, 34], and this could justify the presence of more females than males in the population. A female-biased population is more favorable for population growth because more females contribute to reproduction. However, hippopotamus population in the present study area is composed of more adults than youngs, and a population dominated by adults suggests that fewer calves are being born or surviving to adulthood. This might be caused due to various factors including environmental stress, food scarcity, human disturbances or disruption in mating patterns.

Age distribution and sex ratio are critical indicators of population health, reproductive potential, and long-term viability. Thus, understanding the age distribution and sex ratio are essential for assessing the status of the population since these factors reflect population dynamics [35]. Therefore, the hippopotamus population's higher proportion of females than males may result from the fact that males are more likely to die in violent interactions with other males. A small proportion of youngs compared to adults were observed, and this result is also in line with the findings of other researchers since calves become vulnerable to predators including hyenas, crocodiles, and diseases [3]. In the LTBR, the young hippopotamuses are also affected by flooding that might contribute for high mortality rate in calves. There are also several reasons for the declining of young hippopotamus including they are more likely to be killed by humans or other animals, and high mortality rate of the species [9, 36].

The presence of more adult females than calves suggested that the hippopotamus population in the LTBR may be in decline overtime. Moreover, according to [3], hippopotamuses are one of the species in Africa that are more vulnerable to extinction. Due to human disturbance, their populations have decreased in the majority of sub-Saharan African countries [11]. The International Union for Conservation of Natature (IUCN) reported that hippopotamus is becoming less common in many of the countries where it is found. In 1996, the the IUCN classified *Hippopotamus amphibious* as Least Concern. It was estimated with about 115,000 to 13,000 individuals accounting for common hippopothamus [1, 3]. Later in 2006, they were listed as vulnerable [12]. Two human causal factors have been identified as the causes for such declines include habitat degradation since wetlands being converted to agricultural land, and uncontrol hunting for meat and ivory [11, 12]. In some area like Tanzania, local communities suggested the extermination of hippopotamus to mitigate their trampling and crop-raiding behavior [37, 38]. Similarly, in the present study we know that the local communities have attempted to kill hippopotamuses to prevent crop raiding.

Distribution range and habitat suitability of hippopotamus in the LTBR

The findings of this study indicate that habitat destruction due to various human activities significantly impact the distribution and survival of hippopotamus populations in the LTBR. The presence of man-made barriers, such as gravestone barricades and purpose-built holes, restricts the movements of hippopotamus and limits access to essential grazing areas. Moreover, the competition with domestic livestock and increasing human settlements have further reduced the availability of suitable habitats. The study revealed that majority of the lakeshores are unsuitable for hippopotamus grazing, emphasizing the extent of habitat loss. Moreover, the assessment of habitat disturbances highlights that only small proportion of the terrestrial habitats of the LTBR remain undisturbed, while morethan half of its habitats face severe human interference. Such high levels of disturbance pose a significant threat to the survival of hippopotamus populations, as they rely on undisturbed areas for grazing, reproduction, and social interactions.

As the rainy season ended, hippopotamuses showed a significant increase in their association with the shoreline vegetation in the LTBR. As reported by [31] a shift in the frequency and abundance of hippopotamuses to temporary water sources occurred as the rainy season progressed. Hippopotamuses are well-adapted to aquatic life [37]. They never located far from water since water is necessary for their thermoregulation [6]. They are severely affected by foraging, especially during the dry season when the grasses dry out. As a result, they migrate seasonally into the area where abundant green forage is available in different habitat types. They have a high preference for riverine vegetation during the dry season and grassland vegetation during the rainy season based on a comparison of seasonal variations in habitat association.

Based on field observation and Satellite image analysis of the LTBR, the slope classes that facilitate hippopotamus' movement to the land have been identified. Consequently, it was determined that a lakeshore gradient of less than 7% would make a suitable grazing ground for this species. According to [26] the shape and body size of hippopotamus can result in accessibility issues at places with a high slope. Thus, as the species' body size and structure prevented it from ascending steep gradients, the suitable slope values were those that represented a journey that was favourable to it. As a result, hippopotamuses prefer to rest in areas with slow moving, moderately shallow banks with gentle slope because they can lie partially immersed in water.

The distribution of hippopotamus in the LTBR revealed that they are drawn to open, shallow, stagnant, and slowly moving water that can cover their bodies far from the land line. This supports the findings of [1] who found that open, slow moving, and shallow water habitats that hippopotamuses may fully submerged and that is surrounded by sufficient grasses for foraging is a suitable habitat for this species. Hippopotamuses chose their daily roosting site based on the accessibility of water and the distance from human disturbance [24]. One of the main habitat descriptors influencing animal's mobility, choice of habitat, and distribution is the abundance and distribution of food resources [18, 39]. Food abundance plays a particularly significant role in shaping the ecology of large herbivores [40, 41]. For this reason, accurate measurement of food supplies is essential to comprehend the ecological interactions between large herbivores and their environment.

The most suitable sites of hippopotamus in the LTBR include Gorgora, Tana Woyna, and Esey Deber sites. Apart from the availability of food, water scarcity and greater temperature are also the major environmental factors that are likely to affect hippopotamus distribution, abundance, and behavior during the dry season [42]. The kind of habitat, the characteristics of the lake or river bed, the water's depth, and its current all have impact for the occurrence of hippopotamus in the LTBR. As a result, majority of hippopotamus may be found on very firm, slightly sloping shores and smooth-flowing waters within the 5 km buffer surrounding the Lake. As described by [1] locations can sustain hippopotamus abundance by offering year-round feed and water.

Human- hippopotamus conflict

Our study revealed that the main threats to hippopotamus in the LTBR include habitat distraction due to the expansion of agriculture and settlements, pollution from Bahir Dar city, Gorgora, and other nearby cities, flooding, competition with livestock, and killing of hippopotamus by the local communities as a result of crop raiding. The finding of [15] has also recognized similar threats of hippopotamus in Ethiopia. The results of the present study are also consistent with those in the Mara Region of Kenya as reported by [43]. The sad consequence of these threats on hippopotamus is the decline of the population in their various natural habitats across the African continent [11].

The abundance of hippopotamus in the 5 km buffer of the LTBR can be explained by different factors including conflict between hippopotamus and the local communities residing near hippopotamus resting sites and grazing areas. Permanent settlements in wildlife habitats have a significant habitat disturbance, consistent with the finding of [25]. Hippopotamuses are heavily hunted for their meat, tusks, and skin [44]. However, in the LTBR, the local communities do not hunt hippopotamus for its meat and tusks but they hunt them for its skin. In addition, farmers close to the LTBR kill hippopotamus as a result of crop raiding.

Water scarcity is becoming an issue in the LTBR, particularly along the shores of Lake Tana, intensifying competition between hippopotamuses and livestock. The expansion of agriculture and human settlement has raised concerns about wetland conservation in the LTBR. Human activities have profoundly influenced ecosystem structure and function, particularly affecting the spatial and temporal distribution of wild herbivores [45]. In the area, conflicts between humans and hippopotamuses are often linked to overgrazing and crop destruction. Moreover, hippopotamus attacks are unpredictable and can be highly destructive [1]. Crop damage caused by hippopotamus results from feeding, trampling, and the destruction of specific field areas [46].

The overlap between human activities and hippopotamus habitats in the LTBR creates significant conflict. Key drivers of human-hippopotamus conflict include crop raiding as hippopotamus frequently graze on crops such as maize, sorghum, teff, and wheat, causing significant economic losses to local farmers. Usually hippopotamus graze at night [47], and this feeding strategy may indicate that they are utilizing the food that is available in the vicinity of their daytime resting places. If a feeding site is close by, hippopotamuses are likely to use it to satisfy their dietary needs [34]. According to [20], when resources became few, animals had to adjust their activity budget, leading to distinct activity patterns. Moreover, hippopotamus rely on wetlands for grazing, which often overlaps with areas used for livestock grazing and water extraction, leading to resource competition and human-hippopotamus conflict. Consequently, people often turn to killing or harassing hippopotamus, posing a further threat to their population. To address this, effective management strategies that balance the needs of both hippopotamus and the local communities are essential to ensure the species' long-term conservation while mitigating economic losses and safety risks for residents.

Conclusion

The LTBR serves as an essential habitat for hippopotamus populations, supported by its extensive wetlands, rivers, and year-round water availability. However, increasing human activities including agriculture, fishing, and expansion of settlement have brought humans and hippopotamus into closer proximity, exacerbating conflicts. These primarily involve crop raiding, competition for grazing resources, and safety threats, resulting in significant economic and social challenges for the local communities. The study aimed to examine the distribution range and human-hippopotamus conflicts in the LTBR. The findings revealed that hippopotamus' distribution is influenced by the availability of water, vegetation cover, food resources, and terrain of the shore. Temporal and spatial variations in habitat suitability were identified, with higher hippopotamus populations concentrated in areas with consistent water availability. Conversely, drier areas with limited water sources during the dry season harbored significantly lower hippopotamus. Conflict is a growing issue, with crop damage and resource competition identified as major threats in the area. To address these challenges, it is essential to establish systems that offer economic benefits to local communities, encourage coexistence, and compensate for losses caused by wildlife. Implementing sustainable management strategies including designated grazing areas for livestock, buffer zones for hippopotamuses, habitat conservation, and community-driven conflict resolutioncan foster a balanced human-hippopotamus coexixtence in the LTBR, Ethiopia.

Acknowledgements

We would like to express our gratitude to all individuals who directly contributed in this study during the data collection period. We especially appreciate the invaluable roles of local farmers around LTBR in facilitating the data collection process. We sincerely thank everyone who participated in the focus group discussions and questionnaire surveys for their time and insights. The Department of Biology and Science College at Bahir Dar University is acknowledged for logistic and financial supports. The help rendered by Mr. Challachew Mulu in revising the map of the study area is highly acknowledged. The authors are very grateful to the Journal editor and the anonymous reviewers for their critical comments, which greatly improved the manuscript.

Author contributions

Dessalegn Ejigu proposed the research idea; Dessalegn Ejigu and Getasew Mulu designed the study, participated in data collection; GM and DE organized the data and performed data analysis; and DE prepared the manuscript. Both DE and GM have read and approved the final manuscript.

Funding

The project has been supported by the Science College of Bahir Dar University.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Research Review Board (IRB) of Bahir Dar University and the consent to participate is already accepted as the participant is a researcher who participated during data collection period.

Consent for publication

All the two authors agreed to publish this original research work.

Competing interests

The authors declare no competing interests.

Received: 5 October 2024 / Accepted: 13 May 2025
Published online: 23 May 2025

References

1. Eltringham SK. The Hippos: natural history and conservation. Cambridge: Cambridge University Press; 1999.
2. Ransom C, Robinson PT, Collen B. Choeropsis liberiensis. The IUCN Red List of Threatened Species. 2015: e.T10032A18567171. https://doi.org/10.2305/IUCN.UK.2015-2.RLTS.T10032A18567171.en
3. Lewison R, Pluháček J. Hippopotamus amphibius. The IUCN Red List of Threatened Species. 2017: e.T10103A18567364. https://doi.org/10.2305/IUCN.UK.2017-2.RLTS.T10103A18567364.en
4. Jablonski NG. The Hippo's tale: how the anatomy and physiology of late neogene *Hexaprotodon* shed light on late neogene environmental change. Quatern Int. 2004;117(1):119–23.
5. Taylor LA, Rudd J, Hummel J, Clauss M, Schwitzer C. Weight loss in pygmy hippos (*Choeropsis liberiensis*). In: Steck, B. International Studbook for the Year 2012 - Pygmy Hippopotamus. Basel: Zoo Basel. 2013;20–25.
6. Cerling TE, Harris JM, Hart JA, Kaleme P, Klingel H, Leakey MG, Passey BH. Stable isotope ecology of the common hippopotamus. J Zool. 2008;276(2):204–12.
7. Thévenet J, Grimault N, Fonseca P, Mathevon N. Voice-mediated interactions in a megaherbivore. Curr Biol 2022;32(2):70–1.
8. Graham HL, Reid K, Webster T, Richards M, Joseph S. Endocrine patterns associated with reproduction in the nile hippopotamus (Hippopotamus amphibious) as assessed by fecal progestagen analysis. Gen Comp Endocrinol. 2002;128:74–81.
9. Estes R. The behavior guide to African mammals: including hoofed mammals, carnivores, Primates. Los Angeles, California: University of California Press; 1992.
10. Lewison R. Infanticide in the hippopotamus: evidence for polygynous ungulates. J Ethol Ecol Evol. 1998;10:277–86.
11. Lewison R. Population responses to natural and human—mediated disturbances: assessing the vulnerability of the common hippopotamus (*Hippopotamus amphibius*). Afr J Ecol. 2007;45:407–15.
12. Lewison R, Oliver W. *Hippopotamus amphibius* (On-line). IUNC Red List of Threatened Species. 2008;Accessed February 01, 2012 at http://www.iucnredlist.org/apps/redlist/details/10103/0
13. Furstenburg D. Focus on the Hippopotamus (*Hippopotamus amphibious*). S.A. Hunter 2012;06065:54–56. https://www.researchgate.net/publication/316154826
14. Chansa W, Senzota R, Chabwela H, Nyirenda V. The influence of grass biomass production on hippopotamus population density distribution along the Luangwa river in Zambia. J Ecol Nat Enviro. 2011;3(5):186–94.
15. UNEP-WCMC. Review of significant trade: species selected by the CITES Animals Committee following CoP14. CITES Project No. S-346, AC25 Doc. 9.4 Annex. Geneva: CITES; 2011. https://cites.org/eng/com/ac/25/index.php.

16. Pettorelli N, Ryan SJ, Mueller T, Bunnefeld N. The normalized difference vegetation index (NDVI): unforeseen successes in animal ecology. Climate Res. 2011;46:15–27.
17. Bennitt E, Bonyongo MCand Harris S. Habitat selection by African Buffalo (*Syncerus caffer*) in response to Landscape-Level fluctuations in water availability on two Temporal scales. PLoS ONE. 2014;9(7):e101346. https://doi.org/10.1371/journal.pone.0101346.g002.
18. Johnson DH. The comparison of usage and availability measurements for evaluating resource preference. J Ecol. 1980;61:65–71.
19. Admassu M. Damage caused by large mammals in Wonji-Shoa Sugarcane Plantation, central Ethiopia. MSc. thesis Addis AbabaUniversity, Ethiopia. 2007; Pp. 76.
20. Kifle Z, Assefa WW, Moges A. Human-hippo conflicts around lake Tana biosphere reserve, Ethiopia: vulnerability of hippopotamus in human-dominated landscape. PLoS ONE. 2023;18(10):e0291802. https://doi.org/10.1371/journal.pone.0291802. PMID: 37796939; PMCID: PMC10553267.
21. Ejigu D, Tassie N. Present and future suitability of the lake Tana biosphere reserve in Ethiopia for the nile monitor (*Varanus niloticus*) using the maxent model. Environ Syst Res. 2020;9:31. https://doi.org/10.1186/s40068-020-00197-y.
22. Teshome K, Erena MG. Common hippopotamus in the upper Dhidhessa River and its conflicts with Arjo-Dhidhessa Sugar Factory, Ethiopia. 2022; https://doi.org/10.1111/csp2.12790
23. Chansa Chomba C, SimpambaT, Nyirenda V. The influence of grass biomass production on hippopotamus population density distribution along the Luangwa river in Zambia. Open J Ecol. 2013;3(6):395–406. https://doi.org/10.4236/oje.2013.36045.
24. Martin BR. Transboundary species project – background study hippopotamus: The transboundary mammal project of the ministry of environment and tourism, Namibia. 2005; Pp. 78.
25. Wengström A. How Maasai settlements affect the grazing habits of the Common Hippopotamus (*Hippopotamus amphibius*) in the Maasai Mara National Reserve, Kenya. 2009.
26. Dietz AJ, Mohamed MA, Okeyo-Owuor JB. The hippopotamus: nothing but a nuisance? Hippo-human conflicts in Lake Victoria area, Kenya. Thesis Environmental Geography Aenne W.C.H.M. Post, University of Amsterdam. 2000.
27. Norton PM. Hippopotamus numbers in the Luangwa Valley, Zambia, in 1981. Afr J Ecol. 1988;26:337–9.
28. Naughton-Treves L, Treves A, Chapman CA. Temporal patterns of crop-raiding by primates. J Appl Ecol. 1998;35(4):596–606.
29. Getis A, Ord JK. The analysis of Spatial association by use of distance statistics. Geographical Anal. 1992;24:189–206.
30. Scott LM, Jankas MV. Spatial statistics in GIS. In: Fischer MM, Getis A, editors. Handbooks of apllied spatial analysis: Software, methods and applications. Berlin: Springer; 2010. p. 27–40. PP. 811.
31. Chomba C. Factors affecting the Luangwa (Zambia) Hippo population dynamics within its carrying capacity band – Insights for better management. Int J0urnal Biodivers Conserv. 2013;5:109–21.
32. Clutton-Brock TH, Iason GR. (1986). Sex ratio variation in mammals. Quarterly Review of Biology. 1986; 61(3): 339–374.
33. Zubkowicz R. Selected problems of organizing exhibition areas for common hippopotamus (*Hippopotamus amphibius*) zoological data, annals of Warsaw agriculture University – SGGW. Horticul. 2005;26:211–8.
34. Blowers ET. Social grouping behaviours of captive female *Hippopotamus amphibius*. [MSc thesis]. Orlando (FL): University of Central Florida; 2008. 44 p.
35. Wilson DE, Cole FR, Nichols JD, Rudran R, Foster M. Measuring and monitoring biological diversity. Standard methods for mammals. Washington D.C: Smithsonian Institution; 1996. pp. 5–19.
36. Magalhaes J, Costa J. A database of vertebrate longevity records and their relation to other life-history traits. J Evol Biol. 2009;22(8):1770–4.
37. Herbison L, Frame GW. Hippopotamus Mammal species IN: Encyclopaedia Britannica. 2008; www.britannica.com/EBchecked/topic/266707/hippopotamus/Additional reading Accessed on 10/10/2008.
38. Kendall CI. The Spatial and agricultural basis of crop raiding by the vulnerable common hippopotamus (*Hippopotamus amphibius*) around Ruaha National park. Tanzan Oryx. 2011;45(1):28–34. https://doi.org/10.1017/s0030605310000359.
39. Van Beest, FM, Gundersen H and Mathisen KM. Long-term browsing impact around diversionary feeding stations for moose in Southern Norway. Forest Ecology and Management. 2010;259:1900–1911.
40. du Toit JT and Yetman CA. Effects of body size on the diurnal activity budgets of African browsing ruminants. Oecologia. 2005;143:317–32.
41. Ofstad EG, Harfindal I, Solberg EJ and Saether BE. Home ranges, habitat and body mass: Simple correlates of home range size in ungulates. Proceedings of the Royal Society B. Published by The Royal Society. Online ISSN: 2016;1471–2954. Print ISSN:0962–8452.
42. Manteca X and Smith AJ. Effects of poor forage conditions on the behaviour of grazing ruminants. Tropical Animal Health and Production. 1994;26:129–138.
43. Kanga EM, Ogutu JO, Olff H, Santema P. Population trend and distribution of the vulnerable common hippopotamus (*Hippopotamus amphibius*) in the Mara region of Kenya. Fauna & Flora International. Oryx. 2011;45(1):20–27.
44. Okello JBA, Nyakaana S, Masembe C, Siegismund HR and Arctander P. Mitochondrial DNA variation of the common hippopotamus: evidence for a recent population expansion. Heredity. 2005;95:206–215.
45. Ogutu JO, Piepho HP, Dublin HT, Bhola N and Reid RS. Dynamics of Mara–Serengeti ungulates in relation to land use changes. Journal of Zoology. 2009;278:1–14.
46. Post A. The hippopotamus: nothing but a nuisance? Hippo-human conflicts in Lake Victoria area, Kenya. MSc. thesis, University of Amsterdam, the Netherlands. 2000.
47. Lewison RL, Carter J. Exploring behavior of an unusual megaherbivore: a spatially explicit foraging model of the hippopotamus. Ecol Model. 2004;171:127–138.

Publisher's note