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Ecological studies and Threats on African elephant (*Loxodonta africana*) in Babile Elephant Sanctuary, Eastern Ethiopia

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ABSTRACT

A study was conducted on the ecological, and threats to African elephants in the Babile Elephant Sanctuary in eastern Ethiopia from March 2019 to December 2021. The research aimed to understand population size, age structure, movement, feeding preference, impact on woody plant species, and threats to elephants. For the study, before carrying out data collection, the habitat of the sanctuary was first divided into riverine, woodland, and bushlands. A total area of 48 km^2 divided into 16 km^2 each, was sampled to compare and collect the dung of an elephant. The study used dung counting techniques and woody species assessment to estimate elephant population size, feeding preferences, and the impact of elephants on woody species. The sanctuary had 210 to 250 elephants or (i.e., 230±20) at a Mean of (χ) =230 and SD=20, with 47% being younger and 2.6% sub-adult. Others were adult (19%), calves (17.2%), and Juveniles (13.4%). According to all (100%) key informants and observations revealed, the elephants' movement followed the Erer and Gobele valleys. The result also showed that 24(63.15%) of the 38 woody species were selected by elephants as a diet. The Acacia seyel (PI= 3.3033) and Opuntia ficus- indica (PI= 2.0328) were the most frequently browsed tree and shrub species, respectively. Observations revealed elephants uprooted debarked trees and destroyed parts, particularly a small size class. The study found that the high human population and settlers' need for land for cultivation increased conflicts between people and elephants. Despite a remnant elephant population in the sanctuary, the species could be negatively affected by human activities. Therefore, rehabilitating woody plants consumed by elephants, reducing threats and conserving the remaining elephant population is crucial.

Key Words: African Elephant's Population, Age Structure, Feeding Preference and Impact, Threats, Woody Species.

1. INTRODUCTION

1.1. Background and Justification

The African elephant (*Loxodonta africana*), the largest land-living and long-lived mammal, is grouped into two subspecies: savannah elephant (*L. a. africana*) and forest elephant (*L. a. cyclotis*) (Alex *et al*., 2017). In Ethiopia, there are three subspecies of African elephants: *L. a. oxyotis*, *L. a. knochenhaueri*, and *L. a. orleansi* (Yalden *et al*., 1986). These species maintain habitats, nutrient cycling, seed dispersal and provide space for small mammals (Poulsen *et al*., 2018), and also generate an income through tourism (Koldowski *et al*., 2020).Their diet consists of bark, leaves, stems, flowers, and fruits, and require large home ranges (Matseketsa *et al*., 2019). Despite their importance, elephants have faced threats such as poaching for ivory, HEC, and habitat loss (Saaban *et al*., 2020). In Ethiopia, 90% of elephant populations have been lost since the 1980s, making them severely endangered (Mekbeb Eshetu *et al*., 2019). Currently, small dispersed elephant populations exist mainly in the six protected areas in various ecosystems (Sintayehu Workeneh, 2016). In the moist tropical forest in Cebera Curchura National Park (CCNP), the semi-desert scrubland and *Acacia-commiphora* woodland in Babile Elephant Sanctuary (BES), Omo National Park (ONP), and Mago National Park (MNP), and the lowland moist evergreen forest ecosystem with a humid savanna in Gambela National Park (GNP). Additionally, riparian types in Kafta Shiraro National Park (KSNP) in the northern country include *Acacia-commiphora*, *Combretum-Terminalia*, and dry evergreen montane forests (Teklay Girmay *et al*., 2020). As relatively few studies were available with regards to the ecology (Yirmed Demeke, 2008), food habits (Yihew Biru & Afework Bekele, 2012), and threats (e.g., HEC/HWC) of African elephants (Sintayehu Workeneh & Ready Uttama, 2014) in BES. This study was conducted since there has been little information on the feeding ecology and current status of the species. So, this study investigated the causes and severity of threats, the status, and the ecological state of elephants in BES. Hence, promote conservationists to design a suitable plan for the restoration of habitat and elephant populations.

2. MATERIALS AND METHODS

2.1. Description of the study area

The Babile Elephant Sanctuary (BES), established in 1970, spans 6,982 km^2 and is located 560 kilometers east of Addis Ababa, Ethiopia. Geographically, located between 08°22′30″ - 09°00′30″N latitude and 42°01′10″-43°05′50″E longitude (Fig.1). It is part of the Somali-Masai Centre of Endemism and is situated in the Eastern Hararge Gara-Muleta Mountains and the Ogaden Desert (Yirmed Demeke, 2008). The sanctuary is located in the arid and semi-arid (Abdulbasit Hussein, 2019) or "Kola" agro-climatic zone with an altitude of 850 to 1,785 meters (Yirmed Demeke, 2008). It is divided into the Eerer and Gobele Valleys, where elephants rely on the valley's rivers for water. Four significant drainage river valleys, Fafem, Daketa, Eerer, and Gobele, are found inside and outside the sanctuary (Fig.1) (Yirmed Demeke, 2008). These valleys eventually connect to the Wabi Shebelle River Basin as they travel south through the sanctuary (Anteneh Belayneh, 2006; Yirmed Demeke *et al.*, 2006).

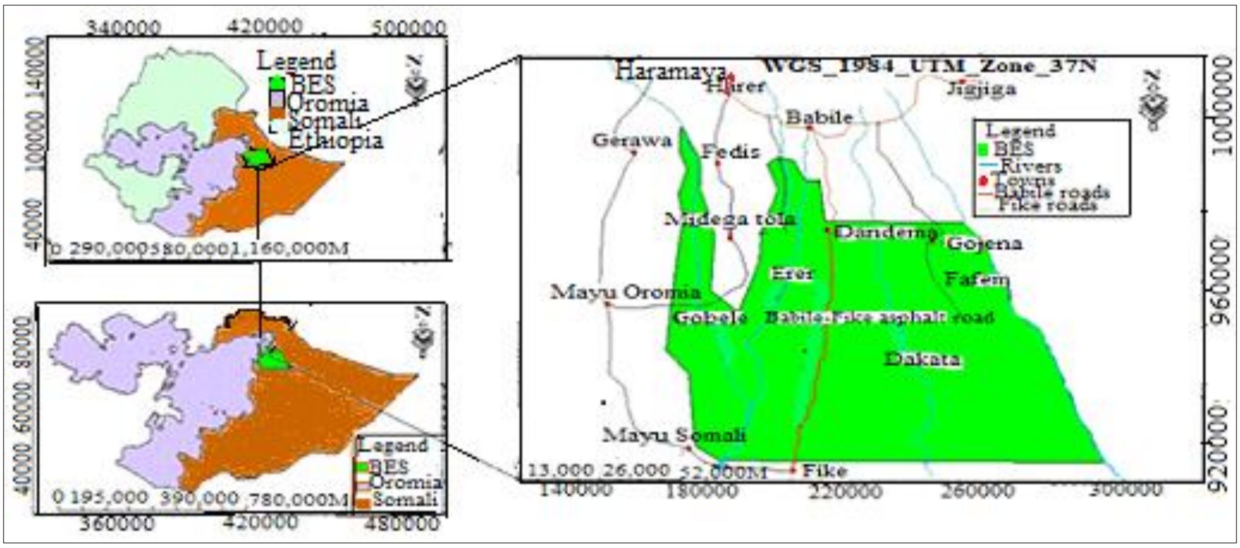

Figure 1. Map of Babile Elephant Sanctuary

The sanctuary has an average yearly temperature of 15.89 °C, with maximum and minimum temperatures of 24.02 °C and 7.76 °C respectively (Fig. 2-partC). The mean monthly maximum and minimum temperatures are 31.38 °C and 2.75 °C respectively (Fig. 2-partA). The hottest months are between February and May, while the coldest months are from October to January. The highest mean monthly temperatures are 24.02 °C and the lowest are 7.76 °C. Other studies have found that the coldest months are 7.8 °C between October and December (Anteneh Belayneh and Sebsebe Demissew, 2011) and 8.2°C between October and December (Firahewot Lemma, 2022). The sanctuary has two wet seasons, with a total yearly distribution of rainfall ranging from March to May and June to October. The mean monthly rainfall is 45.53mm, with significant fluctuations ranging from 60.32 mm to 734.51 mm/yr on an average of 397.41 mm. The highest mean monthly rainfall was recorded in August at Haramaya station, while the lowest was in February at Fedis station (Fig.2-partD).

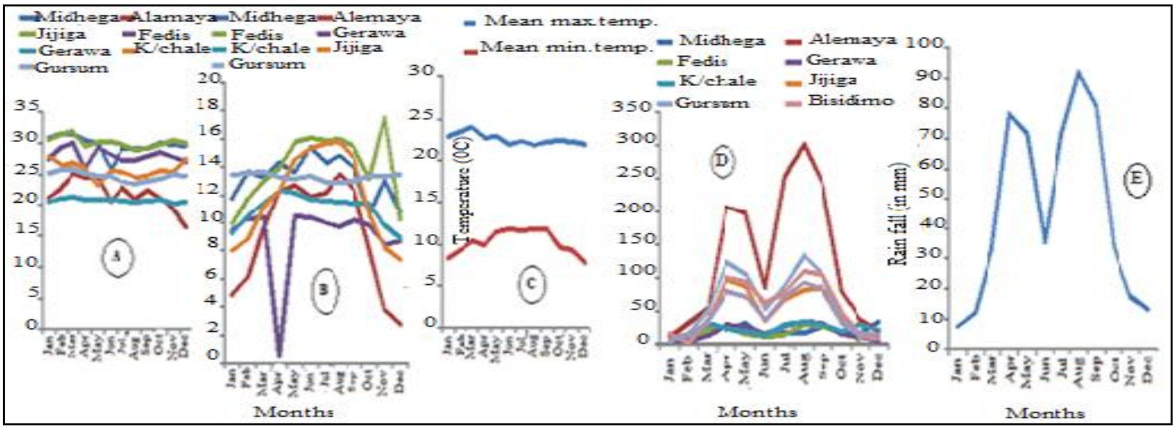

Figure 2. The maximum (A), minimum (B) & mean monthly (C) temperatures; & monthly (D) & mean monthly (E) RF distribution data (in mm) for BES b/n 2000 & 2022 (Source: NMSA)

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The BES is a semi-arid region with a rich biodiversity, including a variety of crops, animals, and plants (Tadele Mirkena *et al*., 2018). The main subsistence agriculture in the BES involves raising cattle and crops, producing fruits, vegetables, oilseeds, and cereal crops such as sugar cane, sorghum, maize, tomatoes, green pepper, and sweet potato. Rain-fed agriculture is also common, with crops like corn, haricot beans, millets, and groundnuts being produced (Zelalem Wodu, 2007). People both inside and outside the BES participate in farm and non-farm activities to improve their living conditions. The BES's vegetation consists of semi-desert scrubland, evergreen scrub habitats, and *Acacia commiphora* forests, with many distinct species highly indigenous to the region (Anteneh Belayneh and Sebsibe Demissew, 2011). The floristic composition of the BES is predominantly shrubs, with ten families, twenty-one genera, and thirty-nine species (Anteneh Belayneh and Sebsibe Demissew, 2011). In most areas of the sanctuary, shrubs were the predominant floristic composition. The composition of wildlife in East Ethiopia is relatively high, with mammals, birds, and reptiles that have adapted to the semi-arid environment. The sanctuary is home to several species of mammals, snakes, lizards, and other smaller animals and invertebrates (Yirmed Demeke *et al*., 2006). Birds are more common than other animal species, with about 191 bird species identified (Mihret Ewnetu *et al*., 2006). In general, the semi-arid environment of Eastern Ethiopia supports a high diversity of wildlife species, including mammals, birds, and reptiles.

2.2. Methods

2.2.1. Population estimate

Sampling design

A reconnaissance survey was conducted from March to May 2019 to familiarize the study area for ecological studies. Various sampling techniques: vehicle survey, foot survey through counting method used to estimate the elephant population. The dung count method (Meier *et al*., 2021) by the belt or strip transect technique was chosen to estimate elephant population size due to its less biased estimates and lower standard error (Bicho *et al*., 2023). Two types of systematic sampling techniques used: line transects and belt or strips transect techniques used for ecological study. The study identified three vegetation types' components in the sanctuary: riverine, woodlands, and bushlands. Habitat stratification and belt transects were used based on vegetation types, elephant movement patterns, and dung availability. Twelve key informants and local community members participated in interviews. Six sites selected: two riverine vegetation sites—one each from Erer Ebada and Ebada Gamachu PeA in the Babile district—and two woodland vegetation sites—one each from Alola and Gabibda PeA in the Mayu Muluke district, and two bushland site--Aneni PeA in the Fedis district and Bilusuma PeA in the Midega Tola district, were purposively selected , covering 1605km^2, with 18 line transects allocated in proportion to dung pile densities (i.e., each having three transects in each of three habitats)(Fig.3).

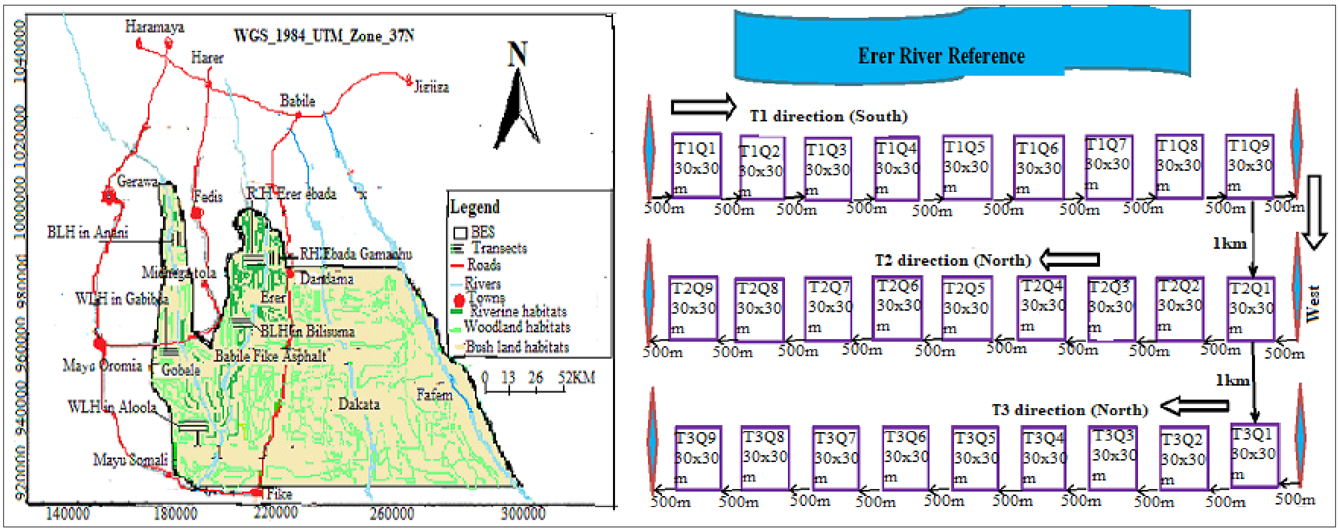

Figure 3. Mapped transects and quadrants for the study sites and its diagrammatic representation sample in BES

The study surveyed 18 transects, each 4km long and 1km apart, to determine the size of elephant populations in different habitats. Six transects were perpendicular to the Erer River baselines for riverine habitats, while every six transects were around the Gobele Valley River for woodland and bushland habitats (Fig.3). The first transect randomly selected and placed at a 1km interval in every three habitats of six sites. Each transect had nine quadrants, each having 30 m by 30 m and 500m equidistance. One hundred sixty-two quadrants or plots were laid along the transects (i.e., every 54 quadrants in the riverine, woodland, and bushland habitats), with distance between transects and along transects measured using tape meters or distance walked. During the survey, dung piles were counted and recorded using the dung count method to estimate elephant size. The dung pile density obtained from the distance program was converted to elephant density (Buckland *et al*., 2001). Dung pile density, defection rate, and decay rate were used to estimate elephant population size.

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Estimating dung-pile density (dung-piles per Km^2)

The study monitored dung piles using bamboo sticks (Billah *et al*., 2021) and other materials for three months before disappearing (Inogwabini, 2020). The morphological stages of dung piles classified into A-E categories based on their shape and existence (Table 1) (Hedges and Lawson, 2006). The dung piles were observed for three consecutive months until they disappeared (Inogwabini, 2020).

Table 1. Dung piles categorized on the condition of the dung

Categories	Description
A	Boli intact, very fresh, moist with odor
B	Boli is intact and fresh but dry, without odor
C	Some of the boli have disintegrated, others are still recognizable as boli
D	All boli get disintegrated, and dung piles now form an amorphous flat mass
E	Decayed to stage not detected at a range of 2m from the centerline

The study analyzed the decomposition of dung piles in transects by observing them while walking along the center line of the transect. Dung piles identified, counted, and aged using specific categories (Table 1). The program ELEPHANT used to estimate total dung-pile densities, using data on perpendicular distances from a file. A file containing data on perpendicular distances were recorded. The program reads this file and uses the perpendicular distance of dung piles to calculate f (O). Using the steady-state assumption, the density of dung piles, Y, was calculated as:

$$Y = \frac{n.f\,(O)}{2L}$$

Where n = the number of droppings,
L = the total length of the transects
f(O) = an estimate of the reciprocal of the effective strip width
Generally, the density of dung piles for each habitat provides an overall estimate for the entire study area by adopting the work of Barnes *et al.* (1995) and Norton Griffiths (1978).

Estimating rate of defecation (d)

The defecation rate is the average number of dung piles produced per elephant per day, determined by following a known number of elephants for 12 hours and recording droppings (Poulsen *et al*., 2017). However, determining the rate in the study area was challenging due to high hunting pressure on elephant movements. Several field workers estimated different values for the defecation rate. The dry season data analysis used several observation hours from Poulsen *et al*. (2017), resulting in a defecation rate of 18.1 dung piles per elephant per day with SE of 0.23.

Estimating decay rate (r)

The decomposition of elephant droppings can be estimated by monitoring dung piles until they disintegrate (i.e., until they pass from morphological stage D to stage E) (Hedges and Lawson, 2006). A fieldwork was conducted to search for 50 sample fresh dung piles from different vegetation types in the northern and central parts of the sanctuary. Each pile was measured, marked, mapped, and monitored until it disappeared. Percentage for the daily decay rate was calculated from Bames (1992) as:

$$r = \frac{\ln (No)-\ln (Nt);}{t}$$

Where: No = initial number of droppings; Nt = numbers left after t days; r = rate of decay; t = number of days; using this calculation the mean decay rate of elephant droppings in the BES for the dry season was 0.009 (SE=5.6).

The dry season elephant population in each habitat estimated by multiplying elephant density by each sampled area. Summing the population numbers in each habitat or multiplying elephant density with the total sanctuary area can estimate the overall population size. Below, dung pile density and estimation of elephant population size are indicated in Table 4.

2.2.2. Population age structure estimation

The study categorized elephants into five age groups: calf/infants (< 2 years old), juvenile (2< X < 4 years old), intermediate (5< X < 8 years old), sub-adult (9 < X < 12 years old), and adults (> 13 years old) (Druce *et al*., 2011). Age estimation based on counting and measuring the mean circumference of three non-deformed bolus from a single defecation observed in all study sites (Hema *et al*., 2017). The observed age-specific dung-pile circumferences were the droppings having circumference less than or

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equal to 20 cm grouped under infants/ calf, between 20.5 and 31.8 cm grouped under juvenile, between 32 and 43.7 cm grouped under intermediate, between 44.7 and 51.2 cm grouped under sub-adult male or adult female, and more than or equal to 52.5 cm grouped under adult male (Table 4.3).

2.2.3. Movement patterns and distribution of elephants

Elephant movement and distributions were identified through footprint measurements, dung piles, feeding signs, and observation (Koirala *et al*., 2016). Data was collected during wet and dry seasons, using questionnaire surveys and discussions with KI. Information about type and routes was also recorded on notebooks and GPS.

2.2.4. Elephant feeding preferences and impact on woody species

The study aimed to investigate the food habits and feeding preferences of elephants by examining their feeding activity, consumed plant species, feeding remains, and partly used food plants(Ashokkumar *et al*., 2021), indirectly by interviewing wildlife rangers and residents and identifying seeds in the dung (Amusa *et al*., 2017). The collected plant species seeds were assessed, fresh to nearly fresh boli, at 5 m intervals (Crespo, 2018). For further identification, the dung samples were taken to Haramaya University, Ethiopia. Vegetation data assessment from all three land units of the six study sites, including 162 quadrants/ samples. The study focused on the feeding impacts of elephants on woody species, recording the local names of these species, their uses, and their influence on them. Dung collections were taken in December 2019. The feeding impacts assess all plant specimens found within each plot, including species height, status (alive or dead), and level of impact, vegetation photographs, and GPS records at the start and end of each quadrant. Each study site area had 27 quadrants, with plant specimens with stems within each plot. The level of impact on woody plant species was assessed by observing the damage effect on them and categorizing them into six groups: no damage, very small used, secondary branches broken, greater than one primary branch broken, main stem broken, heavily browsed/bark stripped, and the whole tree uprooted. Levels 1 and 2 attributed to elephants causing minor damage. The 3, 4, and 5 levels grouped as more damage occurred on primary branches, main stems, and uprooted trees, respectively (adapted from Tchamba, 1995 and Hiscocks, 1999).

2.2.4. Human and elephant conflict

Sampling design

The study involved reconnaissance surveys, discussions with local experts, and field observation to identify elephant movement patterns and their impact on the study area. The surveys were conducted through questionnaires and face-to-face interviews, and translated into local languages of "Afaan Oromo" and Somali. Respondents were selected based on a purposive sampling technique. The survey included interviews, participant observations, and the use of archive data to understand human-elephant interactions. Five districts (Babile, Fedis, Midhega Tola, Mayu Muluke, and Babile-Somale district) were chosen based on proximity to the sanctuary. From these districts, 20 "Kebeles" (divisions within a district) were selected based on prevalent occurrences of HEC incidents. Key Informants (KIs), Focus Group Discussants (FGDs), and Households (HHs) were chosen from the "Kebeles" near the sanctuary. Key informants (KIs) were selected to provide reliable sources of information, including professionals, community leaders, local government officials, or others with first-hand experience of the community. They were also selected based on their participation in their "kebeles" leadership during different seasons and their knowledge of the people in their corresponding sites. The Key informants helped classify farmers into socio-economic status, using criteria such as the number of cattle, annual crop production amount, and type/standard of housing. The wealth ranking method is based on the number of livestock populations used for this study (Table 2). A study was conducted to gather information on the nature and extent of Human-Elephant-Conflict (HEC) in 20 PeAs. 65 Focus Group Discussants were selected from five districts, each consisting of 13 individuals. Three experienced farmers, including the elderly, traditional leaders, and school youths, participated in each "kebele." Data collection methods included field visits, interviews, and questionnaires. Primary data was collected through field visits, interviews, and questionnaires, while secondary data was collected from archive data and the BES of Wildlife Office. The study also included information on the quantification of losses incurred in the five study districts and the current and historical levels of HEC. Households were selected based on their ability to maintain and manage HEC on the agricultural landscape, socioeconomic status, and wealth ranking (Crowley, 1997).

Table 2. Average wealth ranking criteria done by the key informants among the selected five districts

Live stock	Fedis district			Mayu Muluke			Midega Tola			Babile-Oromia			Babile-Somale		
	R	M	P	R	M	P	R	M	P	R	M	P	R	M	P
Cows	>7	1-3	≤ 1	>20	15	≤ 5	>10	6-8	≤ 5	>10	5-10	≤ 4	>15	15	≤ 5
Donkey	>2	1-2	≤ 1	-	-	-	>2	1-2	≤ 1	>5	3-4	1-2	>2	1-2	≤ 1

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Goats	>20	15	≤ 4	>20	15	≤ 5	>15	10-15	≤ 2	>15	15	≤ 5	>35	20	≤ 5
Sheep	>4	1-3	≤ 1	-	-	-	>8	5-8	≤ 5	15	5-8	≤ 2	-	-	-
Camels	≥1	≤ 1	-	>20	15	≤ 5	≥7	5-7	≤ 2	>5	2-4	≤ 1	>15	10	< 5
Hens	-	-	-	-	-	< 5	>15	5-10	<5	>20	15	≤ 5	>15	10	< 5

Key: Where; R= Rich, M= Medum, P= Poor

A random selection procedure was used to obtain samples of individual HHs from each wealth category (Table 2). A semi-structured questionnaire was administered to respondents aged 25 years and above who had lived in the respective location for at least five years or more. Without regard to whether there are HEC victims or not, 138 HHs from five districts of their corresponding "kebeles" around the boundary of the BES were selected using Kothari (2004) (Table 3). The total HHs of the 20 "kebeles" were 32,829, with 5594, 11,139, 7139, 1575, and 7382 HHs for Oromia-babile, Fedis, Midhega-tola, Mayu Muluke, and Somali-babile districts, respectively. The ultimate sampling sample frame for the HHs living in the 20 "kebeles" includes persons who own at least a plot of farmland. The number of sampled HHs that was included in the study areas was determined from the sampling frame following Kothari (2004). The formula to determine the sample size for the finite population is indicated below.

$$n = \frac{Z^2 * p * q * N;}{e^2 (N-1) + Z^2 * p * q}$$

Where, n= sample size,

Z = 95% confidence limit (interval) under the normal curve, i.e. 1.96.

p = 0.1(proportion of the population to be included in the sample, i.e.10%)

q = non-occurrence of event which is equal to (1- 0.1), i.e. 0.9

N = Total number of population or Households

e = margin of error or degree of occurrence (acceptable error term) 0.05.

The study involved 138 HHs from 20 "kebeles" in 20 study areas. All HHs from three wealth categories were interviewed. 84% of the sampled HH farmers were medium and poor, indicating a subsistence farming and livestock production system for livelihood income. Of the total sampled HHs, 16% were rich, 36.2% medium, and 47.8% poor (Table 3).

Table 3. The number of selected HHs for the study

Name-of districts	Name of PeAs	No. of pop.	No.of HHs	Households distributions based on wealth status						
				Total no. of HHs			Sampled HHs			
				R	M	P	R	M	P	Total
Babile (Oromia)	Erer ebada	8851	1490	149	596	745	1	2	3	6
	E/Gamachu	9655	1559	187	592	780	1	3	3	7
	Gamachu	7750	1350	135	540	675	1	1	3	5
	Berkele	7660	1195	84	418	693	1	1	3	5
Fedis	Anani	4528	1132	283	396	453	1	2	2	5
	Bidibora	6504	1227	184	491	552	1	2	2	5
	Umerkule	7608	3790	758	1327	1705	2	7	8	17
	Agidoraa	6856	1945	292	778	875	1	3	4	8
	N/Bobasa	7440	1566	157	626	783	1	3	4	8
	Qufa bobasa	7027	1479	400	500	579	1	2	3	6
Midhega Tola	N/ Midhega	7267	762	169	273	320	1	1	1	3
	Bilisuma	6267	865	203	307	355	1	1	1	3
	Qarensa	3890	722	153	264	305	1	1	1	3
	Lencha	17043	2012	201	805	1006	1	3	4	8
	Barzalaa	8147	895	223	402	270	1	2	1	4
	Qufaa	4387	1883	188	660	1035	1	3	5	9
Mayu Muluke	Alola	955	787	93	240	454	1	1	1	3
	Gebdida	1030	788	157	276	355	1	1	1	3
Babile (Somale)	Dandema	25000	4000	680	1205	2115	2	7	8	17
	Bikkoo	19500	3382	507	1184	1691	1	4	8	13
	Total	**167365**	**32829**	**5203**	**11880**	**15746**	**22**	**50**	**66**	**138**

Key: where, HHs= Households, PeAs= Peasant Associations, R= Rich, M= Medium and P=poor

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2.4. Data Analysis

The study aimed to estimate elephant populations using various methods, including the ELEPHANT program (Dawson and Dekker, 1992; Barnes, 1996), dung pile density, elephant density, and defecation rate. Elephant age structure was also investigated by measuring and counting the number of dung pile circumferences category (Hema *et al.*, 2017). The movement patterns and distribution of elephants were analyzed using GPS readings and a GIS program. KIs' information on elephants' routes and seasonal patterns was noted. The food preferences identified by different woody plant species consumed by elephants, their relative frequency and abundance, and their preference indices were analyzed. The preference index (PI) was calculated by dividing percentage utilization by the percentage available in the environment. The study aimed to provide valuable insights into elephant populations and their diet preferences.

Using the following formula: Food preference Index (PI) = $\frac{\text{Percentage Utilization}}{\text{Percentage Availability in the environment}}$

Where, percentage utilization is the percentage of a given consumed plant as food with a ratio of all species consumed in the diet, while percentage availability in the environment is a ratio of the total number of individuals of a single species to the total number of individuals of all species observed in all observation blocks. At last, all the data collected on seasonal dietary composition and preferences were analyzed using SPSS Version 20. One-way ANOVA, correlation analysis, and t-test were used to investigate it.

The study assessed the impact of elephant feeding on vegetation by calculating the total damage per species per transect and the total damage per species per vegetation type, using the formula: Σ (# trees per damage category per species/ transect x damage category) (Hiscocks, 1999). The impact of woody species was coded and analyzed using SPSS version 20. A t-test was used to determine significant differences between sampled areas. Descriptive and quantitative statistics are used to examine conservation threats, such as human-elephant conflict (HEC). A questionnaire survey was gathered on causes, types, and human-elephant interaction. To locate invasive species and HEC distributions, Arc Map 10.8 was used. Comprehensive data based on people's views and attitudes was summarized and evaluated using descriptive statistics. The Chi-square test was used to determine the frequency of reported HEC and types of conflicts in BES over the past five years. Results were analyzed using tables, graphs, charts, and pictures.

3. RESULTS AND DISCUSSION

3.1. Elephant population estimates and age structure

3.1.1. Population estimates

From the three land units of dung piles survey, there was an estimated total computed mean decay rate of 0.0085 (SE= 5.4) and defecation rate of 19.75 droppings per elephant per day were observed. The mean dropping density of 710 dropping per habitat for the dry season was observed (Table 4). According to the estimate (210 to 250), there were 230±20 elephants overall in the research region (Mean (χ) =230; SD=20). Elephants were sighted in the sanctuary overall at a density of (0.033/km^2).

Table 4. Elephant population number estimation and dung pile density in the three habitats of the BES

Habitats	Stratum area (Km^2)	Trans ects no.	Transects length (km)	Sampled area (km^2)	Dropping no. (sampled area)	Dropping Density (stratum)	Elephant density (Eleph./km^2)	Elephant No.
Riverine	308	6	24	16	274	17.12	0.289	89
Woodland	610	6	24	16	125	7.81	0.065	40
Bush land	687	6	24	16	311	19.44	0.147	101
Total	**1605**	**21**	**72**	**48**	**710**	**(χ =14.79)**	**(χ =0.17)**	**230**

Compared to earlier records, Fig.4 demonstrates less elephants relatively observed during the research period (i.e., 230) (the higher recorded were 600 in 1976, 300 in 1986, 264 in 2006, 250 in 2011, and 237 in 2015). Therefore, the few elephants that had seen along the BES's track and trails suggest that there has been a decline in population or that their range has shrunk (Table 4). In this study, analysis of census data from the long-term elephant population (over 44 years) revealed a drop in the elephant population (Fig.4). Numerous academics have provided information about the number of elephants in the sanctuary. There were 600 elephants in the population in 1976 (Stephenson, 1976; aerial survey), 300 in 1986 (Yalden *et al.*, 1986; aerial survey), 264 in 2006 (Yirmed Demeke *et al.*, 2006; foot survey), 250 in 2011(Anteneh Belayneh *et al.*, 2011; foot survey) and 237 in 2015 (Sintayehu Workeneh *et al.*, 2016; aerial survey) (Fig. 4). The populations of the sanctuary fell after 1970. The worst population

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loss occurred between 1970 and 1986 (i.e., 300 populations). The population declined from 1986 until the present research (230+20 [210 to 250]. However, the pace was not as high as it was between 1970 and 1986 (Fig. 4).

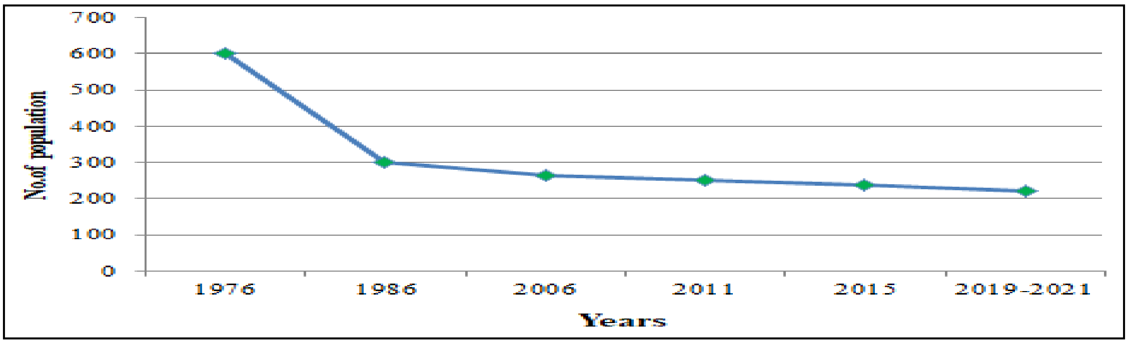

Figure 4. Elephant populations trends in the BES ecosystem between 1976 and 2019/21 (Source: Stephenson 1976; Yalden *et al*., 1986; Yirmed *et al*., 2006; Sintayehu *et al*., 2016; and present study)

Due to collaboratively working with regional, zonal, and district stakeholders and implementing the existing wildlife laws (i.e., Wildlife Proclamation No.575/2008) by legally institutionalized concerned body EWCA for wildlife protection, development, and utilization as the key informants interviewed. Therefore, cooperation effects might reduce the conflict and poaching rate (i.e., elephant population numbers after the 1980s) when related to the elephant population number between 1970 and 1986. This study and the estimations of all earlier researchers on elephant populations showed a population reduction. One of the reasons for the sanctuary's declining elephant population, according to KI interviewed, is poaching. For example, ivory is imported into Djibouti and Somalia and transported to other Arab and Asian countries (BESDMP, 2010). Generally, decreasing human-wildlife conflict (HEC) and poaching in and around protected areas that impact animal population dynamics may improve ecological resilience (Stoldt *et al*., 2020).

3.1.2. Age estimation

The study found that only 2.7% of dung piles had circumferences between 44.7 and 51.2 cm, while over 47% had circumferences between 32 and 43.7 cm (Table 5). In the Gemechu research site, no juveniles, subadults, or adult elephant populations were seen. In the Ererebada and Gabibda sites, no calves were seen. Sub-adults not found in Gamechu, Ererebada, Gabibda, and Bilisuma. Alola, Gamachu, and Bilisuma had no juveniles or intermediate or young elephant populations.

Table 5. The distribution of dung piles and their circumferences in the study sites of BES

Study sites	Distribution of dung pile (cm)					Total dungs
	≤ 20cm	b/n 20.5cm and 31.8cm	b/n 32cm and 43.7cm	b/n 44.7cm and 51.2cm	≥ 52.5cm	
Gamachu	5	-	125	-	-	130
E/Ebada	-	16	88	-	40	144
Gabibda	-	13	27	-	21	61
Aloola	48	-	-	7	9	64
Anani	34	66	19	12	-	131
Bilisuma	35	-	80	-	65	180
Total	**122**	**95**	**339**	**19**	**135**	**710**

From more to fewer elephants, the estimated age distributions of the population were intermediates, adults, calves, juveniles, and sub adults, which were, respectively, 47.74%, 19%, 17.2%, 13.4%, and 2.66% (Fig.7). Young and middle-aged grouped make up the majority of the population (47.74%), followed by adults and calves. Yet, there were fewer sub-adult males or females (2.66%). The ratio between sub-adults and adults in the population was 1:7.3 and, between calves, juveniles, and intermediates it was 1.26:1:3.55. The age structure revealed that there might be a temporary pause in the continuation of childbirth due to the low age class of sub-adult males and females and juveniles in the population (Fig.5). Similarly, Ashokkumar *et al.* (2021) study found that the majority of the elephant population in at Mudumalai Tiger Reserves in southern India was less sub-adult females, calves and juveniles might reduce the birth rate. However, this study showed a higher number of young/intermediate and adult elephants (Fig.5). Generally, the present age structure of elephants in BES has a desirable demographic age class for birth continuity and will have an opportunity to promise the upcoming delivery.

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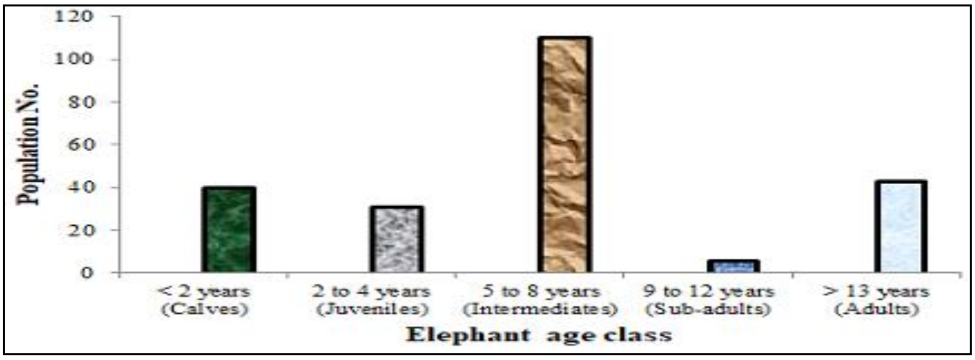

Figure 5. The age structure of elephants in BES based on dung pile circumference

3.2. Feeding preferences and impacts of African elephants

3.2.1. Feeding preference

Elephants tend to favor some habitats while avoiding others. Elephants preferred 24 different plant species out of the 38 trees and shrubs in the sanctuary (Table 6). The most frequently browsed tree was *Acacia seyel*, while the most browsed shrub was *Opuntia ficus-indica* (i.e., PI= +2.0328), because of its higher PI value (Table 6). Additionally, elephants avoided *Dodonoea angustifolia* (i.e., PI= -0.4033) and *Kleinia squarrosa* (i.e., PI= -0.4325), due to lowest preference (Table 6). According to the preference indices (PI) and percentage of species occurrence in the diet, the estimated F-ratio value (i.e., 41.142) is higher than the tabulated value (i.e., 4.45) (MSBG = 5.45, MSWG = 0.132, DF (1, 17), F-ratio=41.142, F = 4.45 at 5% CV). There were significant differences in preference indices values occurred because of a species' varied prevalence in the diet (i.e., percentage occurrences of a species in the diet were directly proportional to PI). However, species' percentage existence in the field correlated inversely with PI. In general, elephants preferred the species with higher values of PI (Table 6).

Table 6. Preference indices (PI) for the top species consumed by elephants across the study sites of BES

Species' scientific names	Family	% in the diet	% in the field	PI	P
Acacia seyel Del.(*T)	Fabaceae	9.13	2.76	3.3033	+
Acacia nilotica (L.) Wild. Ex Del.(*T)	Fabaceae	7.03	2.83	2.4790	+
Opuntia ficus-indica(L) Miller (*SH)	Cactaceae	13.35	6.57	2.0328	+
Aloe pirottae Berger (*SH)	Aloaceae	1.41	0.76	1.8480	+
Acacia oerfota (Forssk.) Schweinf. (*SH)	Fabaceae	1.41	0.78	1.7936	+
Trachilia emitica Vahl.(*T)	Meliaceae	1.17	0.78	1.4947	+
Dobera glabra (Forssk) Poir.(*SH)	Salvadoraceae	3.28	2.24	1.4670	+
Acacia robusta Burch. (*T)	Fabaceae	3.04	2.17	1.4057	+
Cordia monoica Roxb...(*T)	Boraginaceae	0.70	0.53	1.3257	+
Balanities aegyptica (L.) Del..(*T)	Balanitaceae	3.75	2.83	1.3221	+
Ochnainermis(Forssk)schweinf.expenzing (*SH)	Ochnaceae	4.92	4.15	1.1858	+
Carisaa spinarum L.(*SH)	Apocynaceae	2.34	2.07	1.1293	+
Asparagus leptoclododius(*SH)	Asparagaceae	1.64	1.45	1.1293	+
Cadaba farinosa Forssk (*SH)	Cappardiaceae	1.64	1.45	1.1293	+
Cardia ovalis R.Br.(*SH)	Boraginaceae	1.64	1.47	1.1117	+
Acokanthera schimperi (A.DC.) Schweinf (*T)	Apocynaceae	2.34	2.14	1.0929	+
Acacia brevispica Harms.(*SH)	Fabaceae	3.75	3.53	1.0629	+
Acacia tortills (Forssk) Hayne..(*T)	Fabaceae	4.45	4.22	1.0553	+
Tamarindus indica.L..(*T)	-	3.04	2.90	1.0487	+
Terminalia brownie Fresen.(*T)	Combretaceae	4.45	4.26	1.0439	+
Grewia villosa Willd. (*SH)	Tiliaceae	1.41	1.38	1.0164	+
Berchemia discolor (Klotzsch) Hemsl.(*T)	Balanitaceae	4.22	4.19	1.0052	+
Acacia nigari (*SH)	Fabaceae	4.92	4.91	1.0021	+
Pyrostria phyllanthoidea (Baill.)Bridson.(*SH)	Rubiacaea	4.68	4.68	1.0014	+
Lanthana camara L.(*SH)	Verbenaceae	2.81	3.64	0.7719	_
Opuntia stricta (Haworth)(*SH)	Cactaceae	1.64	2.24	0.7335	_
Acacia mellifera (Vahl) Benth.(*T)	Fabaceae	1.87	2.83	0.6611	_
Capparis sepiaria L.(*SH)	Capparidaceae	0.47	0.71	0.6557	_
Capparis tomentosa Lam.(*SH)	Capparidaceae	0.47	0.76	0.6160	_
Acacia bussie Harms ex.Sjostedt (*T)	Fabaceae	3.04	4.98	0.6117	_
Grewia schweinfurthii.Burret (*SH)	Tiliaceae	2.58	4.24	0.6076	_

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Euclea racemosa Murr.Ssp.(*SH)	Ebenaceae	0.94	1.54	0.6068	_
Euclea schimperi(*SH)	Ebenaceae	2.11	3.53	0.5979	_
Ziziphus spina christi (T.) Desf.(*T)	Ramanaceae	1.17	2.12	0.5524	_
Grewia erythraea Schweinf. (*SH)	Tiliaceae	0.70	1.45	0.4840	_
Dichrostachys cinerea (L.) Wight & Arn. (*T)	Fabaceae	1.64	3.55	0.4620	_
Kleinia squarrosa Cufod. (*SH)	Astraceae	0.47	1.08	0.4325	_
Dodonoea angustifolia L. f.(*SH)	Sapindaceae	1.17	2.90	0.4033	–

Where; % in diet = percentage occurrence of a species in the diet, % in field = percentage occurrence of a species in the field, P = preference, + = Species preference, - = Species avoidance). The asterisk (*T) and (*SH) designated for Tree and Shrubs respectively.

This study discovered that elephants in BES utilized 69 plants in the wild from 36 various families across the riverine, woodland and bush land habitats. Similarly, Yihew Biru (2009) revealed that elephants in the BES consumed roughly 75 species (61 wild and 14 cultivated plants). Another study concurred that 87 plant species, including crops, may be utilized by forest elephants (Djoko *et al*., 2022). Elephants dislike resources and exhibit preferences for specific environments while avoiding others (Ahimsa *et al*., 2018). Elephants demonstrated a selective preference for 24 of the 38 most important species that ingested in the diet (Table 6). As reported by Yihew Biru and Afework Bekele (2012), elephants choose 22 out of 35 species for the best feeding. However, this study result is slightly greater than (Yihew Biru and Afework Bekele, 2012) (i.e., 24 out of 38 species of trees and shrubs) (Table 6). Elephants prefer feeding different trees, including their bark, leaves, fruits, and developing shoots. Elephants, for instance, preferred to use trees that offered fruit or shade, such as *Balanites aegyptiaca* and *Berchemia discolor*. Elephants in this study displayed both preference and avoidance of specific Acacia species. *Acacia Seyal* (3.3033+) and *Acacia nilotica* (2.4790+) have high preference index values, which could be explained by their rarity and greater impact on the BES (Table 6). Similar to this, Anteneh Belayneh (2006) and Zalalem Wodu (2007) showed that the preferred use of elephants in BES had a significant negative influence on *Acacia Albida* and *Acacia Seyal*. Elephants selectively avoided *Acacia mellifera* (0.6611-) and *Acacia bussie* (0.6117-), which have a negative preference value (Table 6). A species may have a significant role in the food while still having a low preference value. Consequently, avoiding a species selectively does not necessarily mean avoiding it entirely (Parker, 2004). For instance, *Acacia mellifera* and *Acacia bussie* were in the diet with fairly similar frequency (1.87 and 3.04 % respectively). But *Acacia bussie* (4.98%) was slightly more common or plentiful in quantity than *Acacia mellifera* (2.83%) (Table 6). Since *Acacia mellifera* was used more frequently than *Acacia bussie* despite the fact that both species were significant to the diet, it is more likely that elephants will harm *Acacia mellifera* than *Acacia bussie*.

Based on dung analysis estimation, the availability and favorite food in elephants' diets are affected during both wet and dry seasons. The extra seeds were available in the dung during the wet season (i.e., 2009 in number, 71%) than during the dry season (i.e., 832 in number, 29%) (Table7). For instance, the *Opuntia ficus indica* woody species' had the highest numbers of seeds as 632 and 252 were recorded during the rainy and dry seasons, respectively (i.e., more than 30 % of seeds that were available in the dung). As informants responded, the species consumed by humans besides as a source of money in local markets. In total, 75 dung boli were removed from the sample and dissected, producing 2841 seeds of 24 distinct plant species for BES to distinguish the seasonal seed content of elephant dung (Table 7). Woody plant species such as *Acokanthera schimperi*, *Bersema abyssinica*, *Calpurnea aurea*, *Euphorbia abyssinica*, *Pinus patula*, and *Pyrostria phyllanthoidea* was recorded in the habitat of the river, where the dung was collected (Table 7). But no seeds were seen during the diet monitoring. There was a significant difference in the seed number observed in the wet season (mean value (X) = 83.71, SD=167.202; V^2 =27956.389, DF=23, at 95 % CI) than the dry season (mean value (χ) = 34.67, SD=71.446; V^2 =5104.580, DF=23, at 95 % CI). The mean number of seeds per dung bolus found during the wet/dry seasons exhibited a perfect positive association with the number of seeds in the dungs (correlation significant at the 0.01 level; two-tailed t-test results). Hence, more food was available for elephant during the wet season (such as the growing shoots, leaves, and fruit species) than the dry season. The result revealed that the majority of the elephants' diets consisted of browsing during both wet and dry seasons. Similarly, Elephants in Chebera Churchura National Park (Meseret Ademasu, 2006) and BES (Yihew Biru, 2009) both saw comparable outcomes. The observed seeds in this result (2841numbers) (Table 7) were less than other study reported by dissecting 71dung boli from 21 plant species (3442 seeds; Yihew Biru & Afework Bekele, 2012). However, the average number of seeds from woody plants/bolus (48.23 seeds/bolus) was comparable by Yihew Biru & Afework Bekele (2012). In this study, other than elephants, huge browsers including Greater and Lesser kudu were currently seen in the sanctuary browsing. The huge browsers like giraffe, eland, impala, and greater kudu preferred to browse *Acacia seyal* (Milewski and Madden, 2006). Due to its wider range and greater availability (Leweri *et al*., 2022), and palatability (i.e., having high crude protein, water, and low fibre content), Acacia species were therefore more consumed by elephants in the BES regardless of seasons (Ikanya *et al*., 2022). Generally, lack of food availability and water in their diet, seasonal variations

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influence how elephants use their habitat (Devi *et al.*, 2022), and particularly influence the feeding preference for elephants (Beirne *et al*., 2020).

Table 7. Seasonal seed content of elephant dung and mean seed per dung bolus as determined by dung analysis

Species' scientific names	Family	SFWS	SFDS	TS	% in dung	MSDB
Acacia brevispica Harms.	Fabaceae	17	6	23	0.81	0.405
Acacia bussie Harms ex.Sjostedt	Fabaceae	50	17	67	2.36	1.18
Acacia mellifera (Vahl) Benth.	Fabaceae	21	8	29	1.021	0.51
Acacia nigrii	Fabaceae	45	16	61	2.147	1.07
Acacia nilotica (L.) Wild. Ex Del.	Fabaceae	4	0	4	0.141	0.005
Acacia robusta Burch	Fabaceae	278	73	351	12.35	6.17
Acacia seyel Del.	Fabaceae	15	8	23	0.81	0.405
Acacia tortills(Forssk) Hayne	Fabaceae	72	38	110	3.87	0.02
Balanities aegyptica (L.) Del.	Balanitaceae	0	19	19	0.67	0.33
Berchemia discolor (Klotzsch) Hemsl.	Balanitaceae	57	15	72	2.53	1.27
Dichrostachys cinerea (L.) Wight & Arn.	Fabaceae	2	0	2	0.07	0.035
Dobera glabra (Forssk) Poir.	Salvadoraceae	0	4	4.00	0.14	0.07
Ehretia cymosa Thonn.	Boraginaceae	1	0	1	0.035	0.018
*Grewia schweinfurthii.*Burret	Tiliaceae	3	0	3.00	0.11	0.053
Lanthana camara L.	Verbenaceae	538	265	803	28.26	14.13
Ochnainermis (Forssk) schweinf.expenzing	Ochnaceae	19	6	25	0.88	0.44
Oncoba spinosa Forssk.	Flacourtaceae	1	0	1	0.035	0.018
Opuntia stricta (Haworth)	Cactaceae	150	61	211	7.427	3.71
Opuntia ficus-indica (L) Miller	Cactaceae	632	252	884	31.12	15.56
Ricinus communis L.	Euphorbiaceae	90	23	113	3.98	1.99
*Tamarindus indica.*L	Fabaceae	3	7	10	0.35	0.18
Terminalia brownie Fresen.	Combretaceae	10	0	10	0.35	0.18
Trachilia emitica Vahl.	Meliaceae	1	6	7	0.25	0.12
Ziziphus spina christi (T.) Desf.	Ramanaceae	0	8	8	0.282	0.14
Total		**2009**	**832**	**2841**	**100.0**	**48.01**

Key: SFWS-Seeds Found during the Wet Season, SFDS- Seeds Found during the Dry Season, TS-Total Seeds, and MSDB-Mean Seed per Dung Bolus. The dungs were only taken from Riverine Habitat (i.e., between Erer Ebada and Ebada Gamachu boundaries, on the right and left sides of the Erer river).

3.2.2. Impact of elephants on vegetation

Elephants utilized or affected woody plant species to varying degrees. Based on the level of impact on a plant that scored (using six categories: no damage, little used, primary and secondary branch broken, main steam and bark stripped, and uprooted tree), the elephants' impact on woody species parts was illustrated (Fig. 8a). The distribution of woody species occurred in the three land units. More than (94%) of the total accessible woody species are not impacted by elephants (i.e., have zero level detrimental value) (Fig. 8a). From the total number of woody species impacted with in each study site, there were 205 (10.41%) in riverine habitats, 841 (5.82%) in woodland habitats, and 1,340 (14.36%) in bush land habitats, with a mean impact proportion of 0.81, 2.8, and 2.92 in each land unit, respectively (Fig. 8a). The overall mean proportion of impacted woody species ranged from 0 to 5 while 0.08 to 5 for the observed impacts. There was a significant differences occurred on woody plants that elephants used between the three land units (mean value (χ) =549, SD = 439.97, V^2 = 193,572, at 95 % CI). Woody plants on bush land habitat (i.e., 5 Mean Maximum Impact Proportion Level-MMIPL) were more impacted than riverine (1 MMIPL) and woodland habitat (3 MMIPL) (Fig.8a). When related with damaged parts of woody plants, there was a significant differences occurred on the damaged parts of secondary branch of woody plants than others damaged parts (Mean value (χ) = 2.2, V^2= 5.94, SD= 2.44, and DF=2 at 95 % CI). However, there was insignificant differences occurred on uprooted trees (Mean value (χ) = 0.32, V^2 = 0.023, SD= 0.15, DF=2 at 95% CI). According to the findings, elephants consumed or had an impact on roughly 23 woody species (11 trees and 12 shrubs) in the riverine habitat, 36 (18 trees and 18 shrubs) in the forest habitat, and 19 (12 trees and 7shrubs) in bush land habitat. Stem breaking or bark stripping and primary and secondary branch felling were the principal damages occurred by elephants on woody species. Fewer uprooted trees' damage was seen from the total damage. For instance, a photo of a few uprooted trees and broken branches of a woody species was seen, as shown in (Fig. 8b). Depending on the vegetation type and diameter size class, different ratios of impacted trees were observed among the trees. Based on the guide to tree sizes: seedlings (<1m height, and less than 2.5cm DBH), saplings (<1m height, 2.5cm to 15cm DBH), small tree (3.6m-9m) height, medium tree (9m-15m) height and

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large trees above (15m) height were considered while estimating the tree size by observing the physical appearance (source: https://www.perriehale.co.uk/useful-information/guide-to-tree-sizes).

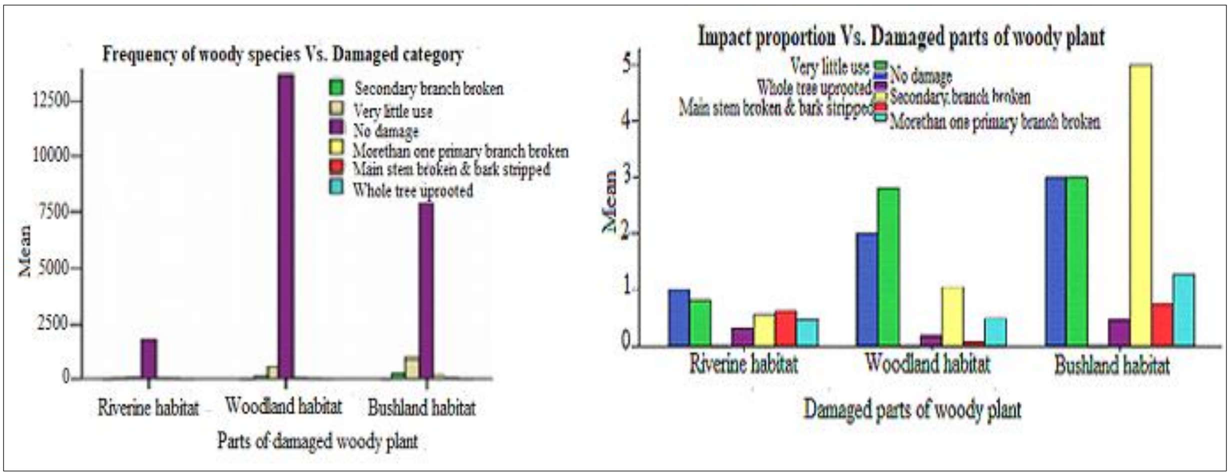

Figure 8a. Average frequency and proportion of impacted woody species by elephants in the three BES land units

Note: The damaged categories were characterized or grouped by different levels of value Expressed as Level (0)- no damage; Level (1)- very little use; Level (2)- secondary branches broken; Level (3)- more than one primary branch broken; Level (4)- main stem broken, heavily browsed or bark stripped and Level (5)- the whole tree uprooted.

Small trees (38.6%), seedlings (28%), and saplings (23%) were more impacted in bush land habitats than in riverine forests and woodland (Fig.8b). Medium-sized trees (23.76%) and large-size trees (12.87%) in the riverine forest were consumed by elephants more than in the bush land habitats. However, woodland areas saw the highest impacts (Fig.8b). In general, there was a significant damage (highest average frequency) was occurred on small tree size class (mean value (χ) =2.2 and SD=181.6, V^2 =32,977, DF=2 at 95% CI) while insignificant damage (lowest average frequency) was occurred on large trees size (mean value (χ) =43.67 and SD=24.007, V^2 =576.333, DF=2, at 95% CI).

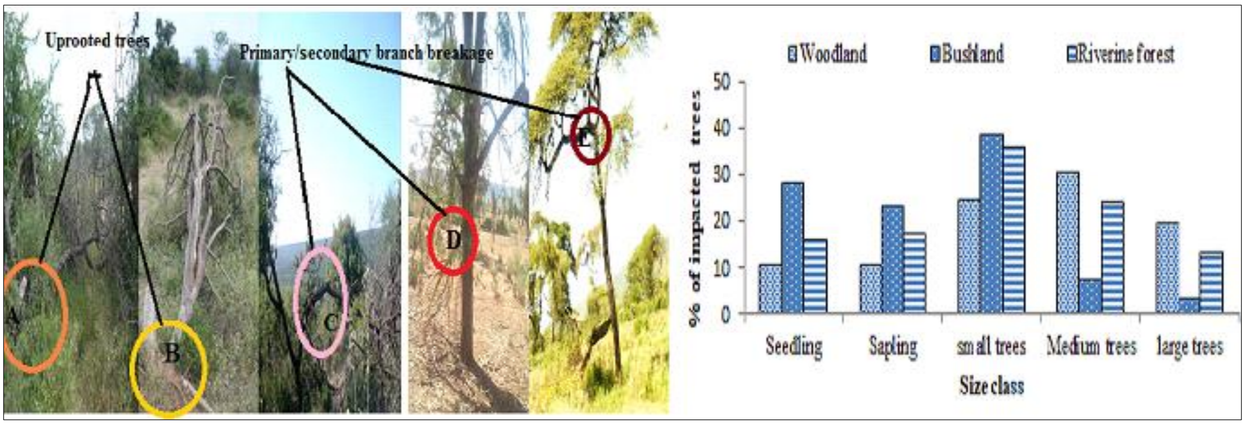

Figure 8b. Impacted woody species part & proportion of impacted trees per diameter size class per vegetation type in BES

The result revealed that elephants' impacts on the woody species showed that they harm the plants at various damage levels by altering the behavior of woody plants (damaging its primary/secondary branches and main stem, heavily browsed/bark stripped, and whole tree uprooting). Similarly, research by Wilson (2020) and Thompson (2022) showed that elephants harm woody vegetation by felling, debarking, splitting stems, breaking leader shoots, and affecting the trees and shrubs. Elephants also graze and browse a variety of plant species. Even in this investigation, breaking off branches and uprooting trees were seen (Fig.8b). Elephants may need to eat a variety of specific plant parts, such as leaves, bark, roots, stems, and twigs, to meet their nutritional needs. 62.44% of the injured woody species in the riverine habitat were Accacia (Mainly *A.bussie*, *A. robusta*, and *A. tortills*). For instance, among the heavily impacted secondary branches of woody plants, 35% of it was the *A. robusta* species (i.e., 15 out of 43). Moreover, woody species such as *Opuntia stricta*, *Opuntia ficus-indica*, and *Ziziphus spina Christi* were also significantly impacted. Elephant consumption of plant tissues that influence relative survival, growth, and reproduction of woody species was noted. Similarly, Owen- Smith *et al.* (2019) noted that elephants alter the relative abundance patterns and vegetation dynamics by influencing the growth and survival of various herb, shrub, and tree species. Large and medium-sized trees are more affected in

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habitats of woodlands and riverine forests (Fig.8b). Similarly, Abdulbasit Hussein (2019) reported that in woodland settings, the size of large, medium, and small trees had an impact that was greater than the average across all stems. In the riverine and woodland habitats, small, medium-sized, and big trees had either broken stems or were entirely felled. Despite the vast impacts, the primary and secondary branch breakages were distributed more in all bush land, woodland, and riverine vegetation of the sanctuary.

3.3. Movement patterns and their seasonal distribution

The historical movement of elephant distribution in the sanctuary was identified. Elephants once resided in four drainage river valleys following the Garamuleta-Gursum highlands, including Fafem, Daketa, Erer, and Gobele (Fig. 9). They moved along the Harer-Babile road before the sanctuary's establishment in 1972 (Fig.9). Key informants and locals explained that five to six groups of elephant herds traveled between the Oromia and Somali regions. The first movement was observed along the Al-Ethiopia regions of Somalia and the Oromia region of Bikko and Midega Tola district of Bilisuma PeA and other villages. The second movement was from the outside east of the BES boundary of the Dala areas of the Somali region to the southwest direction of the Oromia region of the Babile district. The third, fourth, and fifth routes occurred in the Oromia region. The fourth route occurred between the Mayu Muluke district areas of Alola and Gabibda to the Midhega Tola district areas of Karensa, Barzala, Lencha, Negaya Midhega, Kufa, and Bilisuma PeAs. The fifth route occurred between Kurfa Chale district areas of Dire Gudina and Grawa district areas of Serkema, Biftu, Rasa Nagaya, Jirubali, Tuta Janati, Berkume, Ufe, and nearby villages of Mayu Muluke district areas of Alola, Ligba, Gabibda, and Gedomisera (Fig.9). The same groups of elephants were moved west of Mayu Muluke district areas to outside sanctuary territories in the Somali regions.

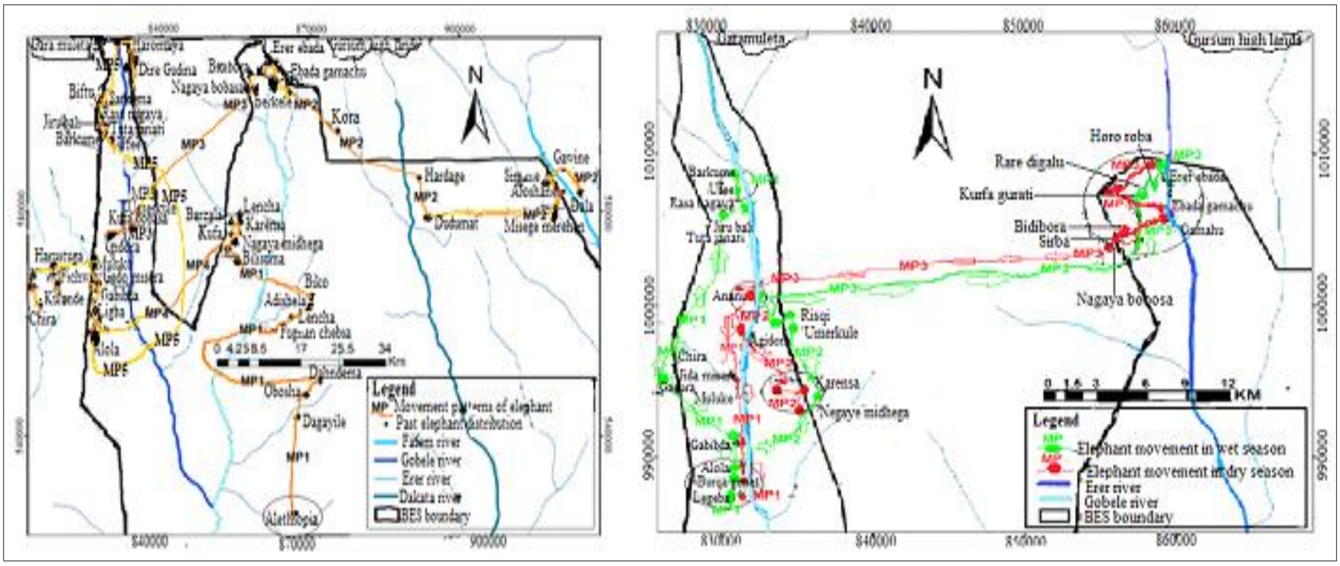

Figure 9. Historical (left) and current dry and wet season (right) elephant distribution in the Babile Elephants Sanctuary

Elephants in the Mayu district of BES moved in various patterns during the rainy and dry seasons. During the rainy season, elephants are more likely to be found in the surrounding Fedis district, while during the dry season, elephants move in the Erer Valley of the Babile district. The Erer and Gobele valleys are the main routes for elephant movement during these two seasons (Fig.10). Elephant movements have been observed in the Oromia region parts of the sanctuary, followed by the Erer and Gobele valleys. These movements have been concentrated in most parts of the sanctuary sites, covering both regions (Fig.9). Long elephant routes occur during the rainy or wet season (Desales *et al*. (2020), as elephants choose the healthiest and tastiest plants available (Walter *et al*., 2019). Large elephant populations are present throughout the rainy season to combat nutritional stress and replenish energy stores. During the dry season, elephants from several herds gather into groupings needing regular food and water and sometimes need to fight poachers in groups. The herds always concentrate in the sanctuary's northern and southern sections of the Erere and Gobele valleys. The home range area of the BES is 3014 km^2, with 85.7% located inside and 14.3% outside the BES but close to it (Yirmed Demeke *et al*., 2012). This current home range is half that of the elephants' past home range. However, it is more than other elephants' average home ranges, such as the Gourma National Park in Mali and Kruger National Park in South Africa (Wall *et al.*, 2021). However, it is less than the average elephant home-range size in Kunene National Park in Namibia, which was between 2500-4300 km^2 (Lorena *et al.*, 2022). Despite the sanctuary's size and abundance of water and rich feed, ongoing urbanization, agricultural development, and poaching have restricted and congested many elephants' migratory pathways. The study highlights the importance of understanding elephant movement patterns and seasonal distribution in the context of the BES.

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3.4. Threats

Human-elephant conflict and other conservation challenges are the threats for the conservation works in the sanctuary. Various human induced effects were observed in the study sites, as discussed below.

3.4.1. Human-elephant conflict types and nature

3.4.1.1. The HEC incidents

Crop-raiding incidents were more frequent than other incidents, with 87.7% of respondents identifying it as a contributor to high-emission crops (HEC) in the study site area (Table 8). However, 12.3% of respondents were not concerned. Of the 100 respondents (78%) were against an elephant conservation system, viewing elephants as a threat to their way of life and a significant resource competitor. There was a significant difference in local community perception towards crop raiding ($\chi2$ =7.8, DF=3, P< 0.05). The second incidence was elephant deaths due to crop raiding and poaching, with 117 respondents estimating that 31 elephants were affected, 25 died, and six were injured. In the last five years, 473 (69%) of the 685 incident occurrences were brought by an elephant on crops (Table 8).

Table 8. Respondents' view on total number of incidents occurred by HEC over the last five years in BES (2017-2021)

Causes to incidence	Number of incidents	Total number and % of respondents
Humans death	22	75(54.3%)
Injured human	15	53(38.4%)
Killed Live stocks	47	52(37.7%)
Livestock injured	52	50(36.23%)
Damaged on water taps/structure	7	10(7.24%)
Damaged on irrigation materials	7	17(12.32%)
Damaged on food stores	31	36(26.1%)
Destroyed crops (crop raiding)	473	121(87.7%)
Elephant death (by man)	25	117(85%)
Elephant injured(by man)	6	21(15%)
Supporting the existing elephant conservation	-	30(22%)

Note: The numbers outside parentheses represent frequencies (the number of respondents), and the numbers inside them represent percentages. Field observation, questionnaires, and annual reports of the sanctuary to gather data for the study on the number of HEC incidents included.

The study found that elephants have caused significant harm to local people and livestock by causing damage to crops, food storage facilities, and irrigation systems. The extent of elephant destruction ranges from severe crop-raiding to killing people, with the species becoming the most hazardous and destructive (Manoa *et al.*, 2021). The study found that elephants trampled numerous crops, including vegetables, fruits, oilseeds, and cereal crops, day and night. Only 22 people were killed in the five-year study period (2017-2021G.C) (Table 8), which is small compared to research conducted in Asia, where elephant mortality rates are high (Gunawardhana, 2018). The study found the most attractive crops to elephants and areas of farmlands where HEC was most prevalent. HEC hot spots in the "kebeles" divisions were concentrated in lowland regions dominated by seasonal crops, particularly sorghum and maize, and intermingled with only a few settlements. Elephants are more likely to influence study sites if a village or field is close to the sanctuary (Bhuyan and Kar, 2018; Hariohay *et al.*, 2020). Most HEC hotspots occurred in farmlands adjacent to the sanctuary. Similarly, Mmbaga *et al.*(2017) reported high HEC adjacent to protected areas.

4.4.1.2. Crop yield loss and the estimated cost of production

The study found that elephants in various locations caused crop damage, with 87.7% of respondents believing total yield losses over five years were 12,900 Qt, costing an estimated 1,392,247.49 Ethiopian Birr (ETB) from 740.52 ha of land (Table 9). The overall effect of crop raiding was significant ($\chi2$ = 0.98, DF= 1, P < 0.05), with 26.8% of respondents resulting in losses of 877,561.02 ETB from *Sorghum bicolor* and *Zea mays*. All (100%) respondents agreed that no compensation had been given for the lost crops. The frequency of HEC was largely seasonal, with crops like Sorghum and maize sown in the first few days of May and crop raiding occurring when the crops ripened in August and September. According to a similar finding by Mukeka *et al.* (2018), agricultural damage caused by elephant raids was highest in August when crops began to grow. The anticipated costs of crop loss in this study were around 35 USD per ha, with a charge rate of 53.69 ETB/1 USD in January 2023 (Table 9). Unlike previous studies, this research revealed that elephants favor maize and sorghum over other crops and only occasionally destroy coffee (insignificantly) or fruit plantations (significantly). The study supports previous findings that elephants prefer certain crops, such as coffee in India (Thammaiah and Vijaya, 2018) and bananas in Tanzania's Serengeti region(Loussakou and Zhu, 2019).

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Table 9. Respondents' view of total area covered, yield loss, and production costs for each crop consumed by elephants in the study areas (2017-2021)

Scientific names	Common names	No.of respondents and %	Estimated area and yield loss over the last five years					Total yield loss (Qt)	Total area (Ha)	Total cost of production (ETB)
			2017	2018	2019	2020	2021			
Magnifera indica	Mango	10 (7.25%)	7.65(163.1)	6(110)	18.1(359.4)	10.2 (82.8)	20 (630)	1345.3	61.95	81,421.41
Saccharum officinarum L	Sugarcane	2(1.45%)	1.3(50)	-	-	1(40)	0.5 (10)	100	2.8	3,013..90
Carica papaya	Papaya	6(4.35%)	1.9 (60.4)	4.1 (62)	11.2 (45.2)	-	5.25 (52.5)	220.1	22.45	25,696.93
Psidium guajava	Guava	4(2.9%)	4.5(99)	3.3(102.8)	20 (150)	19(123)	10 (149)	623.8	58.6	69,421.9
Citrus aurantifolia	Key lime	1(0.72%)	0.2(1)	-	-	3(10)	-	11	3.2	25,53.9
Musa paradisiaca	Banana	8(5.8%)	6(197)	3.4(62)	12.6(91.52)	14 (89)	5(40)	479.52	41	35,968.96
Sorghum bicolor	Sorghum	19(13.76%)	29.5 (486)	28.2(368.5)	24.2 (395)	29.2 (524)	35.6 (477)	2250.5	146.7	300,577.81
Zea mays	Maize	18(13.04%)	32.5 (975)	34.22 (934)	33.3 (977)	29.6 (816)	54.2 (1567)	5269	183.8	576,983.21
Ipomoea batatas	Sweet potato	8(5.8%)	-	-	2.8(26)	4.1 (57.54)	7.1 (52.5)	136.04	14	15769.17
Apios americana	Groundnut	1(0.72%)	-	0.5(8)	5(18.9)	6.4 (165)	10.6 (275)	466.9	22.5	62431.66
Capscium annuum	Sweet pepper	11 (8%)	0.5(5)	4.5 (13.5)	9.7 (81.87)	6.5 (46.4)	15.8 (108)	255	37	35,038.11
Citrullus lanatus	Watermilon	4(2.9%)	4.5(44)	5(22)	11 (114)	12.5 (57.4)	9(330)	281	27.5	23,611.19
Cucurbita maxima	Pumpkin	6(4.35%)	4.5(46)	3.5 (17)	9.5 (117)	3(25)	7(76)	567.4	37	28,216.27
Annoona senagalensis	Wildapple custard	4(2.9%)	-	-	-	-	2(12)	344	35.5	49731.45
Lycopersicon esculentum	Tomato	4(2.9%)	3(96)	-	-	-	16 (102.5)	92	9	13,197.51
Sesamum indicum	Sesame	2(1.45%)	2(28)	1(8)		4(24)	2(32)	10	2	1373.45
Catha edulis	Chat	6(4.35%)	2(6)	1(10)	1.5 (13)	3 (37.5)	0.8(8)	198.5	19	43,368.17
Phaseolus Vulgaris	Turkishgreen beans	1(0.72%)	-	4.5 (78)	9(35)	14 (151)	8(80)	12	2	1631.02
Allium cepa	Onions	2(1.45%)	3(112)	-	-	-	-	112	3	11701.52
Arachis hypogea	Peanut	4(2.9%)	-	2(10)	-	-	-	58.5	8.3	10,539.96
Total		**121(87.7%)**	**103.05(2369)**	**101.22(1806)**	**167.9(2474)**	**159.5(2249)**	**208.85(4002)**	**12,900**	**740.52**	**1,392,247.49**

Notes: The respondents' percentage and yield loss per quintal over the last five years were shown in the bracket. ETB stands for Ethiopian Birr. Labor and variable costs were added to determine costs of agricultural production (such as ingredients like fertilizer, seed, and herbicides). Other expenses were also not assessed in the study sites due to insufficient data.

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4.5.2. Others conservation challenges

The conservation areas might influenced by natural and human factors. However, in this study, most of the factors were human-induced. Internal issues (e.g., lack of competence) and external issues (e.g., less stakeholder participation) are recognized as conservation challenges in the sanctuary. All respondents (n=138, 100%) believe human population growth, driven by land scarcity and resource extraction, is the primary cause of the sanctuary's threat (Fig.10). The study analyzed the impact of residents' relocations from nearby and far away districts on conservation efforts in a sanctuary. Over 89% of respondents said that deforestation was worsened by people moving within or near boundaries (Fig. 10).

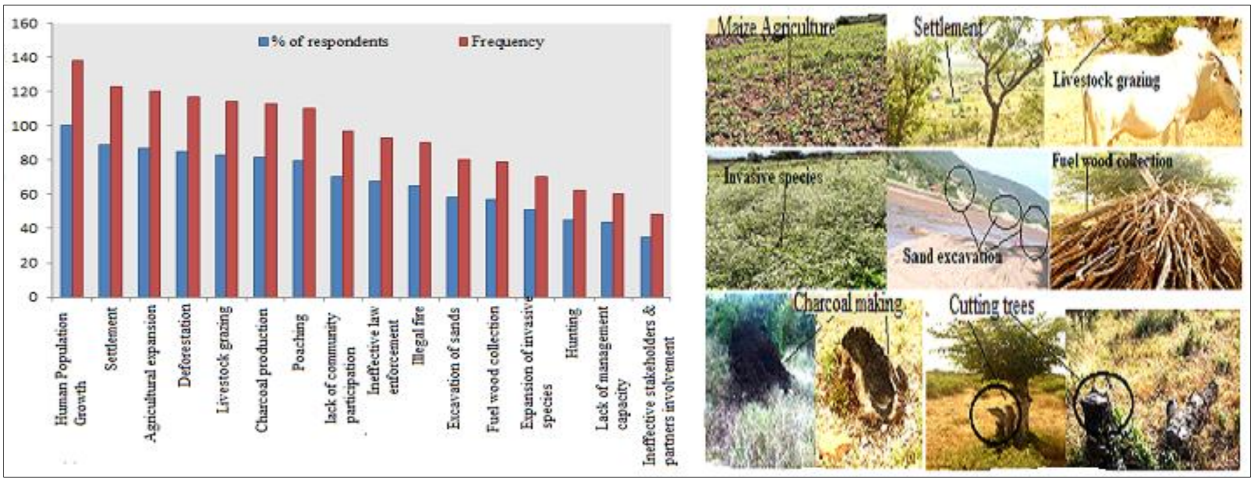

Figure 10. Respondents' perceptions of the conservation threats and some observed anthropogenic impacts in BES

Agriculture was also expanding, with livestock grazing being the most common and traditional activity by locals, especially pastoralists in the Somali area. Local people were involved in charcoal production and fuel wood collection, with a non-significant difference ($\chi2$=22.5, DF = 19, P< 0.05). Illegal hunting and poaching were observed in the sanctuary. Less than (n= 62, 45%) respondents reported hunting some wild animals, but hunting is insignificantly related to other conservation risks ($\chi2$ = 30, DF = 19, P< 0.05). More than 79% of respondents said that poachers rarely killed elephants, leading to a decline in the elephant population. However, considerable poaching was seen in the sanctuary ($\chi2$=344.43, DF=19, P >0.05). Sand excavation in the sanctuary's Gobele Valley had a significant impact ($\chi2$ = 63.98, DF = 19, P > 0.05), due to wild animals hearing loud noises while sand was loaded into trucks. Invasive species such as *Lantana camara*, *Prosopis juliflora*, *Parthenium hystrophorus*, and other locally identified species (such as Eri, Dersa, and Xadii weed species) were observed during data collection (Fig.10). Over 50% of respondents believed invasive species were dominating other native fauna and flora in the sanctuary. The sanctuary faced conservation challenges due to ineffective law enforcement, management capacity, and lack of stakeholder and partner involvement. There was no significant difference between law enforcement and management capacity ($\chi2$ =8.9, DF=19, P < 0.05), but significant differences occurred between law enforcement and stakeholder and partner involvement ($\chi2$ =3.72, DF=19, P < 0.05). In general, most conservation challenges were severe.

The BES has faced numerous challenges that have negatively impacted conservation efforts. Humans have increased pressure on land and other resources, leading to habitat loss, overgrazing, deforestation, soil degradation, and abuse of natural resources (Israel Petros, 2021; Simachew Wassie, 2020). Hence, the number of elephants in the sanctuary might decline. In the BES, humans reside within or close to its boundaries, particularly near the Erer and Gobele rivers. The BES is home to numerous small communities, agricultural activities, and illegal settlements, which have worsened due to the rising demand for building materials, cultivated land, and wood for fuel. Deforestation by human settlements affects wildlife resources and habitats. Overgrazing by animals is another issue, with competition between pastoralists' livestock and elephants. The lack of buffer zones around the sanctuary has affected vegetation and wildlife. Overgrazing by livestock around/inside the BES must be addressed. Illegal hunting and poaching are also challenges in the sanctuary. The lack of patrols and low enforcement of wildlife laws encourage poaching and illegal hunting. Traditional weapons used by poachers have not significantly impacted larger animals in the past, but modern firearm types have altered the issue. Poaching and the illegal ivory trade are currently the biggest dangers to elephants in the nation. Local participation in wildlife census, developmental activities, management plan preparation, and meetings has been less due to a lack of knowledge on the benefits of wildlife and a lack of enough benefit shares. This lack of benefit-sharing and community participation has affected many protected areas (Amare Wondirad and Biruk Ewnetu, 2019). Respecting mutual and sharing benefits fully and equitably is necessary to reduce the impact in the future. Invasive species dominate other native fauna and flora in the sanctuary, covering grazing land and becoming a threat to the grassland, the feed source for elephants. In this study, 15%

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and 18% of species in the sampled riverine and bushland habitats were invaded by *Lanthana camara*, respectively. If the infection rate continues, it could threaten the natural vegetation in the sanctuary. Generally, effective enforcement of protected areas authorities' measures on different management aspects is necessary to address these internal and external challenges.

5. CONCLUSION

The study revealed that there are still remnant populations of African elephants in the BES, implying the requirement of urgent conservation measures to revert the situation. Both current and trend status indicated a decrease in elephant population due to several interrelated factors such as habitat destruction and fragmentation derived by human population growth leading to loss of habitats and poaching for ivory. The age structure shown tends more toward the Younger elephant population, revealing that the population is viable and promising. However, the threat posed has been very high, and urgent actions to resolve the problem could save the remaining individuals of the species. Acacia species, particularly *Acacia seyal*, *Acacia nilotica*, and *Opuntia ficus-indica* have been shown as the most frequently consumed plant species, and availability is vital for the species' survival and reproduction. Shrubs and trees are selected by elephants for survival in the area. Elephants in the sanctuary were observed following the Erer and Gobele valleys. Other factors than food might have led to the decline: Habitat fragmentation, human-elephant conflict, and poaching for their valuable Ivories. Hence, urgent conservation measure is needed to save the globally vulnerable *Loxodonta africana Orleans* sub-species in Ethiopia in its stronghold area of BES.

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DECLARATION

Abbreviations: **BESDMP-**Babile Elephant Sanctuary Draft Management Plan, **EMEPA-** Enhanced Management and Enforcement of Ethiopia Protected Area estate, **NMSA-**National Meteorological Service Agency, **EWNHS-**Ethiopian Wildlife Natural History Society, **HEC-** Human-Elephant Conflict, **BES-**Babile Elephant Sanctuary, **HHs-**Households, **FGD-**Focus Group Discussion, **MMIPL-**Mean Maximum Impact Proportion Level, **PeAs-** Peasant Associations, **PAs-**Protected Areas, **SDPASE/EWCA-**Sustainable Development of Protected Area System of Ethiopia/Ethiopia Wildlife Conservation Authority

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