Ecology, modelling of habitat suitability and conservation challenges of African elephant (*Loxodonta africana* Blumenbach, 1797) in and around Omo National Park, Ethiopia

By

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DECLARATION

Addis Ababa University, School of Graduate Studies

This is to certify that this thesis prepared by Girma Timer, entitled "**Ecology, modelling of habitat suitability and conservation challenges of African elephant (*Loxodonta africana* Blumenbach, 1797) in and around Omo National Park, Ethiopia**" and submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Zoology (Ecological and Systematic Zoology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Ecology, modelling of habitat suitability and conservation challenges of African elephant (*Loxodonta africana* Blumenbach, 1797) in and around Omo National Park, Ethiopia

Girma Timer, PhD dissertation, Addis Ababa University, November 2024

The African savannah elephant (*L. africana*) is a large endangered herbivorous mammal. Understanding its ecology, habitat suitability, distribution and conservation challenges in and around the Omo National Park (ONP), is key to guide conservation and management initiatives. The survey took place between 2021 and 2022 during both the wet (April–June) and dry (December–February) seasons. Along 32 transects covering a distance of 32 km, elephant dungs were counted using line transect distance sampling technique in the different habitats to estimate elephant population by converting dung density to elephant density. Seasonal habitat suitability and distribution patterns of elephants were assessed using, Species Distribution Models. The seasonal diet composition and feeding behaviour of elephants were assessed using fresh feeding traces collected along their feeding routes. Changes in land use and cover (LULC) between 1993, 2003, 2013 and 2023 in the ONP and surrounding areas were classified and monitored using Landsat satellite imagery, GIS and remote sensing techniques. The estimated number of elephants from the dung count was only 134 (0.22 individuals/km2) for 2021 and 306 (0.44 individuals/km2) for 2022, dry seasons within the extent of elephant habitats in the park. This considerable population difference could be related to habitat requirements and elephant movements in the area. The combined seasonal habitat suitability model using MaxEnt for the currently available potential habitat of *L. africana* predicted approximately 1999 km2 (39% of the study area), with 365 km2 (7.2%) optimal, 748 km2 (14.7%) suitable and 886 km2 (17.5%) moderately suitable. During the wet and dry seasons, proximity to rivers, canals and LULC had the greatest influence on habitat suitability of *L. africana*. Elephants consumed 91 plant species grouped into 34 families and 66 genera. During the wet and dry seasons, the largest proportion of their diet came from family Fabaceae (25 and 20%), followed by Meliaceae (10 and 9%) and Poaceae (4 and 18%), respectively. The LULC has changed over the last three decades and these changes in the buffer areas surrounding the ONP have had a greater impact on the status of the elephant population. Within the ONP, the open grassland decreased while other land covers such as savannah wooed grassland, bush land, woodland, forestland and water bodies increased.This could be related to the wildfire, grazing pressure and decline of browsers over the period. Conversely, in the surrounding buffer areas of the ONP, forestland and open grassland decreased, while agriculture land increased significantly. The main factor contributing to the changes in the study area land cover has been agricultural expansion related to local farms and large scale agricultural investments, which have increased by approximately 284% over the past 30 years. Large-scale agriculture and human activities have a significant impact on changes in LULC, which may disturb elephant suitable habitats and migration corridors. These factors were identified as the main causes for the decline of elephant populations in study area. It is therefore recommended to formulate a site and species specific strategy and work with relevant stakeholders at all levels to address the prevailing conservation issues.

Keywords: Dung count, feeding , landsat imagery, land use land cover, Lower Omo Valley , MaxEnt, species distribution modelling, classification

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ACRONYMS/ ABRAVATIONS

AfESG	African Elephant Specialist Group
AEC	African Elephant Coalition
AUC	The value of Area under Curve in MaxEnt
BES	Babile Elephant Sanctuary
CCNP	Chebera Churchura National Park
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
DEM	Digital Elevation Model
ECA	United Nations. Economic Commission for Africa
ESC	Ethiopian Sugar Corporation
ESMF	Environmental Social Management Framework
EWCA	Ethiopian Wildlife Conservation Authority
EWNHS	Ethiopian Wildlife Natural History Society
GEC	Great Elephant Census
GEF	Global Environment Fund
HEC	Human-Elephant Conflict
IGAD	Eastern Africa Inter Governmental Agency for Development
IUCN	International Union for Conservation of Nature and Natural Resources
LULC	Land Use Land Cover
MAXENT	Maximum Entropy Modelling
MIKE	Monitoring the Illegal Killing of Elephants
MNP	Mago National Park
OGL	Open Grassland
ONP	Omo National Park
ROC	The Receiver Operating Characteristics Curve
SADC	Southern African Development Community
SNNPRS	Southern Nations Nationalities and Peoples Regional State
SWERS	Southwest Ethiopia Regional State
SWG	Savanna Wooded Grassland
TFCA	Trans Frontier Conservation Area

UN FAO	United Nations Food and Agriculture Organization
UNDP	United Nations Devevelopment Program
UN-ECA	United Nations Economic Commission for Africa,
USGS	United States Geological Survey
WDPA	World Database on Protected Areas
WPP	World Population Prospects

1. INTRODUCTION

1.1. Background and justification

Ethiopia has diverse wildlife resources. This is attributed to the differences in altitude and the diversity of climate, vegetation and landscape. It is one of the few countries with unique and characteristic fauna with a high degree of endemism (Yalden *et al*., 1984; Hillman, 1993a, b; Lavrenchenko and Bekele, 2018). The geographical and climatic diversity of the country is characterized by altitudinal differences, i.e. from the highest mountain Ras Dejen in the Simien Mountains National Park (SMNP), which rises from4620 m asl to the Dallol depression which is 116 m bsl and is the hottest place on the planet (*Belay Simane* et al., 2016; Mengesha Asefa et al., 2020) The highland regions of Ethiopia have less biodiversity than many lowland regions, but they have a higher number of endemic mammal and bird species (EWNHS, 1996) The eastern lowlands have a large number of bird and antelope species along the Somali Masai biome (EWNHS, 1996)

The varied ecological systems that resulted from climactic and geographical diversity has contributed to the existence of various forms of life in Ethiopia and made Ethiopia one of the few countries in the world known to possess unique and characteristic fauna and flora with a significant level of endemism (Hillman, 1993). Having evolved on relative ecological isolation from the rest of African mainland, it contains approximately 40% of all land above 2,500 m in altitude (Hillman, 1993). The diverse ecological conditions support a variety of flora and fauna. These include 6,500-7,000 species of higher plants, of which 12% are endemic, 320 species of mammals (17% endemic), 861 species of birds (2.1%), 201 species of reptiles (4.5% are endemic), 63 species of amphibians (38% are endemic) and 150 species of fish (2.7% are endemic).(Afework Bekele *et al.*, 1993; Yalden *et al.*, 1996).

Over the years, the natural ecosystems in Ethiopia have been transformed by humans and natural factors. Much of the highlands and lowlands have been converted to agriculture and pasture, in addition to the utilization of the vegetation for firewood, construction and other purposes (Mengesha Asefa *et al.*, 2020). As a result, the country's wildlife resources are now largely confined to protected areas, although threats also continue to extend to these areas.

Only about 10.6% of the country's total area is currently reserved as protected area for wildlife resources (EWCA, 2015). This includes 27 National Parks, two Wildlife Sanctuaries, five Wildlife Reserves, 24 Controlled Hunting Areas, 12 Community Conservancies and five Biosphere Reserves (EWCA, 2015). Many of these protected areas are managed directly by the National Regional State and only 11 National Parks and two Sanctuaries (Babile Elephant and Sinkle Hartbeests) are managed directly by the Ethiopian Wildlife Conservation Authority (EWCA). These national conservation areas are considered representative sample natural ecosystems, which are sensitive and fragile and require great attention to protect. Omo National Park (ONP) is one such national concern known for its rich lowland biodiversity and the country's abundant wildlife populations.

The vegetation composition of ONP includes savannah grassland, savannah wooded grassland, forest riparian formation and deciduous woodland which is home for diverse fauna (Chiere Enawugaw, 1996). The Park is an important conservation area for diverse avian species and has been designated as one of the 69 Important Bird Areas of Ethiopia (EWNHS, 1996). However, as most protected areas in the country, ONP is under threat due to different factors affecting the state of conservation including poaching, domestic grazing, seasonal settlements together with the ongoing government large scale agricultural investment (Mega sugar development project).

Although ONP is one of the oldest protected areas in the country, the resource base dynamics has not been well investigated largely due to inaccessibility and remoteness of the reserve. There have been few specific systematic research focused on the mammalian and avian diversity, abundance and distribution as well as population status, structure and distribution of a particular species. Similarly, there is no reliable recent information about the *L. africana* of ONP, which is the subject of this research. As the growing human population and the associated pressures continue to affect negatively the natural ecosystem, there is a growing need to regularly monitor the status, distribution and trends of wild animal populations.

Thus, this study provides the current ecology and habitat suitability of the species and conservation challenges related to changes in land use and land cover which is critical to properly manage and conserve the African elephants in and around the Omo National Park.

1.2. Statement of the problem

Despite the presence of a number of elephant range protected areas in the country, knowledge on the ecology, population status, habitat uses, and distribution patterns of African elephant's remains inadequate, highlighting the importance of further exploration and specific studies in their natural habitats. Apart from poaching for Illegal ivory trade, increasing human activities and land conversation for agricultural expansion, deforestation, grazing are affecting elephant populations and its suitable habitats, raising concerns about the long-term viability of elephant populations and the potential ecological impacts on the ecosystem, even though the extent of changes and impacts remain unknown. Such research and studies would be of utmost importance to fill the knowledge gaps in terms of understanding the ecology of target species and threats, which in turn would provide important recommendations for policy makers and practitioners for their decisions and successful management actions. There are available ecological studies conducted in most of the elephant range protected areas of the country even though studies conducted in around the target study area (ONP) are somewhat older and do not reflect the current situation of African elephant population, habitat use and distribution. Thus, it is necessary considering specific ecological research aimed to enhance the conservation efforts of the African elephant population in and around ONP of south-western Ethiopia.

This dissertation focuses on examining the African elephant ecology, habitat suitability and distribution, feeding behaviour and conservation challenges related with LULC changes to support the development of conservation management strategies for the species in and around ONP. It also provides baseline information for the management of the elephant population in the lower Omo Region of the country particularly in and around the Omo National Park (ONP). The result of this study could also help to provide an input for updating of the national elephant action plan and for the national wildlife policy. This reaserch works were supported by state-of-the-art approachs including Maxent|:species distribution modelling, latest landsat images -Arc Gis 10.8 supervised LULC classification, and ecological factor analysis and line transect distance sampling.

1.3. Objectives

1.3.1. General objective

The main objective of this study was to conduct population estimates, distribution, habitat suitability, and feeding ecology of African elephants, as well as to examine conservation challenges associated with land use and land cover (LULC) changes in and around ONP, Ethiopia.

1.3.2. Specific objectives

The specific objectives of this desrtation were to

- estimate the population size of African elephants in ONP,
- determine habitat suitability and distribution of African elephants in ONP,
- explore the feeding ecology of African elephants in ONP,
- investigate LULC changes and their impacts on elephants in and around ONP, and

examine the extent of human activities and conservation challenges associated with LULC changes.

1.4. Research questions

- What are the current population sizes/estimates of African elephants in the ONP?
- How is the population trends of African elephant in the last five decades?
- Is Habitat suitability and associations of African elephants vary with season.?
- What is the seasonal distribution pattern of African elephants in ONP?
- Is there seasonal variation related to distribution and habitat association of African elephants in ONP?
- What are the ecological factors influencing the elephant seasonal distribution patterns in ONP?
- How variable are the diet of elephants on seasons?
- How is the feeding ecology of African elephants in ONP?
- Which habitat is utilized more by the elephant herd during the wet and dry seasons? Is the

Proportion of grazing and browsing of Africa elephants differ with seasons?

1.5. Scope of the study

This study covers four important subjects on L, africana: 1) population size and trends 2) the potential suitable habitat of the species 3)seasonal dite compostion or feeding ecology and 4) land use land cover change and impacts on elephant population and movment.

2. LITERATURE REVIEW

2.1. African elephants

The African elephant is the world's largest mammal walking on the Earth. Their herds wander through 38 countries in Africa. They are slightly larger than their Asian cousins and can be identified by their highly dexterous trunk, long curved tusks, and massive ears (Asian elephants have smaller, rounded ears) (Mosissa Geleta and Abebe Getahun1 (2020).). African elephants have grey skin and differ in the size of their ears and tusks, and in the shape and size of their skulls. They are easily recognized by their trunk that is used for communication and handling objects. Their large ears allow them to radiate excess heat . Upper incisor teeth develop into tusks in African elephants and grow throughout their lifetime. African elephants weigh up to 6,000 kg and stand 3.3 m at the shoulder (Laws, 2008; Mosissa Geleta and Abebe Getahun, 2020). With a trunk weighing 140 kg, an elephant can pick up the tiniest crumb, push over a mature tree, pour 12 liters of water into its mouth or detect a smell from several km away. Their ivory have been coveted by humans for centuries, and the it has played a significant role in the art and culture of many people (Mosissa Geleta and Abebe Getahun, 2020).).

From the order Probocidea, the African elephant *Loxodonta* and its close cousin, the Asian elephant (*Elephas maximus*), are the only surviving species and both genera originated during early Pleistocene in sub-Saharan Africa (Mosissa Geleta and Abebe Getahun, 2020). *Loxodonta* remained in Africa, but others moved into Asia during the late Pleistocene (Mosissa Geleta and Abebe Getahun1 (2020).. The African elephant genus comprises the two living elephant species, the African bush elephant (*L. africana*) and the smaller African forest elephant (*Loxodonta cyclotis*) (Grubb *et al*., 2000; Roca *et al*., 2001). Both are herbivores and live in groups. They have grey skin and differ in the size of their ears and tusks, and in the shape and size of their skulls. The savanna elephant is larger than the forest elephant. It has sparser body hair, more triangular ears that are larger, and thick curved tusks as opposed to the straighter, narrower downward pointing tusks of the forest elephant (Larry and Marc, 1978; Yirmed Demeke *et al.*, 2011). Both savanna and forest African elephants were listed as vulnerable on the IUCN Red List since 2004 and now listed as endangered and critically endangered (IUCN 2021), respectively. They are threatened due to habitat loss and fragmentation.

The African elephants once populated the entire continent and, formerly, within the last three centuries, inhabited all of sub-Saharan Africa in habitats ranging from tropical and montane forests to open grasslands, semi-arid bush and desert (IUCN 2016). In recent years, however, poaching for illegal ivory trade and human population growth and expansion have reduced the species' range and number drastically (IUCN 2016 The majority of the remaining elephants exist in some protected areas and wildlife reserve areas (IUCN 2016; Mosissa Geleta and Abebe Getahun1 (2020).).

African elephants are non-territorial (Moss and Poole, 1983; Hall Martin, 1987). They live in a social system in which males and females live in separate, but overlapping spheres (Moss, 1981; Moss and Poole, 1983). Related females and their young offspring live in tightly bound matriarchal family units while males live a more solitary independent existence with few social bonds (Moss and Poole, 1983; Martin, 1993). They usually occur in large herds when resources are plentiful and evenly distributed especially during and following rainy season in addition to aggregation related to factors like access to mate and renewal of social bonds (Moss, 1988; Poole, 1989). Fragmentation of families take place during the dry season to maintain efficient foraging when resources become scarce (Barnes, 1983). Aggregation in response to poaching and threat of human hostility can be distinguished from social aggregations by the tight bunching pattern of the elephants. Since small families are better able to exploit the patchily available resources (such as fruit) in forests than are larger groups, group size usually tends to be smaller in tropical forests and thick bushland than in more open savanna grassland (Moss, 1988). Elephants are capable of greatly affecting the structure of vegetation, animal communities and have ecological roll as agents of seed dispersal, thus, increasing habitat mosaic in forests and diversifying mammalian communities (Kortland, 1984). Because of their large size, elephants have a huge impact on their environments and are considered keystone species. Their habit of uprooting trees and undergrowth can transform savannah into grasslands; when they dig for water during drought, they create waterholes that can be used by other animals (Shoshani, 1998). Elephants are important seed dispersers; ingest and defecate seeds, with either no effect or a positive effect on germination (Shoshani, 1998). The seeds are typically dispersed over great distances because most of the food elephants eat goes undigested. Their dung can provide food for other animals, such as dung beetles and monkeys (Shoshani, 1998).Elephants can have a negative impact on ecosystems in some protected areas; the overabundance of elephants has threatened several species of small birds that depend on woodlands. Freeman (2011) pointed out that elephant's heavy weight can squash the soil, exposing for runoff, and erosionr.

The status and reliability of information on elephant populations vary dramatically across African elephant range. Southern Africa continues holding the lion's share of Africa's elephants (Maisels *et al*., 2013). African elephants are assumed to have been widely distributed south of the Sahara prior to colonial times (IUCN 2016). Today, African elephants are believed to occur in 35-38 range States. The distribution of elephants varies considerably across the four regions, with small fragmented populations in West Africa and large tracts of range remaining in Southern Africa (IUCN 2016; 2021). The serious threat posed to African elephants from poaching and the illegal ivory trade, range and habitat loss remain a significant long-term threat to the species' survival (Maisels *et al*., 2013).

2.2. Distribution of African elephants

Currently, the distribution of African elephants is restricted to sub-Sahara Africa where they inhabit various habitats such as tropical and montane forests, grasslands and semi-arid bush and desert lands.(IUCN 2016) African elephants are thought to have been widespread in the south of the Sahara prior to the colonial period (Fig. 1). Mosissa Geleta and Abebe Getahun1 (2020). and Blanc *et al.,* (2003) stated that African forest elephants, known to be unique to the Central Africa, have drastically reduced their range and numbers due to the growth of poaching for ivory and human population, and that the majority of the remaining elephants live in some protected lands or in dense forests in the Central Africa.

Figure 1. Range map of the African elephant in 1979 (Source, Thouless *et al.*, 2016).

Nellemann *et al.,* (2013) reported that elephants have become extinct in North Africa since the Middle Ages and are now restricted ' in sub-Saharan Africa. The presence of elephants in countries such as Senegal, Somalia and Sudan is uncertain (Lindsaya *et al*. 2017). The distribution of elephants varies between the four regions in Africa, with large parts of the range found in South Africa, followed by East Africa and with small fragmented populations in West Africa. Maisels *et al.* (2013) indicated that poaching and the illegal ivory trade and habitat loss are the serious threats to African elephants, which remain a significant long-term threat to species' survival.

Nellemann *et al.* (2013) indicated that African elephants have become extinct in at least five countries since 1913, including Gambia (1913), Swaziland (1920) Burundi (1970s), Mauritania (1980s) and Sierra Leone (2009), while their current status in Senegal, Somalia and the Sudan being uncertain (Lindsaya *et al*. 2017). Elephant distribution is becoming increasingly fragmented across the continent though large tracts of continuous elephant range remain in parts of central, eastern and southern Africa, (Fig. 2).

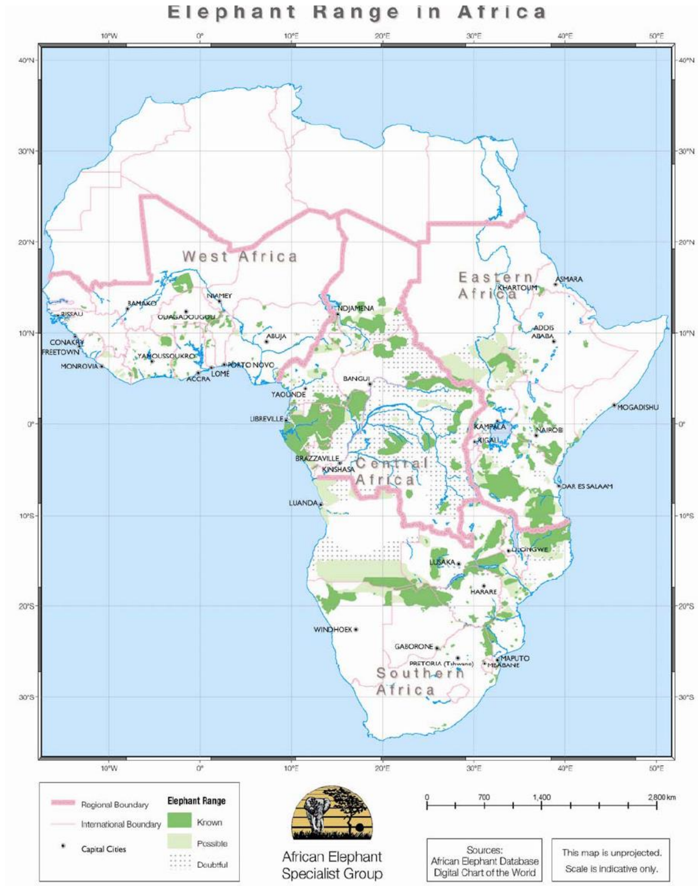


Figure 2. Map of African elephant range as of 2007 (Source, Thouless *et al*., 2016).

2.3. Population status of African elephants

2.3.1. Population estimates

The status and consistency of information on elephatn population varies across the range of African elephants. Figure 3 below shows the African elephant population number in the African Regions. Chwalibog *et al.* (2018) indicated that the quality and reliability of data have improved in Central African countries, while it has declined in Southern Africa and parts of East African countries. The largest share of African elephant, about 55%, is in

Southern Africa, 28% in East Africa and 16% in Central Africa. About 2% of the continent's Africa elephant's are supposed to be spread across the remaining 13 elephant range states in Western Africa (Maisels, *et al*., 2013; Chwalibog *et al*., 2018).

As shown in Table 1, there may have been a maximum of 26,913,000 African elephants from the Sahel in the north to the Highveld in South Africa, in the early 19th century (Milner-Gulland and Beddington, 1993). Later, in the late 1920s, up to 10 million wild elephants roamed across large parts of African continent (Jones, 1984; Grubb *et al*., 2000; Blanc *et al.,* 2007). However, poaching for ivory and conflict have since greatly reduced the elephant's population. Although Blanc *et al.,* (2007) estimated the number of African elephant population at 470,000 to 690,000, this number dropped by 144,000 in 2014 and has been declining by 8% annually since then (Chase *et al.*, 2016) (Fig. 4). Thouless *et al.*, (2016) reports that there are about 415,000 individual African elephants across 275 surveyed areas in Africa, with some more 117,000-135,000 individuals possibly found outside the surveyed areas.

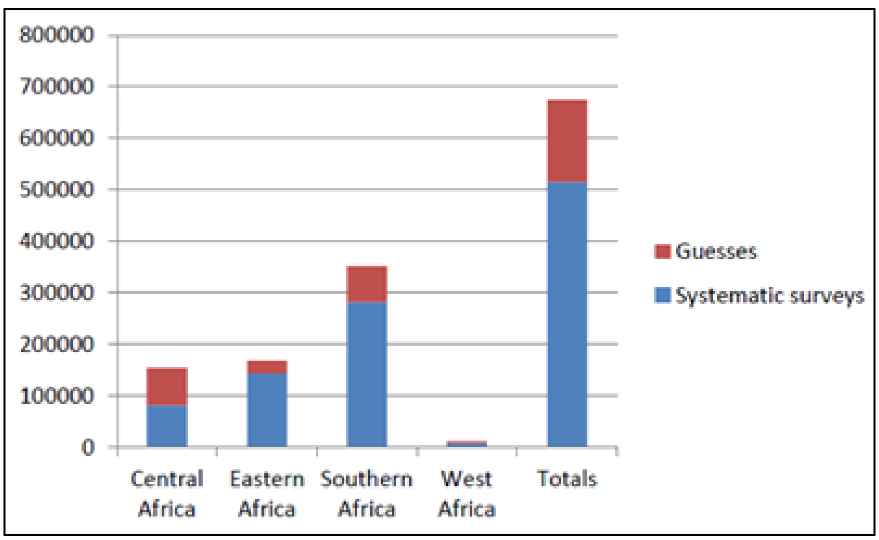


Figure 3. **Elephant population in African regions** (Adopted from Nelleman *et al*., 2013).

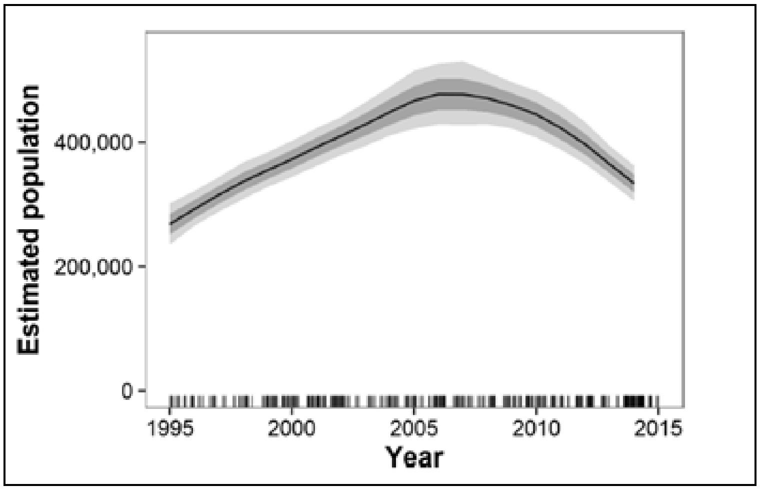


Figure 4. Africa's elephant population trend (Adopted from Chase *et al*., 2016).

African elephant populations are suffering from a general decline at the continenet level due to the increase in poaching for ivory and habitat loss since 2006 (Chase, *et al.,* 2016; *Thouless et al.*, 2016). In 2016, there were about 415,000 elephants in all of Africa (Table 1). The result of the 2016 Great Elephant Census (GEC), the largest comprehensive survey of African elephants to date, spanning 18 countries and 295,000 miles, was frustrating, about 352,271 savanna elephants were found in their current range, showing a 30% decline in 7 years (Chase, *et al.,* 2016).

Table 1. Historical African elephant population estimates

Year	Estimated number	Range	References
Early 19th century	26,913,000	North Sahara and Sub-Sahara Africa	(Milner-Gulland, and Beddington, 1993).
Before 1930	10 million	in Sub-Sahara	Grubb and Groves, 2000; Blanc *et al.*, 2007; CITES, 2010)
1930-1940	3-5milion	in Sub-Sahara	
1976	1.34 million	Sub-Sahara in 8,985,000 km^2	(Sitati *et al.*, 2005)
1987	760000	7,300,000 km^2	(Milner-Gullandand Beddington, 1993).
1989	609, 000	-	(Sitati, 2005)
2007	470,000	3.3 million km^2	(Parker and Martin 1982)
2014	546000	-	(WWF 2018)
2016	415,000 +117,000-135,000	systematic census in 93% elephant ranges	(Chase *et al.,* 2016; Thouless *et al.*, 2016)

African elephant populations had their worst decline in the last 25 years, typically due to the increase in poaching for ivory and habitat loss (IUCN, 2021). The GEC report showed that since 2006, elephant populations in East Africa have almost halved within a decade and, in South Africa and Namibia have increased slightly, while in Botswana have decreased by 15% and in Zimbabwe by 11%. (Chase, *et al.,* 2016; Chwalibog *et al.,* 2018)). MIKE reported that the proportion of illegally killed elephants in South Africa's Kruger National Park increased by 23% , between the year 2014 and 2015 (Chase, *et al.*, 2016). However, recent aerial survey in the Southern Africa region (2022) covers five elephant range states including Angola, Botswana, Namibia, Zambia and Zimbabwe (in an area known as the Kavango-Zambezi Transfrontier Conservation Area, the world's largest conservation area, which covers 520,000 km^2 showed that Botswana continues to lead Africa and harbours the largest elephant population of the World, which harbours almost 132, 000 elephants. The South Africa elephant population is reported to have increased by 5% and remains a stronghold for about 228,000, in the last decades, representing more than 55% of the estimated remaining African elephants in the whole Africa (WWF, 2018; 2022; Dube, 2023).

Although the elephant population shows a slight increase in South African Region , it is also reported that a high mortality rate (10.47%) is recorded in the region, possibly due to a combination of factors including an aging population, disease, habitat loss, fragmentation and poaching and possibly also water pollution. In 2019, Botswana recorded more than 300 deaths of elephants due to bacteria-contaminated drinking water (Dube, 2023).

2.4. Cross-border elephant populations across Africa

The home range of elephants covers a large area. This makes the animal highly mobile and widespread and plays crucial ecological and economical roles in the savanna and forest ecosystems, exemplifying the need for approaches to conservation that cross geopolitical boundaries as a shared resource between countries. Lindsaya *et al*. (2017) has identified 45 examples of Africa elephant populations across Africa that spans the national boundaries of 34 range States. The estimated number of probable trans-boundary elephants (360,499) is more than three times the number of elephants in insular national populations. At least 76% of the continental total is found in trans-boundary populations and some even cross regional lines (Appendix C Table 4).

It is difficult to accurately delineate national or even regional populations of elephants to meet the definition of CITES biological criteria (Lindsaya *et al*., 2017). Often, most African protected areas are clustered along national borders and overlap with other protected areas in their neighbouring countries. As a result, elephant populations and other species with lareger home ranges are commonly found and move in these trans-frontier areas. In accordance with the Convention of Migratory Species (CMS), West African countries have signed a memorandum of understanding for international cooperation in elephant conservation (CMS, 2016). A similar process was followed in Central Africa resulting in a conservation strategy signed by all range states in 2005 (AfESG, 2005). Currently, Southern African, West Africa and Central Africa countries have devevelop common policies and strategies to help protect and conserve their shared resources along their border (IUCN, 2021). In Trans-frontier Conservation Areas (TFCAs) governance and management, the Southern African Development Community (SADC) has a clear policy of encouraging international/regional cooperation (Lindsaya *et al*., 2017). Currently, The SADC region countries (South Africa, Botswana, Namibia, Zimbabwe, Zambia and Angola) have become successful in the management of their shared resources under the co-managmnet arrangement of establishing TFCA. Currently, there are nore than 18 TEFCA in the SADIC region of the continient.

Although it is at infant stage, there is also a growing interest in the Eastern Africa region through Inter-Governmental Agency for Development (IGAD) to consider shared resources governance, conservation and management through the establishment of TFCA between countires. There is also East African region tourism master plan which has been serving as a regional framework for tourism development in the wider region and has element of issues related with the conservation and management of shared resources between countries (UN-ECA, 2015). Ethiopia has a huge potential for the establishment of TFCAs with the six neighbouring countries namely Eritria, DJibuti, Sudan, South Sudan, Kenya and Somalia.

There are seasonal elephant movements in between most of the countries including Gash Setit conservation area (Eritria) and Kafta Shiraro National Park (Ethiopia), Boma landscape conservation area (South Sudan) and Gambella National Park (Ethiopia), Pdangilo Natinal Park (South Sudan), Omo National Park, Northern Range land Trust conservation areas (Kenya) and Gerale National Park (Ethiopia). There are also connections and shared wildlife resources between Sudan and northwest Ethiopia namely Alatish Natinal Park (Amhara Regional State) and Maokomo Proposed Nationa Park (Benishangul Gumuz Region) with Dinder Biosphere Reserve (Sudan) (Appendix C Table 4).

2.5. African elephant distribution and population status in Ethiopia

Historically, elephants had widespread range in Ethiopia including the central and southern Rift Valley areas and in the northern country including Bahir Dar and the Axum area. However, these populations were extirpated by 1940s, with the last records from Awash around 1942 (Yirmed Demeke, 2003; 2010). Wildlife studies in the early 1960s and 1970s reveal elephant ranges extend further east, south and southwest as well as northwest parts of the country including in Kafta Shiraro, Gambella, Omo, Mago, Chebra-Churchura National Parks and Babile Elephant Sanctuary as well as areas outside protected areas like Mizan Teferi and Gura Ferda in the southwest part of the country (EWCA, 2015). In addition, elephant signs have been repeatedly reported by conservation experts and communities in the Alatish, Bejimez and Geralle National Parks as well as in Dabus valley (in Benshangul Gumuz Region) (EWCA, 2015). Figure 5 below depicts the current distribution of African elephants in Ethiopia.

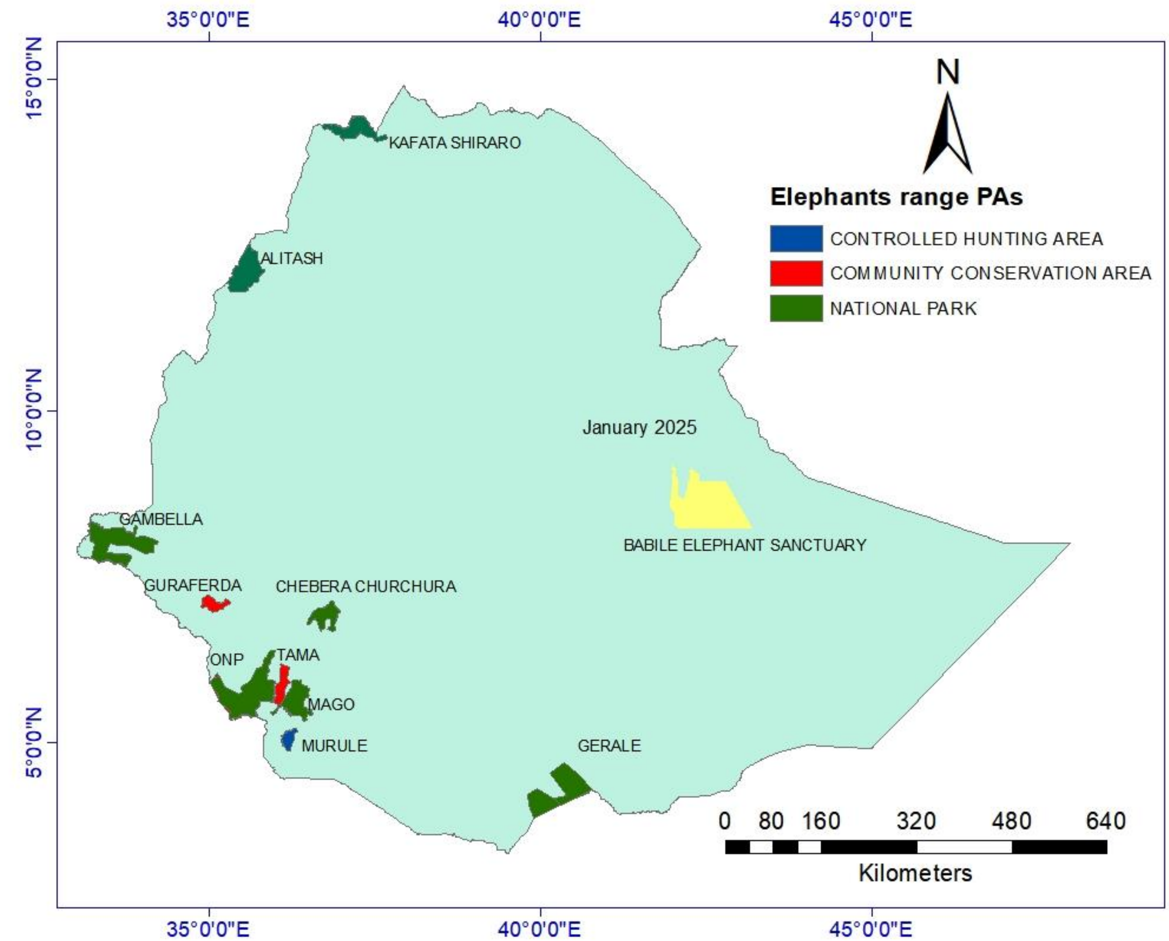


Figure 5. Elephant range protected areas in Ethiopia (Adopted from EWCA, 2015 report)

Elephant population in Ethiopia has declined mainly due to the growing human pressures in and around its natural habitats and movement corridors including hunting for ivory, natural habitat destruction through settlements, deforestation, agricultural expansion and livestock grazing. The total Ethiopian elephant population is estimated between ~1900-2151 (Table 2).

Table 2. Summary of the number of individual elephants in Ethiopia

Population of PA's	Estimated Population Size	Reference
Potential Omo-Mago-Chebera Churchura -Gambella Complex		
Omo	~410	Aerial Survey (EWB 2014)
	306	Current study
Mago	~182	Aerial Survey (EWB 2014)
Mizan Teferi Area	~20	M. Ademasu *pers. comm*. 2015
Chebera Churchura	~420	Ground count (CCNP 2012-2014)
	760	Direct transect count 2019/20 (Adane Tsegaye (2022)
Gambella	~ 340	Aerial Survey (Grossman *et al*., 2013)
Other Populations		
Babille	~349	Ground count (EWCA 2015)
	230	EWCA 2024
Kafta- Sheraro	~350	Ground estimate (EWCA 2015)
Alatish /Bejimez	<20	A. Mariye, *pers. comm.*2014
Dabus Valley	~20	C Enawgaw, *pers. comm.* 2015
Geralle	~50	Melkamu Aychew, *pers. comm.* 2015
Total	~1900-2151	

Sources : EWCA 2015 and stucy result by Adane Tesgaye 2022)

2.6. Ecosystem roles of African elephants

Across Africa, elephants have inspired respect from the people that share the landscape with them, giving them a strong cultural significance. As icons of the continent, elephants are tourism magnets, attracting funding that help protect wilderness areas. They are also both umbrella and keystone species, playing an important role in maintaining the biodiversity of the ecosystems in which they live (Cardoso *et al.*, 2020). Thus, some of the uses and ecosystem roles of elephants are explained as follows:

2.6.1. Digging watering holes

African elephants are among the important keystone species and play a number of vital roles in balancing natural ecosystems, which cannot be replicated by any other species. Elephants in dry regions are able to smell water close to the surface of the ground and use their feet, trunks and tusks to dig small waterholes on riverbeds when rainfall is low(Elephant Sanctury, 2022). By doing so, elephants make new watering holes that not only they use, but other animals benefit from too (Elephant Sanctury, 2022). As such, elephants in Africa actively help other animals from becoming dangerously parched by having difficulty locating sufficient water sources (Shoshani, 1998).

2.6.2. Modifying the natural habitats

The large bodies of elephants help to modify their environments and create trails through wooded areas that might otherwise be impassable. They trample and clear forests and dense grasslands, making room for smaller species to co-exist (Shoshani, 1998; Cardoso *et al.*, 2020). These clearings allow light to reach the forest floor, giving lower-lying plants a better chance to grow. Because different types of animals rely on different types of plants, this can promote species biodiversity, providing new niches for organisms to inhabit (Kortland, 1984). Elephants also modify savannah habitats by pulling down trees and breaking up thorny bushes. This assists in keeping the savannah an open plain, interspersed with trees and bushes supporting the type of species that like to live in the savannah biome (Kortland, 1984).

2.6.3. Seed dispersal

Elephant dung also has many natural applications, from spreading plant seeds to offering nutrition to baboons and insects (Shoshani, 1998). Herds travel over vast rangelands, and they disperse seeds in their dung, which helps generate new green growth (Shoshani, 1998). The scarab beetle actually uses large balls of elephant waste to lay their eggs inside. After munching on vegetation that also consists of seeds, elephants transport plant material in their guts, and then drop them off in mounds of dung (Cardoso *et al.*, 2020). In this way, plant material can be dropped off thousands of meters away from where the plants were initially consumed. In fact, some studies have suggested that elephants can disperse seeds over distances of more than 50 km (Shoshani, 1998).

2.6.4. Elephant dung as fertilizer

The dung of elephant is the perfect fertilizer since it is rich in nutrients that allow seeds to germinate and grow (Freeman, 2011). Elephant seed dispersal provides opportunities for plants to colonize new areas, which eventually creates new habitats and food for a range of different animals. Elephant dung is an important and plentiful source of food for a host of different types of dung beetles (Freeman, 2011). After animals drop off dungs, dung beetles can be seen streaming towards it, hoping to grab their share of the nutritious solid and fluid it contains (Freeman, 2011). Besides feeding on dung, dung beetles also burry the dung below the ground where their larvae can feed and grow. By doing this, dung beetles loosen tightly-packed soil and get the nutritious elephant fertilizer to where it is needed most, the layers of the soil where plants begin to grow. So, elephants are important in keeping ecosystems fertile and maintaining plant populations (Freeman, 2011). The submerged beetle larvae that fed on the dung are a source of food for a number of different animals like field mice and honey badgers(Shoshani, 1998). Elephants also bring down branches that may have been too high up for smaller animals to reach. This gives these animals access to more food. So, these food-providers support the survival of other life forms and contribute to species biodiversity within ecosystems (Shoshani, 1998).

2.6.5. Threats and conservation measures

The two main historical factors behind the decline of African elephants are demand for ivory and changes in land-use(IUCN 2016, 2021). Despite a ban on the international trade in ivory, African elephants are still being poached in large numbers. Tens of thousands of elephants are being killed every year for their ivory tusks. The ivory is often curved into ornaments and jewelry. Asia (mainly China and Japan) is the biggest consumer market for such products (WWF, 2019). Besides, decrease of suitable habitat and loss of connectivity due to agricultural expansion, deforestation, livestock grazing, human settlement and climate change are the major cause for the decline of elephant populations in the continent (IUCN, 2016,; 2021). Connectivity is critical for the conservation and management of species for successful reproduction (Cleary *et al.*, 2017; Keeley *et al.*, 2017; Liu *et al.*, 2018). In some countries, insufficient anti-poaching capacity, weak law enforcement and corruption undermine efforts to stop the poaching and trafficking (IUCN 16; 2021). The current prevailing threats and conservation measures being taken are elaborated below:-

2.6.6. Human-Elephant Conflict (HEC)

Most project and sub-project activities in developing countries often involve conversion of natural wildlife habitats into agricultural lands, human settlement and other land uses (Su *et al.*, 2021). Human-Elephant conflict is a growing problem in most elephant range protected areas. When elephant activities intersect with those of humans, they can pose a serious problem (Treves *et al.*, 2006). For instance, when elephants compete with humans for space and resources, significant conflict can arise. When HEC occurs, not only a risk of property loss, but human safety may also be jeopardized (Houdhury, 2004). Worldwide, numerous cases have been described of people being killed by elephants, with HEC the principal suspect (Treves *et al.*, 2006). HEC issue is expected to increase with the growth of the human population in Africa (Chwalibog *et al*., 2018). HEC might also have an adverse effect on elephants. When elephants migrate to areas settled by humans, they may become vulnerable to predation or poaching (Hoare, 1999). Consequently, elephants generally prefer places with fewer human activities (Graham *et al*., 2009). Nevertheless, they require large amount of space – preferably 50 hectares per elephant as they tend to graze and browse large quantities of grass ,and require sufficient water and food (Chwalibog *et al.*, 2018).The primary cause of HEC is generally competition between domestic livestock and elephants for space for water and grazing areas (Graham *et al*., 2009). When they graze during the day, they tend to be guided by headers. However, during the night, elephants use the darkness to search for food and may be shot at by farmers where they affect crops (Sitati *et al*., 1998).

2.6.7. Increase in poaching and ivory trade

Poaching can be defined as the illegal killing of animals (Dunkin *et al*., 2013). According to CITES (2010), poaching is a major and growing threat to elephant populations. Indeed, the increase in the illegal trade of wildlife products has driven biodiversity loss among elephants (IUCN 2016;2021). Numerous factors drive wildlife poaching, particularly of elephants, including poverty and ivory and crop raiding (Nelleman *et al.*, 2013). Elephant populations face high risk of extinction due to the ivory trade (Hoare and Du Toit, 1999). The majority of illegally killed elephants are found without their tusks and taken by the poachers (Nelleman *et al*., 2013). Between 1976 and 1980, about 830 ton (820 long; 910 short) raw ivory was exported from Africa to Hong Kong and Japan, equivalent to tusks of about 222,000 African elephants (Parker and Martin, 1982). Despite a ban on the international trade in ivory, African elephants are still being poached in large numbers. Tens of thousands of elephants are being killed every year for their ivory tusks (Nelleman *et al.*, 2013).

China is the biggest consumer market for such products (Nelleman *et al*., 2013). The ban on international trade was introduced in 1989 by CITES after years of unprecedented poaching. In the 1980s, an estimated 100,000 elephants were killed per year and up to 80% of herds were lost in some regions (Thouless *et al.*, 2016). The ban allowed some populations to recover, especially where elephants were adequately protected. But there continued an upsurge in poaching and illegal ivory trafficking, driven by increasing demand in Asia, which led to steep declines in forest elephant numbers and some savannah elephant populations(IUCN 2016; 2021). Insufficient anti-poaching capacity, weak law enforcement and corruption undermine efforts to stop the poaching and trafficking in some countries (IUCN 2016).

Globally, poaching and trafficking in ivory is at the highest level in 25 years due to a huge increase in demand from the Far East with an increase in the price of ivory from $5/kg in 1989 to $2100/kg in 2013 (EWCA, 2015). Thehe largest ivory seizure ever reorded in 2013, nearly 170 tons, for which 229,729 elephants may have been killed (EWCA, 2015) Following consecutive international pressures, China imposed a domestic ban on the ivory trade in 2017. As a result report had shown that the price of raw ivory is decreasing (WWF 2019). It was good news for Africa's elephants, which have been poached by the thousands for their tusks. Many of those tusks are then smuggled to China, which has been one of the world's largest markets for the banned material. According to the Iain (2017) in the save the elephant's researchers report and WWF, (2019),it was found that the wholesale price in early 2014 was $2100 per kg; by 2017, it had dropped to $730 per kg. As per the later report by the Wildlife Justice Commission"Rapid Assessment of the Illegal Ivory Trade in 2020' , the price for raw ivory on the black market in Asia was droped in between $597 and $689 per kilogram.

2.6.8. Habitat loss and fragmentation

The African elephant is currently in danger of extinction throughout a significant portion of its range. The range of the African elephant has decreased from 8.98 million km^2 in 1976 to only 3.3 million km^2 in 2007, a 54.8% decrease over 31years, and this unsustainable trend continues today (Blanc *et al*., 2007).

As human population continues to expand throughout the range of the African elephants, habitat loss and degradation are expected to continue to be a major threat to the survival of elephants(WWF 2019). Expansive habitat is a prerequisite for healthy elephant populations, given their nature as a migratory animal and the heavy impacts they will cause on a landscape if a population is concentrated in one place for too long. Numerous factors contribute to elephant habitat loss according to Blanc *et al*., (2007) which include habitat encroachment, increased human population densities, urban expansion, agricultural development, deforestation and infrastructure development.

2.6.9. Climate change

Apart from natural processes such as the circulation of oceanic currents, increasing human activities such as fossil fuel combustion, deforestation and industrial activities cause climate change (Patz *et al.*, 2000; Shine, 2000). High temperature affects animals in different ways, but such changes are particularly severe for those that cannot dissipate heat easily, such as elephants (Chwalibog *et al*., 2018). Many species of mammals use sweat glands or pant to cool down when air temperatures are high. However, elephants do not have a sweat duct (Wright, 1984), rendering heat dissipation a major issue (Williams, 1990). When temperatures are high, they must use non-evaporative techniques (Dunkin *et al*., 2013) such as flapping their ears in order to maximize heat transfer (Williams, 1990). They may also use behavioural strategies such as hiding in shaded areas under trees (Dunkin *et al*., 2013).

Elephants require a large amount of water, about 150-300 L of water per day. During drought events, elephants may die due to limited amount of water availability. Climate change may also enhance conflict between humans and elephants as they must compete for increasingly limited land, water and other natural resources (Nelleman *et al.*, 2013).

Moreover, climate change may stimulate humans to alter their living patterns and livelihoods. Drought and flooding coupled with the increasing human population cause people to move and establish permanent and temporary settlements in elephant habitats where they can easily find food, fodder and water both for themselves and for their livestock (Wright, 1984; Dunkin *et al*., 2013),

2.6.10. International conservation measures

Currently, international elephant conservation measures focus on controlling ivory stockpiles, establishing and strengthening the borders of protected reserves, anti-poaching patrols, and preventative methodologies to reduce human-elephant conflicts. Establishment of new protected areas (community conservancies, National Parks) and increasing the size of conservation areas; establishment of elephant corridors to allow the safe passage of elephants from one area of habitat to another as well as habitat enrichment of elephant areas to enhance carrying capacity are some of the conservation measures among others taken by most African countries (Dunkin *et al*., 2013)

As elephants are highly mobile and move across neighbouring countries as a shared resource, there is an increasing attempt in establishing trans-boundary cooperation that can bring substantial conservation and economic benefit between elephant range countries of western, southern and eastern regions of Africa (Lindsaya *et al.*, 2017) Accordingly, a number of Trans-boundary Protected Areas (TBAs) are being established with the collaboration of neighbouring countries of African regions which would be managed with shared authority and responsibilities (Global Trans-boundary Protected Areas Network, 2017).

Although not yet successful, in 2017, the Council of Elders of the African Elephant Coalition (AEC) comprising 32 African countries and the majority of African elephant range states is calling all countries to follow China's example in closing their domestic ivory markets and also requested up-listing all African elephants to Appendix I, the strongest possible protection under CITES. Currently, elephants in Africa are split-listed with elephants of eastern and western countries listed in Appendix I whereas southern African countries like Botswana, Namibia, South Africa and Zimbabwe in Appendix II, which allow trade under certain circumstances (Lindsay *et al*., 2017). The AEC has long held the view that if elephants are to be fully protected, it is imperative that they all be up listed to Appendix I (African Elephants Coalition (AEC), 2017; Lindsaya *et al*., 2017). The split-listing has led to confusion in consumer demand and resulted in a continued trade in ivory.

With regard to actual protection and management of African elephants and its range governments and international organization like World Wildlife Fund (WWF), World Conservation Society (WCS), African Parks Network (APN), Born Free, Frankfurt Zoological Society (FZS) and a number of other international conservation partners have taken numerous measures to assist elephants in coping with a changing situation and threats.

These international organizations are working in collaboration with governments of African countries providing strategic support and guidance to help guarantee a future for this magnificent species across Africa. Most of the programme aims to conserve viable populations of forest and savannah elephants in at least 34 range states (WWF, 2018). The programmes support different projects related with elephant conservation including: improving elephant protection and management by providing equipment and training to anti-poaching teams; promoting the creation of new protected areas and improving the management of existing protected areas; developing community-based wildlife management schemes that contribute to elephant conservation while providing benefits to local people; and determining population sizes (Adams *et al*., 2004); reduce illegal trade by monitoring trends in the illegal trade in elephant products; conducting surveys to update data on domestic ivory markets; and working with the Wildlife Crime Initiative Programme dedicated to tackling the most impactful, large-scale and organized forms of wildlife crime (Lindsaya *et al*., 2017). Involvement in capacity building activities within the elephant range states by helping range state governments to produce sub-regional and national elephant conservation strategies; developing capacity to survey, census and monitor elephant populations; providing training; and advocating for range states to update and implement legislation to protect elephants are important components (Adams *et al*., 2004). Mitigating human-elephant conflict by training wildlife managers and local communities to use effective tools and refining current methods based on what works best in specific situation should be recommended. Elephant Deterrence including the use of flashes, noise, and other shock tactics to deter elephants (Hoare and Du Toit, 1999) have been tested and used in some protected areas.

2.6.11. Threat of elephant populations in Ethiopia

Overhunting for the ivory trade in the 19th and early 20th century has decimated elephants, reflected by a peak of 66 tons of ivory passing through Djibouti in 1910 (Yirmed Demeke, 2009). The effect of hunting on Ethiopia's elephants has been compounded by decades of habitat losses by human populations, through the expansion of agriculture and livestock. Each of Ethiopia's elephant population has gradually been reduced in size and range (Yirmed Demeke, 2003; 2009).

Loss of ancestral routes and connectivity between elephant ranges has become another major threat in the country. Loss of connectivity of elephant population has already happened between Omo-Tama–Mago wildlife area complex as well as connection with the Chebera Churchura National Park (EWCA, 2015). Even within current ranges, habitat fragmentation is occurring and corridors through which elephants can move are being closed by large scale farming and settlement. The country's pressing need and drive to provide food security and alternative livelihoods for its people, large-scale agriculture and stimulating economic development have to be reconciled with the conservation of Ethiopia's unique natural heritage and the ecosystem services on which the vast majority of the wildlife population still depends. Time is running out to reverse this trend and to maintain the remaining levels of habitat connectivity (EWCA, 2015).

Elephant poaching for ivory has again swept across the East African region. Similarly, poaching for ivory is impacting several key elephant populations in Ethiopia. Over 100 elephants are thought to have been killed in the last 5 years in the Babille Elephant Sanctuary and there is currently an upswing in poaching in the southwest, Mago National

Park particularly is vulnerable (EWCA, 2015). Just recently (within the Covid 19 lockdown period) an organized poacher killed seven elephants in one day around Karo Dus and Kercho Kebeles south of Mago National Park while moving to their watering points south of the Park (EWCA, 2019). This indicates the very weak law enforcement and intelegnece system by EWCA to protect the species from organized poaching. EWCA need to be strong and powerful interm of the conservation wildlife specifically key species like the elephants. Also work is continued by the EWCA and advocacy group and individual to promote wildlife to be one of the government priorities. Ethiopia also faces significant challenges in combating illegal ivory trafficking with ivory transiting the country by land and air. Addis Ababa Bole International Airport has been identified as one of the three major aerial trafficking hubs, along with Nairobi and Johannesburg (EWCA, 2015, 2020).

Similarly, effort is underway to protect and conserve the Ethiopian elephant population and their range with the collaboration of different conservation partners (EWCA, 2015). Most of the elephant population in Ethiopia are restricted within protected areas and listed in CITES similar to most of the eastern and western African region countries (Table 2).

Ethiopia is one of the founding member countries for the elephant protection initiatives (EPI) (EWCA, 2015). Following this international framework like most African countries, Ethiopia has developed and endorsed its own specific elephant action plan which is now under implementation in most of elephant range protected areas in the country. Accordingly, apart from government leading role and intervention, the elephants of Babile elephants Sanctuary and Kafta Shiraro National Park were supported by international organizations like GEF and MIKE; Chebera Churchura by GEF and GIZ, Omo and Mago National Parks were supported by GEF, UNDP and HOAREC (EWCA, 2015).

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location of the study area

The Omo National Park (ONP) is managed by the EWCA and located within the Lower Omo Valley in the Southwest Ethiopia Regional State (SWERS). The SWERS is known for its rich wildlife resources in the country and has two National Parks, one wildlife reserve, one community conservation area and one UNESCO biosphere reserve. The ONP was established in 1958 (Hillman, 1993), and it is known for its rich diverse flora and fauna (Cherie Enawgaw , 1996). ONP is located between 05° 30'to 06° 40'N and 35° 20' to 36°00'E (Fig. 6) and currently covers an area of 5157 km^2 (Fig. 6) . .

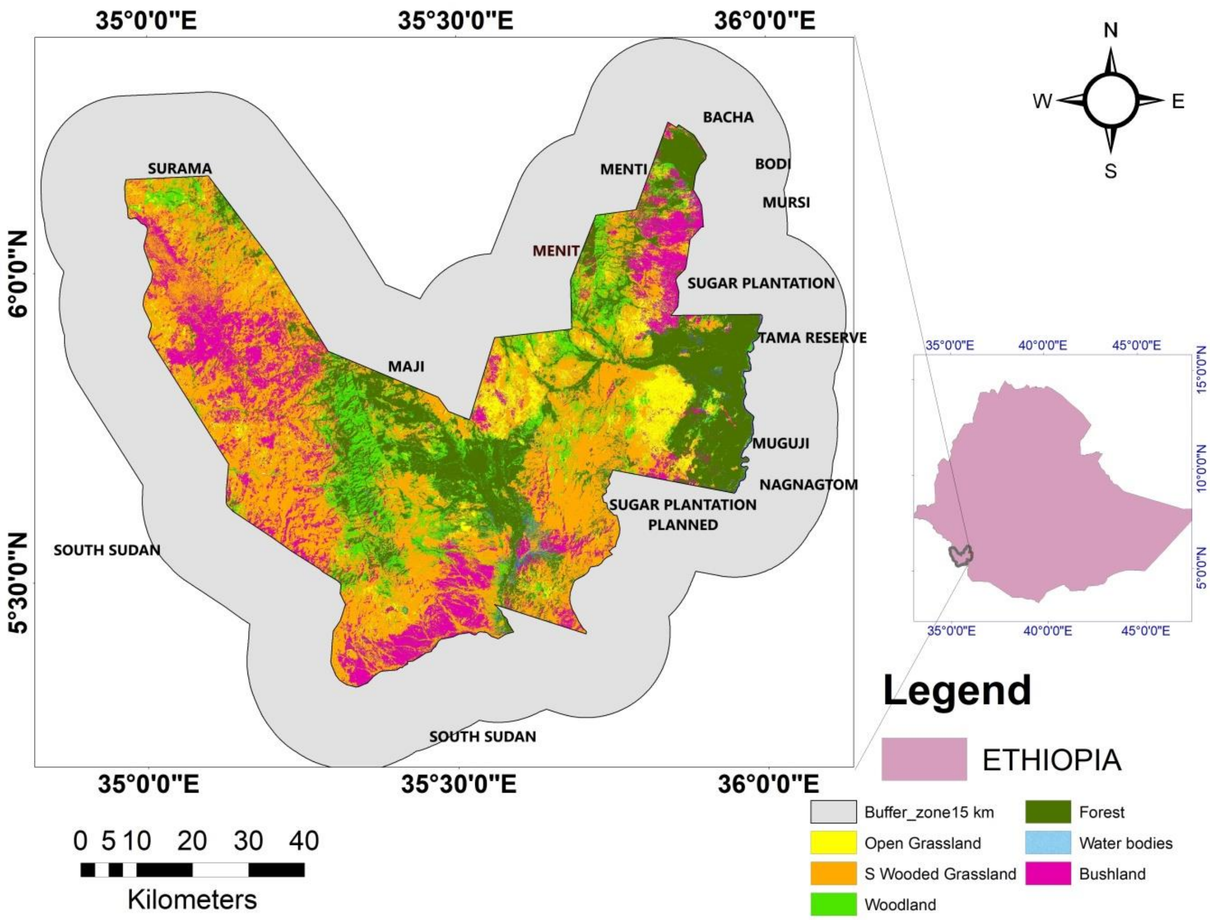


Figure 6. Location map of the study area (ONP and the surrounding buffer areas)

3.1.2. Park boundary modification

The ONP is one of the oldest and biologically richest Protected Areas managed under the auspices of the EWCA. The boundaries of the park have been redefined at least three times since its designation as a National Park. The first re-delineation was in 2001 by the then SNNPRS and excluded the northern habitat on the other sides of the Sherma River due to the local agricultural expansion and the total area of the park was reduced from 4068 to 3998 km2. The second re-demarcation was initiated due to the government's mega Sugar Development Project intervention and the need for land for Sugarvane plantation in 2009. Originally, only the southern park land (cover an area of about 64km2) behind the hot spring of Illilbay (Nagnagtom land) was to be included. This change in park boundaries was accepted and legalized by the then SNNPRS, but later the Sugar Project officials broke the law and took the northern part of the parkland including the Sai plain and Riverine forest habitats (about 42km2) as well as the land above the Kuma River for the factory and sugarcane plantation. Today the area is known as factory three where one of the sugar factories was established.

The EWCA is also a Government body that had tried to defend and reverse the situation, which did not succeed, and had engaged in long negotiations and discussions to save at least some important habitats and Wildlife corridors of the park. With the direct involvement of a Higer Level government, it was finally possible to save one of the elephant corridrros, particularly the Mui Riverine Forests. Significant areas of Suitable Elephant Habitats (about 106 km2 of land) from the northern and southern parts of the parkland were reserved for the Sugarcane planatation and the park area was reduced to 2936 km2. The situation led to the third ONP Boundary Redemaracation.

In 2018, the EWCA, in collaboration with the local authorities, including former SNNPRS, Bench Maji and South Omo Zones, Surma Woreda, Nanagatome Woreda, Mursi Woreda, carried out the third redefinition of the park boundaries (EWCA 2018). In this participatory redefinition, it was proposed to include the former Southwest Controlled Hunting Area (from the Kibish land) in the parkland. The total area of the ONP had increased from 2936 km2 to 5157 km2 . While the expanded land is not as suitable as the land used for Sugarcane plantation, for wildlife species such as elephants, in terms of the important variables such as water and vegetation, it is still very important for other wildlife species.

ONP is linked to other protected areas such as Mago National Park and Tama Wildlife Resourse (currently called Tama Community Conservation Area') in the east and Badangilo National Park in South Sudan through the few remaining natural wildlife corridors (north of the Ilemi Triangle (no man's land between Ethiopia, Kenya and South Sudan). potential to establish a Transfrontire Conservation Area (TFCA) in collaboration with Ethiopia and the Government of South Sudan.

3.1.3. Climate

The climate of the area is comparatively dry and exhibits both temporal and spatial variations in precipitation, humidity and temperature (Fig. 7). Rainfall in the area is low and erratic, with a mean annual rainfall below 482 mm (ESC, 2019). A bimodal rainfall period is observed: The long rains usually begin in March and last until the end of April, while the short rains fall in October and November. The driest season is from December to January. Limited rain may fall in any month of the year (Cherie Enawgaw, 1996). The mean seasonal temperature ranges from 23 to 36°C, although the daily maximum temperature in February can reach 40°C, while the daily minimum temperature can drop to 16°C in April (ESC, 2019).

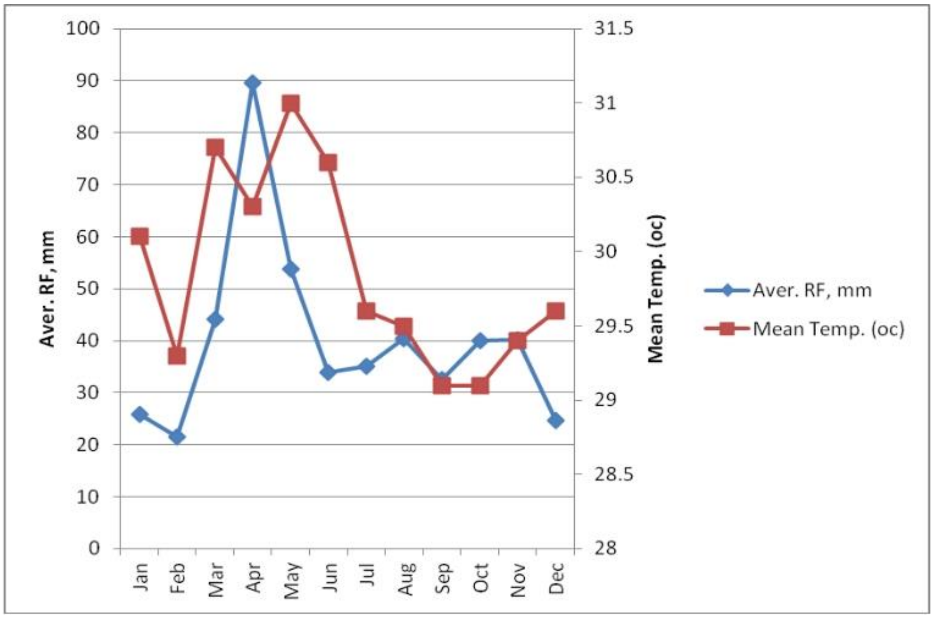


Figure 7. Average monthly rainfall and temperatures from 2013 to 2023 in the study area (Source: Ethiopia Metreology site data).

3.1.4. Topography

The study area, Omo National Park is found in the lower Omo River basin. The predominant topographic features of the Park are flat grassy plain surrounded with Maji Mountain to the west and Sai escarpment to the north. The Omo and Nerube Rivers flow to the south and east, respectively. The altitudinal range fails between 450-1541 m above sea level (Cherie Enawgaw, 1996).

3.1.5. Vegetation cover

The vegetation of the study area is characterized by extensive savannah plains interspersed with wooded grassland and connected deciduous woodland and riparian formation(Stephenson and Mizuno, 1988; Lamprey, 1994) (Fig. 8). The Park embraces extensive open grasslands interspersed with stands of woodland species, herbaceous and bush vegetation along the age. Although the grass species show local variation, the dominant grass species include the elephant grass (*Pennisetum* sp.) with herbaceous species along the margin connected with bushland habitats. The deciduous wooded and the riparian forest habitat occurs along the course of the rivers (Omo, Sherma, Mui, Kuma and Surma) (Fig. 6). These habitats are characterized by mixed vegetation type composed of large trees and herbaceous species. Dominant plant species in this habitat are *Tamarindus indica*, *Ficus sycamorus, F. salicifolia*, *Kigelia aethiopium*, *Phoenix reclinata*, *Terminalia brownii*, *Acacia polyacantha* *Costa* sp., *Albizia grandibracteata*, *Chionanthus mildbraedii*, *Grewia ferruginea*, *Aspilia mossambicensis*, *Arundo donax* and *Ehretia cymosa* (Cherie Enawgaw , 1996). A well-developed shrub layer combined with woody and herbaceous climbers provides dense cover along the edge of the rivers (Fig. 8).

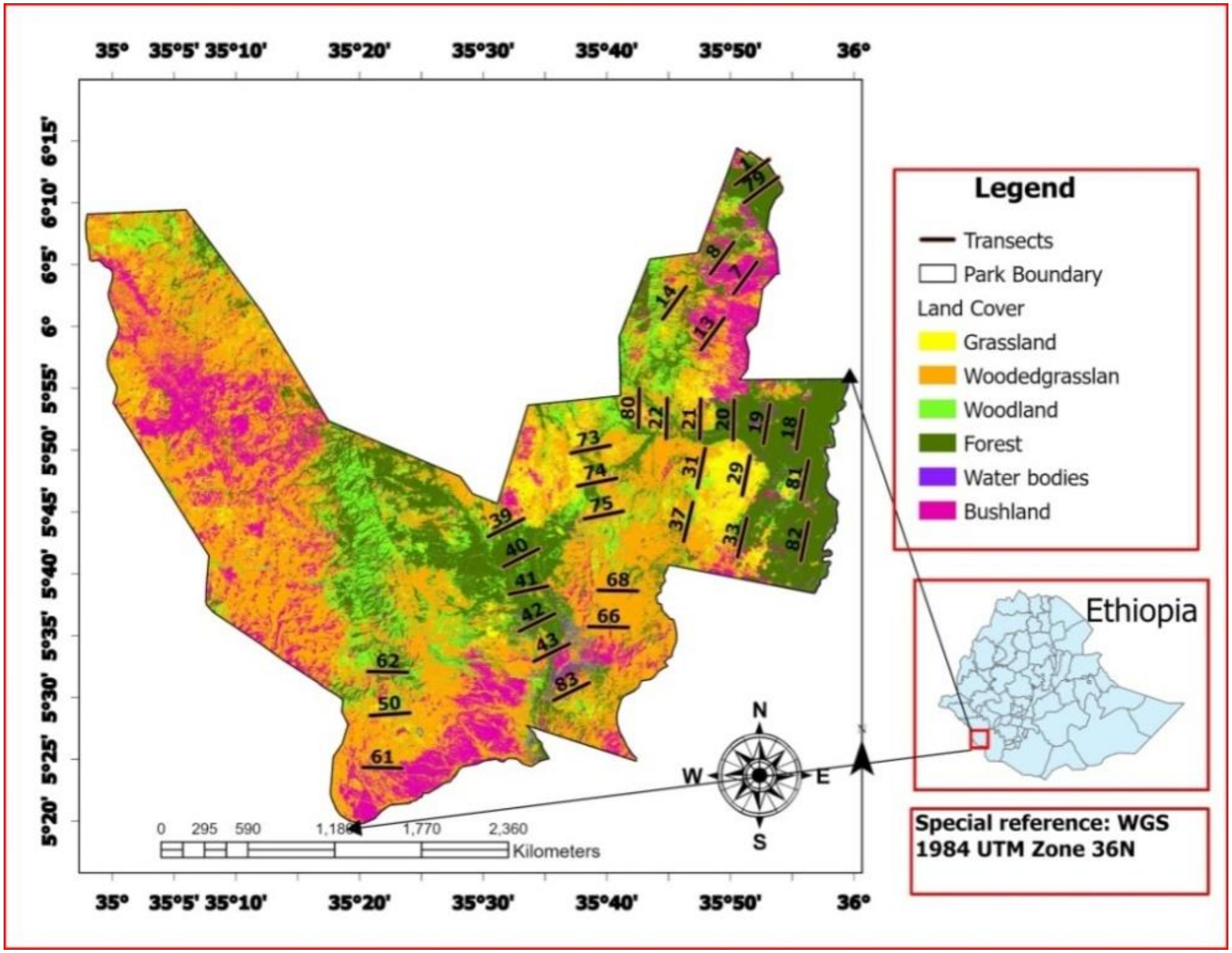


Figure 8. Vegetation Map and transects of Omo National Park

3.1.6. Fauna

Omo National Park Ethiopia is known to possess diverse wildlife resources. So far, 75 large and medium sized mammals, 325 species of bird of which (2 are endemic) have been recorded (Cherie Enawgaw, 1996; Asbl and Fortrop, 2008; Ferguson, 2021;EWCA, 2020) Appendix C Table 3 shows larger mammals known in the park. In addition, there are also numerous reptiles, amphibians and fishes in the Park. ONP has been mentioned as the most recent wilderness in Ethiopia (Stephenson and Mizuno, 1978; Hillman, 1993).

The wildlife includes much of the typical East African fauna and offers one of the wildest and most extraordinary animal panoramas in Ethiopia. ONP is considered an important habitat for animal populations such as the African buffalo, African elephant, eland, hippos, warthog, tiang, Lewel hartebeests, lesser-kudu, greater-kudu, duiker, Grant's gazelle, gerenuk, giraffe, cheetahs, wild dogs, lions, leopards, colobus monkeys, Olive baboons, De'braza's and Vervet's monkeys.

3.1.7. Hydrology

The Park is fortunate in possessing numerous water sources and for its rich wildlife resources. The Omo River flows from north to south along the eastern park boundary, the Park is traversed by various perinnelial and seasonal rivers and streams that are tributaries, most of which, apart from the Kibish River, drain into the Omo River from the western higlands. Some of these rivers include Kuma, Sherma, Mui, Gimwuha and Kibish. There are also three hot springs (namely Sai tsebel, Gelakerma and Ililbay).

3.1.8. Ecological connectivity

The human and livestock population size in and around the ONP has greatly increased over the years coupled with the Mega Kuraz sugar development projects and are major factors in causing degradation and severe competition between wildlife, livestock and human population of the area over the limited biological and physical resources of the ONP and its surroundings.

Apart from the great impacts of sugar development project through land conversion for sugarcane plantation and the long canal construction inside the Park, the presence of increasing human and livestock population has resulted in significant degradation of the habitat and depletion of the wildlife of the Park through grazing, illegal hunting and other unsustainable utilization of natural resources.

Currently, the ONP has become accessable due to the construction of roads (asphalt roads) and bridges over Omo River by gorvenrement from diferent directions Jinka-Murssi hanna –ONP (asphalt road) ; Omo Rate to ONP (Gravele road), Kanagaten to ONP (Aspahalt Road), this infrastructure devevelopment provide advantage better law enforcement operation and tourism activities. Howevere, the park still lacks transportation (vehicles) and communication (radio) facilities. This has prevented proper law enforcement and ecological monitoring of the status and movement of the Park's wildlife species. The recent re-demarcation (2018) has helped the Southwest Omo Controlled Hunting Areas to be included in the ONP boundaries. It was also possible to maintain the connectivity with Tama wildlife Reserve (currently called Community Conservancies) and with Mago Nationa Park to the southeast and to the Padnigilo Nationa Park of South Sudan to the south.

There are indications that human activities and conflicts within southeastern Sudan and southwestern Ethiopia have greatly affected the distribution and natural seasonal movements of many of these species both within and between these conservation areas of the two areas Ecological sustainability of at least a few of the key mammalian species of the Park requires clear understanding of the movement patterns of these mammalian species within and outside the ONP.

3.1.9. The people

The park is also surrounded by sedentary farmers, pastoralists and semi-pastoralists. There are about eight ethnic groups that live in and around the ONP and most of them are pastoralists and they seasonally move with their livestock in and around the ONP in search of water and grazing areas. Ethnic groups include the sedentary Dizi community who practice agriculture and are located in the western hghlands of the park, the pastoral Surma in the southwest, the Nangatom in the southeast, the Muguji in the east, the Mursi and Bodi in the northeast and the northwest Menit and the northern Bacha community.The Mursi, Nagngatom and Surma depend on cattle herding while the Dizi depend on agriculture. Also, Muguji peopel practice fishery activity also depends on the Park resources. All these people use the Park variously for grazing, hunting, honey collection, fishing and gold mining. Nagnagotm people from the south bring their cattle to Ililbai Hot Spring for water and grazing during the dry season (Cherie Enawgaw, 1996). This transhuman movment i.e seasonal movement and utilization of the limited resources of the ONP and its surroundings is also one of the few sources of conflict between the different ethnic groups (Cherie Enawugawu 1996). Establishment of proper contact, trust and good working relationships with the communities that live in and around the Park has also been partly hindered for various reasons due to lack of infrastructures and remoteness of the reserve. Besides, local community involvement in the Park management is somewhat limited.

3.2. Materials and Methods

3.2.1. Materials

The following materials were used for the ecological study in and around ONP. These include: Binoculars, photo and video camera, rangefinder and compass, GPS, meters, field guide books and data sheets, topographic map (1: 50,000 and 1: 250,000), and other necessary field gears (tent and equipment).

3.2.2. Preliminary survey

A reconaissance survey was carried out for two weeks from November 15-30 2020 to collect basic information about the location, topography, habitat types, climatic condition, and approximate size of different habitats in the study area. Information about elephant habitat use, extent of elephant suitable habitats, population status, and distribution in ONP was collected. Also information about the area was also collected from relevant governmental, nongovernmental organizations and from the local community of the region during this survey.

3.2.3. Population size/estimate

Data Sampling and Analysis

The survey zones were defined based on the main vegetation types and corresponding topographic features of the study area, including open grassland (OGL), savanna wooded grassland (SWGL), woodland (WL) and forest land (FL). During the reconaissance and sampling design, discussion with the Park staff/rangers helped to determine the extent of elephant range in the different vegetation types of the Park, which was consistent with the previous elephant studies in the Park. Within the identified elephant range, a random sampling procedure had been made to represent the different elephant habitats/vegetation types. Census zones, sampled census zone, and sampled transects and their areas were defined and established for the study (Table 3). Line transects were laid randomly based on representation of the main habitat types in the sampled census zone (Koster and Hart, 1998; Boafo and Awo, 2011). As indicated in table 3, transects were selected randomly from the sampled census zone that consisted 160 transects to collect the data on elephants of the ONP.

Trained ranger teams (scouts, experts) with the required materials and equipment were deployed along the randomly selected transects to collect the required information per day on transects. Surveys were conducted on an average of 20% of the total plots of each habitat type in **2021-2022** during the wet and dry seasons, from 06:00 to 10:00 o'clock in the morning to 16:00 to 18:00 o'clock in the late afternoon when they were supposed to be active and had good visibility.

During the study period, emphasis was given for the indirect evidences (like dung piles count of elephants) which are present in their absence, to estimate the size of the African elephant population (Yirssaw Demeke and Afework Bekele, 2000). In ONP, the elephants inhabiting the different vegetation types are rarely seen physically during the day as they seem to change their normal activity pattern and locations every now and then due to the increased human activities, yet their signs were conspicuous. Table 3 below shows vegetation types, study zones, sampled area, possible line transects and sampled transects with a width of 16 m were used (site distance 8 m from the transect) to count dung piles in the sampled transects.

Table 3. Elephant range (vegetation) and sampled transects and area in the study zones.

Vegetation Type	Study zones	Total Area km^2	Sampled area in km^2	Possible transect number	Dung count: Transect number ,width & length (km) ESW	Transect-Length (km)
Riparian vegetation and Forest	Kuma Rivers	24	4.8/1.9	10	2x16mx1km	2
	Omo and Mui Rivers	96	19.2/7.7	40	8x16mx1km	8
Open Grassland	Ililbai and Tingn-plains	120	24/3.8	20	4x16mx1km	4
	Sai plain	120	24/3.8	20	4x16mx1km	4
Herbaceous wooded-grassland	Bekele Sefer 3	72	14.4/2.9	15	3x 16mX 1km	3
	Tiliku Ber and Gim wuha areas 5	144	28.8/5.8	30	6x16mx1km	6
	Dingai Wuha	48	9.6/1.9	10	2x16mx 1km	2
	Kibish (south)	72	14.4/2.9	15	3x 16mX km	3
Total	8 Study Zones	696	37.6/30.7	160	32 transect	32

The dung count method involving line transect surveys within a distance sampling framework required a translation of dung density to elephant density (Fig. 9). To achieve this, dung density needs to be calibrated by dung decay rates as well as defecation rates of elephants (Barnes and Jensen, 1987; Barnes, *et al*., 1997; Mohanarangan, *et al*., 2022). Hedges, *et al*. (2013) reported that the results of indirect methods are comparable to those obtained using other methods. The ratio of the relationship between dung bolus diameter and age was determined to estimate the age of the African elephant (Varma, *et al.,* 2012; Mohanarangan, *et al*. 2022). Dung counts were recommended as the most practical means of estimating the number and distribution of forest elephants (Barnes, *et al.*, 1997).

Dung pile survey requires data collectors in the field to be responsible for counting dung piles along the transects and classify in the dung appropriately.This study was conducted by trained ranger teams (rangers and experts) along transects during the wet and dry seasons in 2021-2022. The dung pile data collected along the transects during the wet seasons were insignificant and could not be used for statistical analysis. During the wet season, elephants were widely dispersed in the different vegetation types due to food and water availability and dung pile data were low.

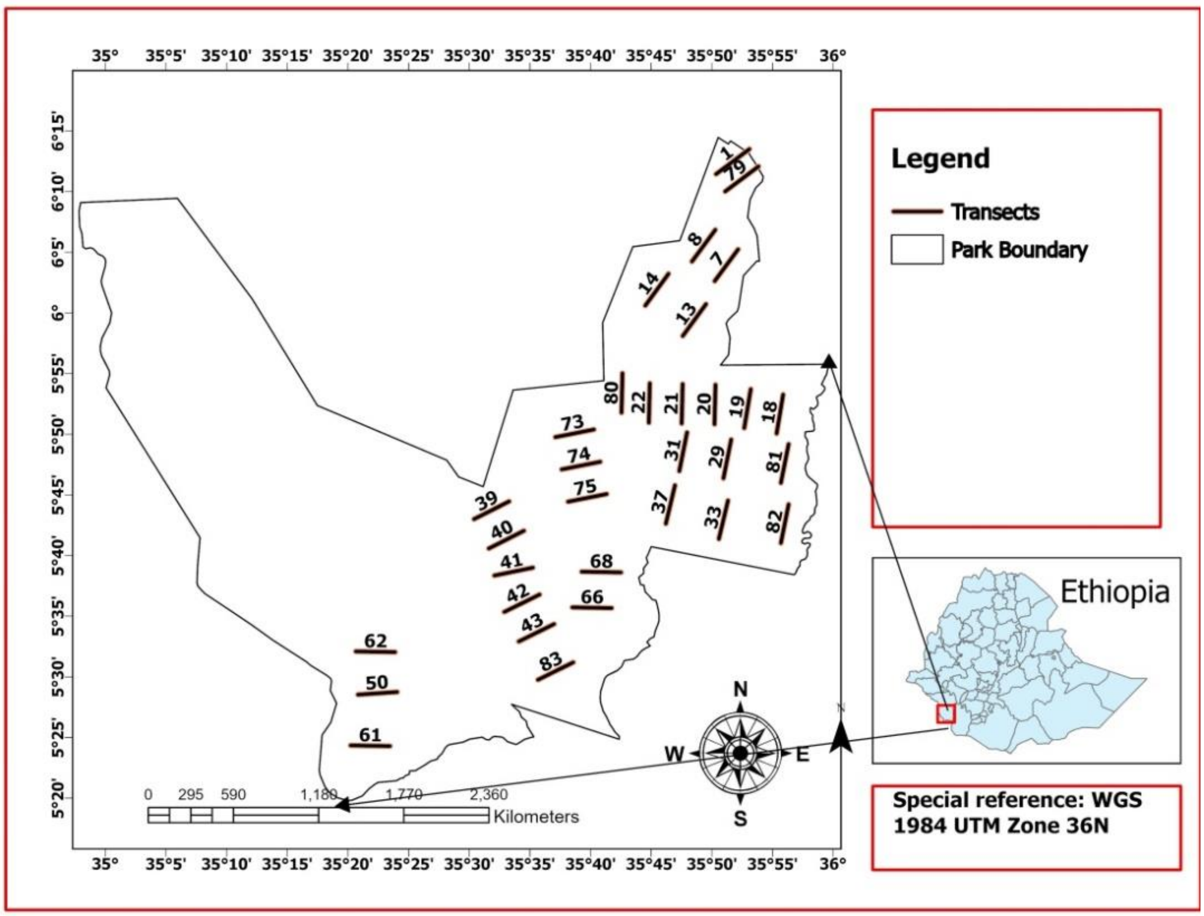


Figure 9. Transect locations in the Omo National Park

During the dry season, elephants were concentrated in forest and woodland habitats near the water points and main rivers. This helped to find significant, representative samples of dung piles that could be analyzed to estimate the elephant population in the study area. Thus, we focused for the dung count survey during the same time of year (i.e during the dry seasons) in order to minimize the problems caused by seasonal elephant movements (Hedges, 2012; Varma, *et al.*, 2012). Censuses were conducted on foot along transect lines to capture dung piles and began between 06:30 and 10:00 am. Data were collected on all 32 sampled transects in a 21 days in each of the 2021 and 2022 seasons. Each team walked quietly along the transect line. Dung piles sighted on either side of the transect were counted, and the perpendicular distance from the observation to the centerline of the transect was measured using a tape-measure Distance along transects was measured using topofil. The locations of dung piles were recorded with GPS devices, habitat types, dung piles or other elephant spoors, and feeding signs were also recorded in the line transect and census zones. The total distance covered on the transect lines was also recorded using the GPS way point measurements for each transect covered.

Decay stages of dung piles or dung categorization of boli on transect walks was classified according to the latest updated Monitoring the MIKE S System (Barnes and Jensen, 1987; Hedges and Lawson 2006; Hedges, 2012). Elephant dung piles observed in category/stage E were not used in the population data analysis, while all detections were used for distribution mapping (Vanleeuwe, 2010). Table 4 below shows the MIKE S system dung pile classification.

Table 4. The MIKE S system dung pile classification and boli stages

Stage	Description
S1	All boli are intact
S2	One or more boli are intact
S3	No boli are intact
S4	No boli intact (All boli completely disintegrated) no coherent fragments present.
ES	No faecal material including plant fibres is present.

Source: (Barnes, 1996b; Hedges and Lawson, 2006; Hedges, 2012)

Statistical program DISTANCE 6.0 (Thomas, *et al.*, 2008) was used to analyze the dung pile perpendicular distance and total length data for each transect to obtain estimates of dung pile densities. To convert dung pile density to elephant density, we used the formula from Laing *et al.* (2003):

$$D1 = \frac{D2}{(DR \times t)}$$

where

D1 is elephant density, D2 is dung density per km2, DR is defecation rate per day and t is the mean dung piles survival time (Decay rate). We used the result of the previous dung decay study conducted in the same habitats in the Omo National Park for the decay rate of elephant dung rate r=0.00271 (Chere Enawugawu, 1996). The defecation rate of an elephant, i.e.the number of dung piles defecated by an elephant per 24 hours/day, for this study, following the recommendation of Hedges *et al*.(2012). We considered the results of a previous study in Rwenzeri National Park, Uganda, for the defecation rate of an elephant D=17.0 dung piles per elephant per day (Wing and Buss, 1970). These two variables were important and required to convert dung density to elephant density (Laing *et al.* 2003; Hedges and Lawson, 2006; Hedges, *et al*., 2012; Mohanarangan *et al*. 2022), where Elephant density (D1) was calculated with a spreadsheet that uses the delta method to estimate the standard error (Seber, 2002). The density multiplied by the area (in km²) where we found elephant tracks gave the number of elephants. The program DISTANCE was also used to calculate elephant density directly by bootstrapping, using the same variables for decay and defecation rates. This results in unequal and narrow confidence intervals for the density estimates of the lower and upper quantiles (Seber, 2002).

As a limitation of dung count method, difficult to get ffresh dung; expensive in terms of time and man power; as well as difficult to difrentntiate whther the fresh dung belong to the same group and individuals as the animal are very active move the whole night. .

3.2.4. Habitat suitability and distribution of African elephants

Occurrence points

During the survey, line transects representing the different habitat types in the National Park were randomly laid (Koster and Hart, 1998). Surveys were conducted seasonally from 2021 to 2022, during the wet season (March and April) and the dry season (December and January) in both years. The distinction between wet and dry seasons was based on the change in rainfall patterns. To collect basic information on African elephant populations in riverine forests, wooded grasslands, and open grasslands, a line transect census method was used for various mammals (Ratti *et al.*.1983) and Sutherland.2006). The stratification and arrangement of transects were based on the vegetation types considered as the sampling unit or survey area, and each of these blocks was divided into different blocks or grids of different sizes depending on vegetation type, visibility and topography. Transect lines were roughly parallel and systematically spaced 1500–2000 m perpendicular to the main watercourses of the area. Since most of the tributaries (Mui, Kuma and Sherma) of the Omo River flow from west to east, the transect lines were oriented from north to south, while the transect lines along the Omo River run from east to west as it flows from north to south. This orientation was chosen to maximize data collection while taking into account landscape conditions and minimizing sampling error (Sutherland, 2006). In addition to the transect counts and observations, a ground survey was conducted to obtain additional information on water bodies, human settlements and farming, roads, the herd sizes of African elephants, and the recording of dung piles and footprints. Coordinates from indirect and direct observations of African elephants were recorded using GPS (WGS 1984). All records were independently checked for spatial auto-coloration in ArcGIS (version 10.8) using analyses of average nearest neighbours (Moran's index = 0.60, z-score = 6.96, P = 0.00 for the wet season, and Moran's index = 0.84, z-score = 12.95, P = 0.00 for the dry season). Thus, a total of 56 and 51 occurrence points (direct observation 10 and elephant dung piles and footprints count 46; direct observation 7 and elephant dunghill count 44) for the wet and dry seasons, respectively, were independently used for modelling in the study region using the MAXENT algorithm (Phillips *et al.*, 2006) (Supplementary Table 1).

Predictor variables

Ecological predictor variables for the MAXENT models were selected on the basis of their potential impact on determining the movement patterns and distribution of African elephants in the Omo National Park. The spatial and temporal distribution of a given species is strongly influenced by certain environmental conditions (Barnard and Thuiller, 2008). Pr'eau *et al*. (2020) stated that climate-related factors and landscape composition are important in determining high-priority habitats for the species. Increasing anthropogenic activities, including poaching, human settlement, and agricultural investments, are among the most important factors limiting African elephant habitat use and distribution in Omo National Park (Cherie Enawgaw, 1996; Asbl and Fortrop, 2008; EWCA, 2015). We used the most recent 19 bioclimatic data sets from Worldclim 2.1 at the 30s (1 km^2) resolution for habitat suitability modelling (Hijmans *et al.*, 2005; Fick and Hijmans, 2017). The digital elevation model (DEM) of the study region was processed using the Spatial Analyst tool of ArcGIS 10.8 to generate topographic attributes, including slope, aspect, and elevation, as predictor variables for the target species. Landsat-8 data extracted from USGS Earth Explorer was used to prepare land use and land cover using ArcGIS 10.8 software (imagery and supervised classification), which included herbaceous woodland, open grassland, forest, water bodies, and settlement and agricultural areas for inclusion in the final habitat suitability prediction. Other predictor variables, including distance to roads, rivers, and settlements or farms, were also prepared using the Euclidean distance from the ArcGIS 10.8 software spatial analysis tools. All predictor variables were adjusted using R and R Studio software to have a similar extent, projection, and resolution as required to run the MAXENT model (Phillips *et al*., 2006).

Predictor variables were selected using ENMTools software in R 4.2.2 (Table 5) and checked for correlations between variables. The highly correlated variables were removed (<-0.7 and > 0.7) (Challa Kufa, *et al.*, 2022) (Appendix B Supplementary Table 3), followed by the removal of the least contributing variable after the MAXENT run (zero value of contribution) (Landau and Everitt, 2004; Fekede Regassa *et al.*, 2019, 2021). Highly correlated variables reduce the efficiency and increase the uncertainty of species distribution models (Dormann *et al.*, 2013; Junior and Nobrega, 2018; Zurell *et al*., 2019). Therefore, 12 predictor variables were selected to determine the habitat suitability and distribution of African elephants in the Omo National Park under current conditions. The selected predictors include slope, aspect, altitude, and distance from water sources, roads, settlements/farming, and land use land cover, as well as the mean diurnal range of temperature (bio 2), isothermality (bio 3), temperature seasonality (bio 4), and monthly rainfall in March (Table 5).

Table 5. Environmental variables selected after multicollinearity test correlation analysis

	Aspect	bio_2	bio_3	bio_4	dist_canal	_ and	dist_river	dist_road	Elev	lulc_o	prec_03	Slope
Aspect	1.00											
bio_2	0.04	1.00										
bio_3	0.1	-0.1	1.00									
bio_4	-0.03	0.19	-0.64	1.00								
dist_canal	0.09	-0.3	0.36	-0.39	1.00							
dist_cultland	0.01	-0.02	-0.2	0.13	0.24	1.00						
dist_river	0.01	0.19	0.1	0.17	-0.25	-0.27	1.00					
dist_road	0.03	-0.07	0.15	-0.32	0.62	0.24	-0.24	1.00				
Elev	0.11	-0.58	0.42	-0.25	0.75	0.11	-0.11	0.32	1.00			
lulc_o	-0.03	-0.04	-0.06	-0.01	-0.13	0.06	-0.04	-0.1	-0.07	1.00		
prec_03	0.1	-0.61	0.4	-0.12	0.36	0.11	0.01	0.07	0.64	-0.01	1.00	
Slope	0.01	-0.49	0.14	0.03	0.11	0.03	0.04	0.03	0.4	0.02	0.5	1.00

Note:- bio_2:,bio_3:, bio_4:, dis_canal:Distance to canal;dist_cultland:Distance to cultivated land; dits_river:Distance to river; dist_road:Distance to road; Elev:elevation; lulc_0;Land use land cover; prec_03:precipitation;

Statstical analyses

MAXENT version 3.4.4K was used to predict the wet and dry seasons of African elephant distribution and habitat suitability in Omo National Park. It is the most preferred method to use either presence or absence-data (if available) or presence-only data to predict the habitat suitability of species (Merow *et al.,* 2014; Morales *et al*., 2017). MAXENT operates on the principle of maximum entropy, making inferences from available data while avoiding unfounded constraints from the unknown (Phillips *et al*., 2006). Entropy is the measure of uncertainty associated with a random variable. The greater the entropy is the greater the uncertainty. Adhering to these concepts, MAXENT utilizes presence-only points of occurrence, avoiding the absence of data and evading assumptions on the range of a given species. Thus, it was used to build and calibrate the spatial models based on 10-fold cross-validation with a regularization multiplier ($\beta = 1$) and linear and quadratic features to have smooth models (Anderson and Gonzalez, 2011; Anderson and Raza, 2010; Elith *et al*., 2010).

The occurrence data were randomly classified into 70% for training and 30% for testing the model (Phillips *et al*., 2006; Zurell *et al*., 2019). Five thousand background locations were randomly generated and chosen considering the targeted study area to determine pseudo presence. For the remaining parameters, the MAXENT default settings were considered for the modelling.

Model performance was assessed by analyzing the area under the receiver operating characteristic (ROC) analysis and the area under the curve (AUC) in MAXENT as a measure of model fit. AUC results were rated as 'high accuracy' for AUC values between 0.90-1.00, 'good' for AUC values between 0.80-0.90, 'moderate' for AUC values between 0.70-0.80, 'poor' for AUC values between 0.60-0.70 and 'no chance' for AUC values below 0.50 (Elith *et al.*, 2011; Swets, 1988). In addition, the variable response curves and jackknife test were used to evaluate the relative contribution of the predictor variables to the model (Elith *et al.*, 2011; Korennoy *et al*., 2014; Fekede Regassa *et al*., 2019). We used the percentage contribution, permutation importance, and jackknife test results to estimate the contribution of each variable to the models (Phillips *et al*., 2006). In addition, the response curve resulting from the model for each environmental variable was used to examine the relative effects of the different environmental variables.

As limitations of Maxent as observed in this study include the difficulty in getting equal extent and resolution in sampling and re sampling in Arc GIS soft ware which was latter possible to manage it using R-software. It took months to get adjust variables. Uses of presence only data or small occurrence points require cleaning the coordinates and for autho-coloration to avoid duplication. Unclear information, in the uses of default numbers in the uses of parameters in Maxent machine.

3.2.5. Feeding Ecology

Data collection and analysis

Data were collected over a period of 12 months, from December 2020-June 2021 and December 2021-June 2022 considering both two dry (December – February) and wet seasons (April-May) to obtain representative data for the whole year. One mtheriarichial focal group herd consisting eight individuals was identified (three adult female and two sub adult male and three sub adult female). Elephant feeding behaviour and food selection was difficult to observe directly due to the frequent activity changes of elephant and trying to avoid humans in ONP. When the Identified elephant herd were observed usually fled immediately once they detect an observer. Thus we really both on direct (that is when we encountered the focal herd) and in direct opportunistic observations (feeding signs and fresh elephant trail follows). Thus the focal group elephants and opertunistic observations were made for a total of 144 hours for both two wet and dry seasons. Observations were made for 3 hours as of early morning and 3 hours in the late afternoon when most animals were commonly active, every other two weeks, (Stephen, 2002; Gordon *et al*. 2016; Swanepoel, 2019). Thus, both focal group elephant (herd) monitoring and opportunistic observation were made for a total of 24 days, for a total of 48 monitoring periods of 6 hours per day in the two years of the study period. When encountered the focal group elephants they were followed on foot and by vehicles at a distance of about 40-100 m from where they were observed through 8x42 binoculars (Nikon Monarch Binoculars) and information was collected on the feeding ecology of the elephants in the study area. Examination of fresh feeding signs after focal groups of elephants and observation of elephant feeding sign on feeding trails was carried out (Chen *et al*., 2006). It was possible to determine the food selection of elephants on the different migratory routes and habitat types. All plant species proven to be consumed by elephant were identified at least to genus level and recorded for the focal group elephants monitored. The following data were recorded at each feeding site to determine to determine the diet composition and proportion for the elephants in ONP: number and type of plant species fed by the elephants; the way the food was taken from the plant including grazing, browsing, debarking and uprooting; parts of the plant including leaf, stem, bark, wood, roots, that were used/eaten; the estimated age of the plant consumed (fresh or recent) and the GPS coordinates of the location. Desiccation of leaves and bark, dryness of exudates and associated signs such as footprints and fresh dung piles near browsed foliage were noted and were used as evidence to estimate the age of feeding signs.

The focal elephants unstable nature, fast activity and change of postion as well as avoidance of observer upon detection can be considered as the main limtations and made difficult the data collection that is why most data were from in direct opportunistic observations (feeding signs and fresh elephant trail follows).

3.2.6. LULC Changes and impacts

Landsat Image acquisition, per-processing, classification and analysis

During the dry season in December of each year, confirmed cloud-free Landsat imagery from 1993, 2003, 2013 and 2023 at a spatial resolution of 30 x 30 m was downloaded from the United States Geological Survey (USGS) (website. htpp://www. usgs. gov) to analyze LULC change in ONP and its surrounding buffer areas (Fig. 6). This Landsat image was suitable to better visualize the LULC due to the less cloud cover and fire effects. All Landsat images were from Collection 2 and Level 2 science products released in early 2021. They are application-ready Level 2 science products derived from Landsat Collection 2 Level 1 (USGS, 2021). Level 2, Landsat imagery is a time series of observational data processed for consistency and continuity to measure the effects of environmental change (USGS, 2021). It is possible to use imagery from different satellites for detecting and comparing changes in the historical time series of LULC classification as long as the Landsat imageries used are from the same level/sensor (USGS, 2021). There may also be slight differences in the wavelength of the different satellites in the same level, but these do not have a significant impact on the final result and the images are comparable (USGS, 2021). Thus, level 2 images are already corrected for radiometric, geometric and atmospheric effects and thus considerably reduce the pre-processing activities required before the actual classification of LULC. These are the Landsat images of time series level-2: 5, 7, 8 and 9 (1993, 2003, 2013 and 2023, respectively) which are considered for this study that have the same path and row (170 and 056) acquired in the same season in December (Appendix C: supplementary Table 1).

Secondly, composite data set images were created for each year and clipped to a polygon shape-file of the study area (the ONP and its surrounding buffer of 15 km distance) using the imported Landsat images of the respective years (1993, 2003, 2013, and 2023) in ArcGIS 10.8 software. Image processing and analysis using the imported Landsat imagery was performed in ArcGIS software (version 10.8) to create LULC maps. For further analysis, the geographic coordinate system World Geographical System (WGS 1984) was used and projected onto the UTM zone.

Third, actual classification of the images: According to Lillesand, *et al*., (2004), the purpose of image classification is to allow the user to categorize all pixels of an image into different categories. In this study, ArcGIS 10.8 software was used to create a temporal inventory of LULC using a supervised classification approach. Different band combinations of landsat images were used for image classification (Table 6). Samples with known identities were used to classify pixels with unknown identities based on the similarity of cases to obtain predefined classes that were spectral characterized: These sites are commonly referred to as training sites (Thomas *et al*., 2004; Kalura *et al.*, 2017).

For the ONP and neighbouring buffer areas, Landsat images were processed using image composition, masking, clipping and mosaicking to create a composite datasets for each year. Supervised classification using the maximum likelihood classifier was used for image classification and the creation of base maps for change detection. Supervised classification is chosen because it classifies land use based on training patches assigned by the classifier (Table 6). Pixel-based classification methods automatically categorize all pixels of an image into land use classes based on spectral similarities (Thomas *et al*., 2004; Erener, 2013).

Table 6. LULC classes description used for ONP and surrounding areas.

LULC classes	General description
Open Grassland (OG)	Area of land on which the existing vegetation cover is grass
Savannah Wooded Grassland (SWG)	Savanna areas or grassy woodland ecosystem characterized by the trees being widely spaced with an unbroken herbaceous layer consisting primarily of grasses.
Woodland	Areas dominated by *Acacia* species having a more open canopy and sparser tree density,
Bushland	Land covered with shrubs and small trees or comprised of plants that are multi-stemmed from a single root base.
Forest	Area occupied by tree clusters resulting from natural vegetation / such as riverine association; ground water forest/. The vegetation is usually evergreen due to continuous water

	supply from the rivers and /or the high ground water table.
Agricultural land	Crop fields and fallow lands or land plough or prepared for crop growing
Water bodies	Fresh water surfaces including perennial an non-perennial rivers and streams, permanent and seasonal lake/ ponds

Fourth: It is important to evaluate the accuracy of the classification results to confirm the extent to which the classification produced is comparable to the actual conditions on the ground (Owojori and Xie, 2003). The classified images were compared with reference data obtained randomly from Google Earth and during the fieldwork for each class of the land cover and used for accuracy assessment and analysis in ArcGIS 10.8. The accuracy of the classified image can be evaluated using the error matrix. The result values of the kappa coefficient were used to determine the degree of correspondence of the classification with the actual situation of LULC (Rahman *et al.*, 2004;). The formula of Congalton, (2001) and Congalton and Green (2008) were used to create and evaluate confusion matrices. The producer, user and overall accuracy and the kappa coefficient for 1993, 2003, 2013 and 2023 were calculated. Finally, based on the classified images from different periods, the change detection function in ArcGIS 10.8 was used to detect the changed areas and to know which land use was changed to which. In this way, it was possible to compare change detection between 1993 and 2003 and 2013 and 2023 using a change detection matrix in ArcGIS software.

When performing Land Use Land Cover (LULC) classification in ArcGIS, limitations can arise from factors like the complexity of land features, the resolution of the satellite imagery used, the chosen classification algorithm, the quality of training data, and the potential for misinterpreting mixed pixels, leading to inaccuracies in the final classification map, especially when dealing with highly heterogeneous landscapes or areas with subtle spectral differences between land cover types. These area re uires strong attention in the process of classification.

Reconaissance survey and community interaction

Before the actual fieldwork, general information such as the current natural habitats and prevailing land use practices about African elephant movement and habitat uses, human population and activities, and livelihood strategies in and around the ONP were obtained during the reconaissance survey. During the actual field observation, information on the LULC types was collected using GPS (recording the X-Y coordinate points and the corresponding attributes) to assess the accuracy of the LULC classification. Stratified random sampling techniques were used to collect a total of 184 sample points to ensure an equitable distribution among the different LULC types of study areas (Das, 2009). LULC photographs were also collected to aid image processing.

Interviews in the form of households, key informants and focus group discussion guided by structured questionnaires were used to collect data on LULCC forces over the past 30 years (1993-2023), which were finally analyzed qualitatively. A total of 132 households were selected using simple random sampling for interview. of the total estimated households 225 in the Kebeles of the study area (10 respondents for each kebeles in which Dizi 50, Surma 20, Nangatom 20, Mursi 20, Bodi 10, and Muguji , Menit and Bacha each 4 resposndents as per their number of kebeles touched the park teritority and their total population in the area) using Kothari's sample size formula (Kothari, 2004).

where

$S=Z^2x\ NP(1-P)/\ D2(N-1)+\ Z^2P(1-P)$ where Z is 95% t value (=1.96), N is total estimated population, P is the minimum population proportion considered (which is 30%) and D is the degree of accuracy which is equal to P value (0.05).

The respondents were 25 years of age and above and had been living in the area for the last 20 years or more. We used local guides from the respective communities for translation and explanation of the questioners. Knowledge of the respondents about the historical LULC types; LULC change trends in the last 30 years, the driving forces of LULC change and its impacts on movement and distribution of African elephants and its suitable habitats in ONP and its surroundings areas were taken into account.

Focus group discussion was additionally carried out with 12 people (who were mainly local leaders and elders who could remember events in land transformation) in and around ONP. The discussions were distributed in the three sampled Kebeles that involved elders, local leader (administrator), senior rangers and Park wardens using the checklist of questions related to land-use changes and its drivers as well as their effect on elephant habitat and conservation in the ONP and the surrounding buffer area. The information obtained from the interviews with the local communities and the experts was analyzed qualitatively.

During the fieldwork and interviews, it was found that population growth and human activities in ONP and surrounding areas increased significantly, especially after the start of the government mega project, Kuraz sugar development project in 2010. The years 1993 and 2003 were more or less similar in terms of human population and human activities in the ONP and surrounding buffer areas. Therefore, the year 2003 was considered the baseline year before higher levels of population growth and human activity occurred, while the subsequent years 2013 and 2023 were the years of higher population growth and human activity in and around the Park.

4. RESULTS

4.1. Dung density and elephant population estimation

In the current dung count study, 153 dung piles were recorded on a total of 32 km transects during the dry season in 2022. The number of dung piles per transect ranged from 0 to19. Of the 32 sample transects, dung piles were recorded on the twelve transects. Combined with the distance sampling package analysis, elephant density was estimated to be 0.528 km² with a 95% confidence interval of ±0.17002. Multiplied by the extent of elephant suitable habitat (696 km²), it gives 306 elephants with 95% confidence limits from 287-522 elephants in ONP. The result is considered a more conservative estimate of elephant numbers in ONP for the year 2022 (Table 7). This result shows that the elephant population in ONP has declined since the estimate of 760 elephants in 1996 (Fig. 10).

Two elephant herds were opportunistically encountered at the two sites during the study period. More than 47 individuals in Bekele Sefer on January21, 2022 and 55 individuals were counted in the nearby Omo and Mui rivers on April12, 2022.

Table 7. Results of transects dung count in the study area (2022)

Vegetation Types	Study site/Name	No T	TL (km)	SA (km^2)	ESH (km^2)	No TD	DD	ED	EP
Riverine Forest	Kuma River	2	2	0.03	24	22	687.5	1.01	24.3
	Omo/Mui Rivers	8	8	0.13	96	52	406.3	0.60	57.4
	Bekele Sefer	3	3	0.05	120	31	645.8	0.95	114.0
	Kibish River	3	3	0.05	72	19	395.8	0.58	41.9
Open grassland	Ililbi/Tingn plains	4	4	0.06	120	14	218.8	0.32	38.6
	Sai Plain	4	4	0.06	72	9	140.6	0.21	14.9
Wooded grassland	Tilkber/ Gimwuha	6	6	0.1	144	6	62.5	0.09	13.2
	Dingai wuha	2	2	0.03	48	0	0	0	0
		32	32	0.51	696	153	298.8	0.44	305.9

Key:- Number of Transect (NoT), Transect Length (TL), Sample Area (SA), Extent of Suitable Habitat (ESH), Total Dropping (TD), Dropping density (DD), Elephant Density (ED), Elephant population (EP)

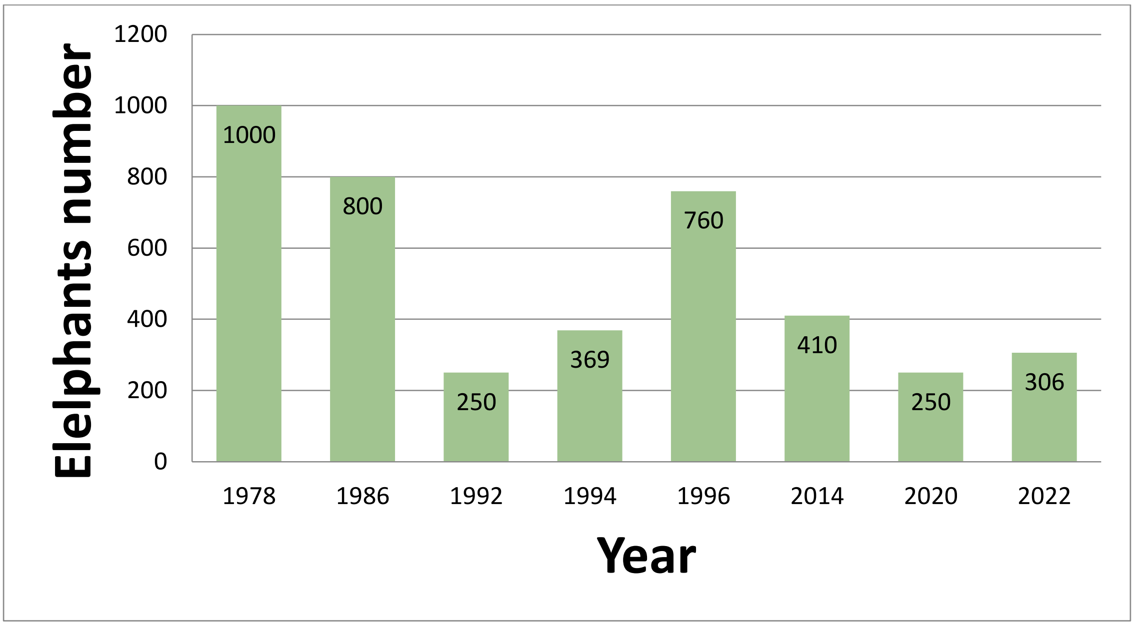


Figure 10. Trends in the population of elephants in ONP (from 1978-2022) (sources :updated Chere, 1996 and EWCA 2015)

In contrast, a similar result from the dung survey in the same study area during the dry season in 2021 had showed low number of elephants with an estimated density of 0.224 km^2 with a 95% confidence limit of ±0.077899.The density multiplied by the extent of suitable habitats where we found elephant signs (696 km^2) gives 134 elephants with confidence limits of 102-217, which we consider as our possible estimate of elephant numbers in ONP for the year 2021 (Table 8).

Table 8. Results of transect dung count in the study area (2021)

Vegetation Types	Study site /Name	No T	TL/ km	SA/ km^2	ESH/ km^2	No TD	DD	ED	EP
Riverine forest	Kuma River	2	2	0.032	24	10	312.5	0.46	11.03
	Omo and Mui Rivers	8	8	0.128	96	16	125	0.18	17.65
	Bekele Sefer	3	3	0.048	120	14	291.7	0.43	51.47
	Kibish River	3	3	0.048	72	17	354.2	0.52	37.5
Open Grassland	Ilibai & Tingn plains	4	4	0.064	120	6	93.8	0.14	16.54
	Sai Plain	4	4	0.064	72	0	0	0	0
Wooded Grassland	Tilikber & Gimwuha	6	6	0.096	144	4	41.7	0.06	8.82
	Dingai wuha	2	2	0.032	48	0	0	0	0
		32	32	0.512	696	67	130.9	0.19	133.94

Key:- Number of Transect (NoT), Transect Length(TL), Sample Area (SA), Extent of Suitable Habitat(ESH), Total Dropping (TD), Dropping density (DD), Elephant Density (ED), Elephant population (EP) and Confident Interval (95% CL).

4.2. Distribution and seasonal habitat suitability of African elephants

The average test omission rate and predicted area with respect to the cumulative threshold were calculated across ten replicate runs in the MAXENT model during both the wet and dry seasons. The receiver operating characteristic (ROC) curve, averaged over the ten replicate runs for wet and dry seasons, indicated higher AUC values of 0.877 ± 0.028 and 0.952 ± 0.006, respectively, for elephant habitat suitability. These values exceed the random prediction line (0.5), demonstrating the model's strong predictive ability in determining the habitat suitability of the elephant in the study area for both seasons (See Appendix B: Supplementary file figures 2 and 3). Figure 11 (A, B) displays prediction maps illustrating the probabilities of elephant occurrence during wet and dry seasons based on the MAXENT model using spatially defined variables. The likelihood of elephant occurrence is generally higher near water sources during the dry season (Fig. 11A), while during the wet season, elephants tend to prefer habitats distant from rivers and scattered across herbaceous, wooded, and open grassland areas (Fig. 11B). Additionally, Figure 11C showcases the habitat preferences of elephants in the study area during both the wet and dry seasons.

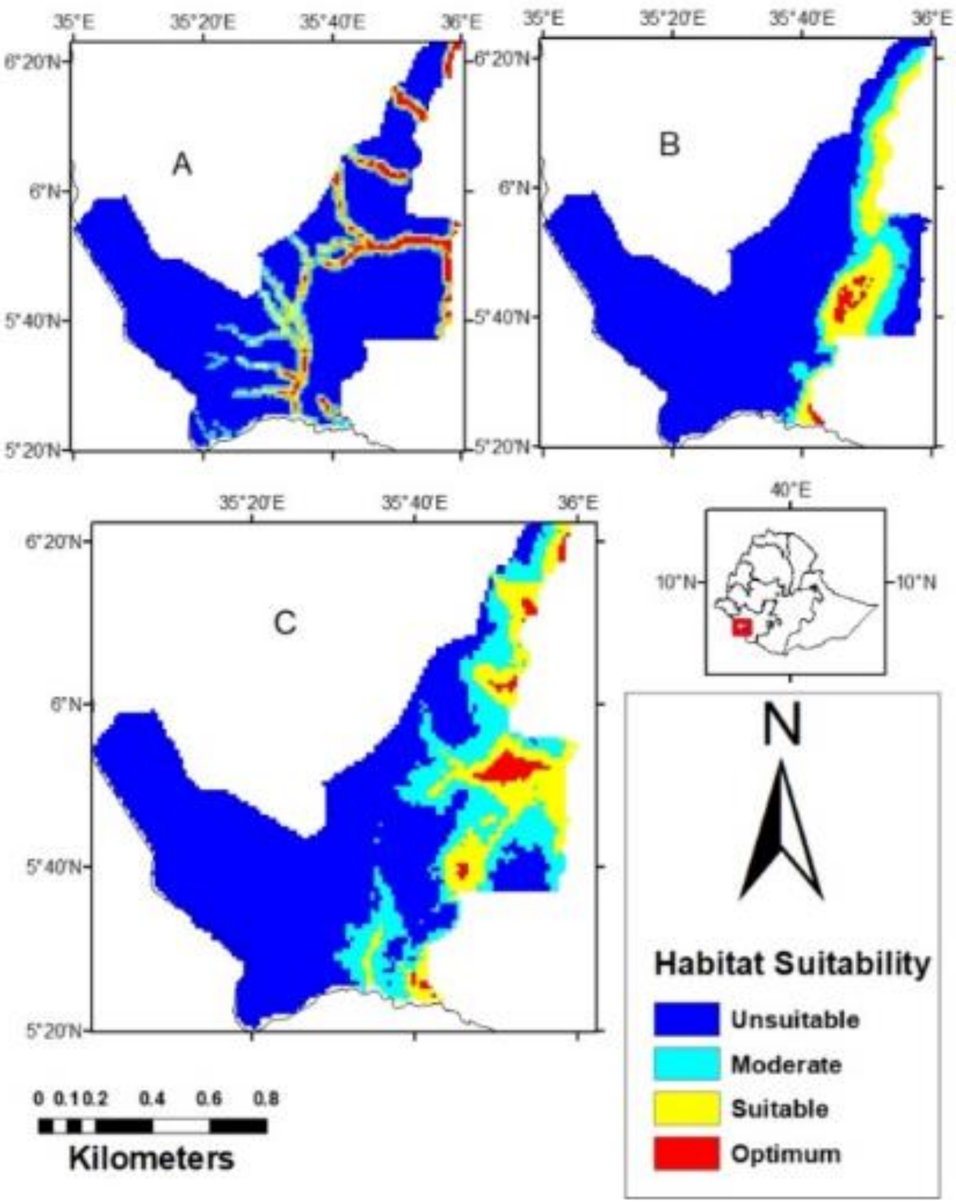
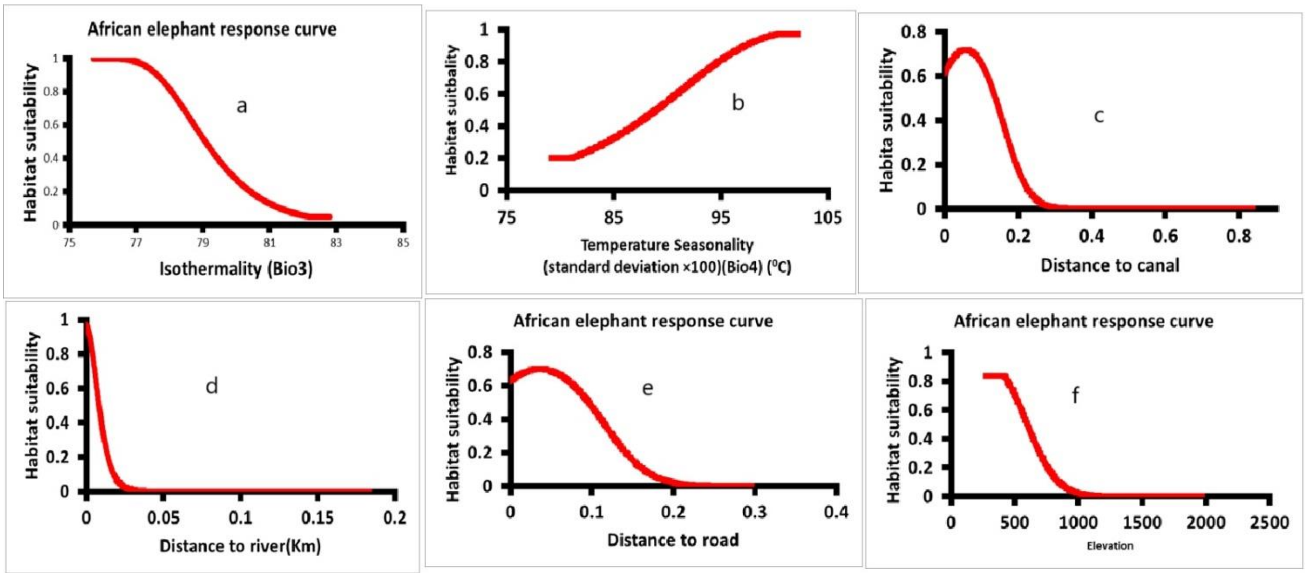


Figure 11. MAXENT model result of African elephant habitat use during the (a) dry season,(b) wet season and (c) both seasons of the year 2020 and 2021.

The wet season (312 km^2) offers a greater area of suitable habitat for African elephants than the dry season (29 km^2). During the wet and dry seasons, the range of African elephants was 1215 km^2 and 191 km^2, respectively. The total area of 1999 km^2 (39% of the study area) is represented by the modelled seasonal combined elephant range results; 365 km^2 (7.2%) are optimum or highly suitable habitats, 748 km^2 (14.7%) are suitable habitats, and 886 km2 (17.5%) are moderately suitable habitats. African elephants were found to not visit or be less suitable for the remaining area (61% of the total study area) in the Omo National Park (Fig. 11) (Appendix B: Supplementary Table 4).

The response curves Figure 12 and 13 below and the categorical variable or land use land cover (Fig. 14), (Appendix B: Supplementary Figure 4), illustrate how each environmental variable influences the MAXENT forecast in both seasons. Elephant habitat suitability improves during the dry season as predictor variables such as elevation, distance to rivers, roads, and canals, and isothermality (bio3) decrease. On the other hand, as the predictor's variables like the mean diurnal range temperature (bio 2) and temperature seasonality (bio 4) increase, suitability does as well. Elephant habitat suitability was shown to be somewhat influenced by slope, aspect, and distance to cultivated land, albeit these factors varied little over time.

During the wet season, the habitat suitability of elephants increases while most predictor variables decrease, except for the mean diurnal range temperature (bio 2),, temperature seasonality (bio 4) and distance to the river. The land use and land cover categorical variables show the highest habitat suitability in the herbaceous woodland (0.2) and riverine associated forest (0.79) during the dry season. Conversely, during the wet season, it was highest in the herbaceous wooded grassland (0.40) and open grassland habitats (0.39).



Dry season

Figure 12. MAXENT model result of African elephant habitat suitability response curve for dry season selected based on their higher impacts on habitat suitability. (key : a, b, c, d, e,, f represent isothermality (bio3),Temeprature seasonality (bio4), Distance to canal, to River, to Road and elevation , respectively)

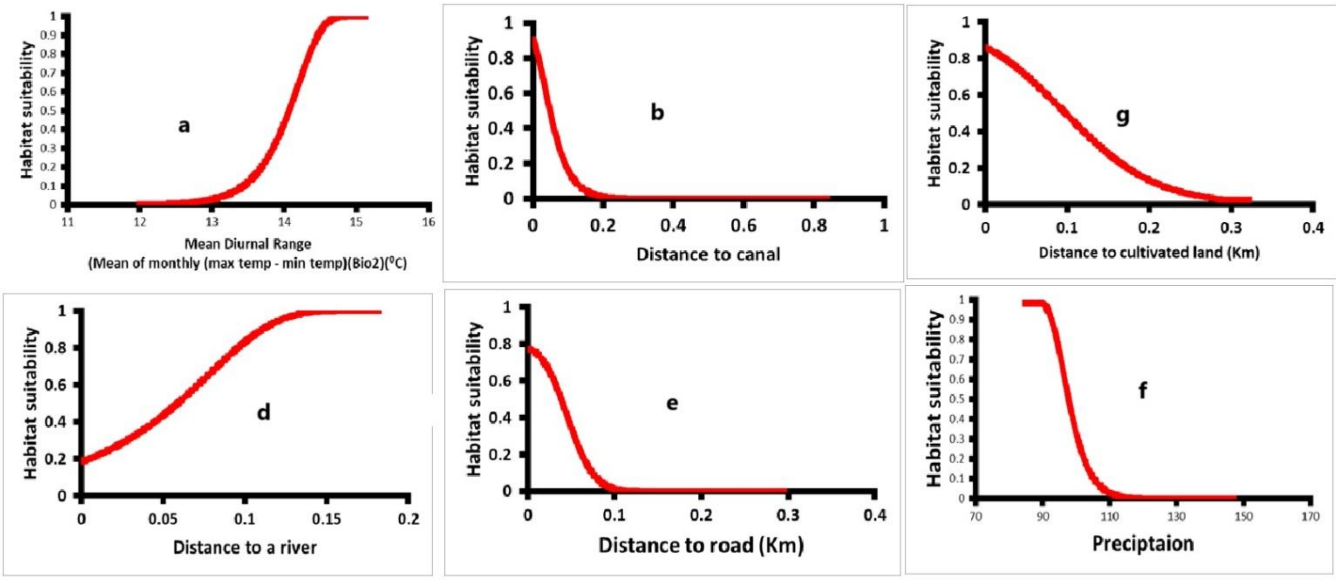


Figure 13. MAXENT model result of African elephant habitat suitability response curve for wet season selected based on their higher impacts on habitat suitability

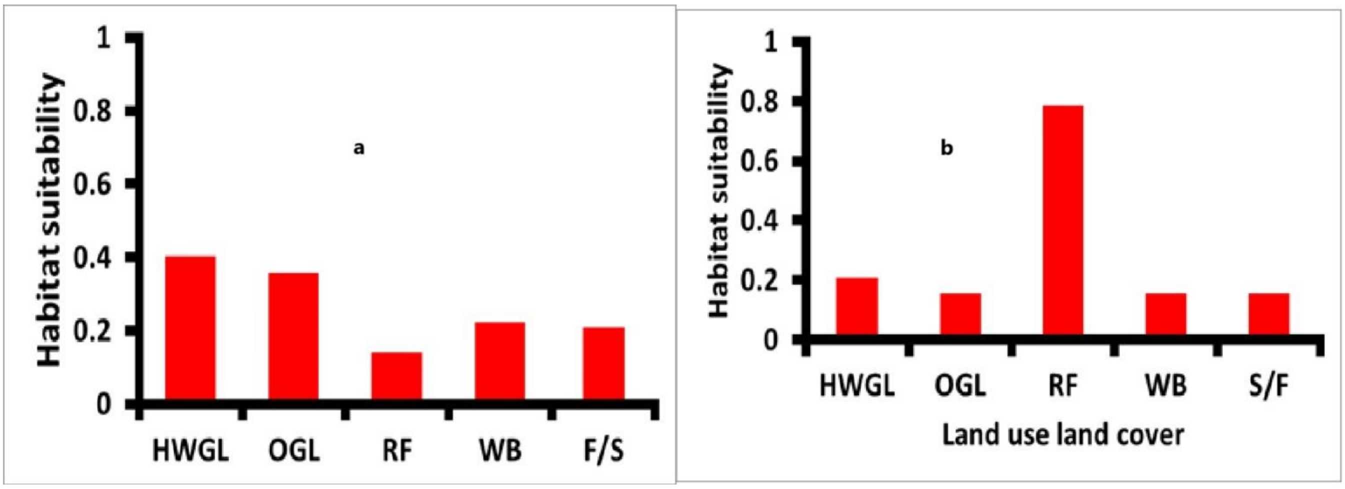


Figure 14. MAXENT model result of African elephant habitat suitability of categorical variable, land use land cover 'a' for the wet season and 'b' for the dry season (HWGL: Herbaceous Wooded Grassland; OGL: Open Grassland; RF: Riverine Forest; WB: Water Bodies; F/S: Farming and Settlement)

In terms of the relative contribution of environmental variables to the MAXENT model (Table 9), three variables – distance to rivers, land use, and land cover – were the most significant predictors, each contributing more than 10% to the model results, but with different percentage contributions for both wet and dry seasons. Table 9 shows the relative contribution and importance of predictor variables to the MAXENT model in the habitat of

African elephants during both the wet and dry seasons (average results of 10 predictor replicates).

Table 9. Relative contribution and importance of variables to the MAXENT model for wet and dry seasons (average results of 10 replicates).

Predictor variables	Code	Percent contribution	Permutation Importance	Percent contribution	Permutation Importance
		Dry season		Wet season	
Distance to river	dist_river	49.2	44.8	10	2.3
Land use land cover	Lulc_o	28.7	0.6	33.8	0.9
Distance to canal	dist_canal	16.3	52.3	40.1	50.8
Temperature Seasonality	bio4	2.6	0.6	0	0.1
Elevation	Elev	1.1	0.4	5	0
Distance to roads	dist_road	0.9	0.7	0.5	5.6
Isothermality	bio3	0.7	0	0.1	1.7
Slope	Slope	0.3	0.1	0.3	0.5
MDR of temperature	bio2	0.1	0.1	7.2	13
Distance to cultivated land	dist_cultland	0.1	0.4	1.5	6.9
Aspect	Aspect	0	0	0.2	0.1
Precipitation (March)	Prec 3			1.3	18.2

Key:- MDR of temperature= Mean Diurnal Ranger of temperature

During the dry season, the model indicated that distance to rivers was the most influential factor (49%), followed by land use and land cover (29%), and distance to the canal (16%) in terms of their impact on elephant population locations. Conversely, during the wet season, elephants tended to disperse in herbaceous, wooded, and open grassland habitats or move away from lowland river valleys. As a result, the MAXENT model revealed that distance to the canal (40%), land use land cover (forest) (34%), and distance to the river (10%) were the primary contributing factors during the wet season (Table 9). The results of the jackknife test of variable importance for the MAXENT model are displayed in Figure 15. This test was crucial in assessing the relative importance of individual predictor variables in predicting elephant presence (habitat suitability). During the wet season, the distance to the canal emerged as the environmental variable with the highest gain when used in isolation, indicating its significant stand alone informative value (Fig. 15). Following this, elevation, mean diurnal range of temperature (bio2), monthly precipitation for March, and distance to (roads, rivers, canals, cultivated land/farming), and slope were ranked in terms of their influence. Land use land cover, temperature seasonality (bio 4), aspect, and isotermality (bio 3) had lower gains when used in isolation. Additionally, the distance to the canal was identified as the environmental variable that had the most substantial impact on the model when excluded, signifying its unique and valuable information compared to the other variable. The inclusion of isothermality (bio 3) in the model does not have a significant impact on the overall training gain. Conversely, the dry season exhibited the highest gain as an individual environmental variable, but had the most substantial impact on reducing gain when the distance to the river was omitted. This suggests that the dry season contains unique and valuable information that is not captured by other variables (Fig. 15).

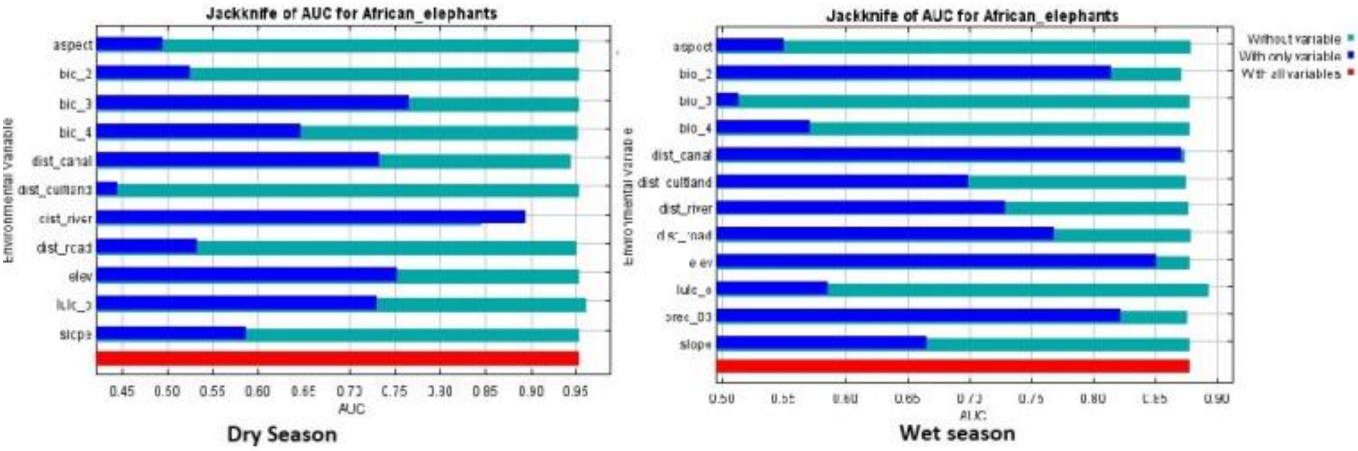


Figure 15. Jackknife of AUC (area under the receiver operating curve) for the African elephant, showing average AUC gains for each variable (abbreviation is in Table 9 above)

The distance to cultivated land or farming does not notably influence the overall training gain when not included in the model. The jackknife tests of variable importance for the African elephant dataset produced the same results for both regularized training gain and test gain (Appendix B: Supplementary Figure 5). These results also identify the variables with the highest training and test gains when used individually, the variables that contribute most to the overall gain and their impact when excluded from the model, and the variables that do not significantly reduce the total training and test gains when omitted.

4.3. Feeding ecology

4.3.1. Elephant diet in ONP

The focal group was observed feeding 11479 times during wet and 11354 times during dry seasons. Elephants were observed feeding on a total of 91 plant species from 42 families and 66 genera, during the 12 month sampling period (Appendix A: Table 1). Woody species were the easiest to identify and were most frequently eaten by elephants during both the wet and dry seasons. Of the total plant species consumed, 77 were woody plant species (48 trees, 18 shrubs and 11 climbers) from 29 families. This contributed 84%. 14 species from 4 families were herbs and grasses and contributed 16% to the total diet consumed by the elephants (Appendix A: Tables 1, 2 and 3).

Elephant herd diets consisted predominantly of browse during both dry and wet seasons (Fig. 14). The seasonal total observed diet of elephants in ONP consisted of 71% and 89% browse (woody species), 7% and 11% forage (herbaceous and climber whole part eaten plants) and 4% and 18% were grazing (grass species) during the wet and dry seasons, respectively (Fig. 16, Appendix A: Table 1).

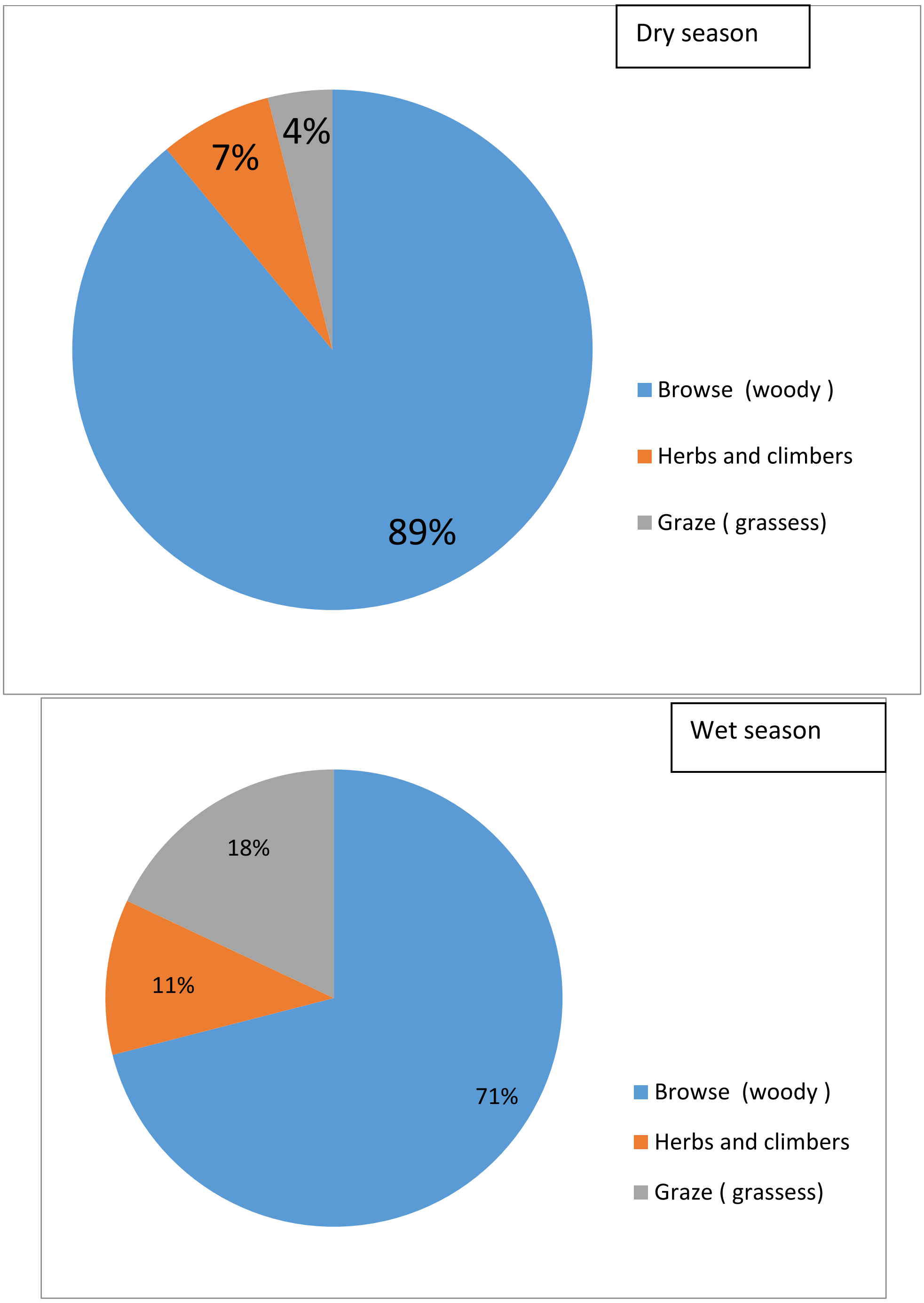


Figure 16. Diet percentage of elephants during wet and dry seasons in Omo National Park

Families *Fabaceae* (25 and 20%), *Meliaceae* (10 and 9%), and *Sapindaceae* (7 and 6%) contributed the most to the diet of elephants during wet and dry seasons, respectively. At the species level, *Cordia africana* (3.5 and 3.1%), *Stereospermum kunthianum* (3.3 and 2.1%), and *Ficus* species (*F. sur*, *F. vasta*) (8.4 and 8.1%) were the largest contributors and the most consumed woody plant species during the wet and dry seasons, respectively. In ONP, species from genus Acacia (*A. nilotica,* A. *brevlsplca, A. sieberana* , A. *tortilis,* A. *horrida, A. melifera, A. pentagona, A. sengal* and *A. seyal*) contributed the most for the elephant diet (15.29% and 13.2%) during both the dry and wet seasons, respectively. (Appendix A: Table 3)

Among the whole part eaten plants including herbs, small shrubs and climbers, they consisted 19 species. Family Amaranthaceae was the most utilized during the wet season (3.1%) and VITACEAE (climbers) utilized (2.2%) during the wet and dry seasons. Almost all 19 herbs and small shrubs were observed to be consumed more frequently during the wet season. Some species (*Blepharis linariifdlus, Pers. Achyranthes aspera, Amaranthus spinosa, Celosia argentea, Digera muricata*) were not recorded in the diet of elephants during the dry season. From the climbers, *Cissus petiolata* and *Cissus rotundifolia* and from herbs *Suaeda monoica* were the most frequently consumed species as a whole during the wet season (Appendix A: Table 1).

Within the family *Poaceae,* grass species were the most consumed genus(18.3% and 3.6%) during the wet and dry seasons, respectively. Among the five species of grasses identified, *Setaria megaphyl/*a is the most consumed species (2.65%) during the wet season, followed by *Panicum coloratu* in the diet (0.41% and 2.6%) during the dry and wet seasons, respectively (Appendix A: Table 3).

4.4. LULC Changes and impacts on elephant in and around ONP

4.4.1. Classification and accuracy assessment

The LULC classes in the study area, as well as the observed changes, impacts and driving factors in the years 1993, 2003, 2013, and 2023 (Figs. 17 and 18), are displayed in our result. The kappa indices of agreement for the years 1993, 2003, 2013 and 2023 were 0.92, 0.85, 0.88 and 0.89 with the overall accuracy of the Landsat-derived classified images 93.1%, 87.8%, 91.7% and 92.6%, respectively (Appendix C: Supplementary Table 2) The results demonstrated a flawless level of agreement between the classified images and the referenced data and in line to the standard land cover mapping accuracy level (85%-90%).

4.4.2. LULC Changes

Both ONP and the adjacent buffer regions saw changes in land cover during the study period, albeit to varying degrees and at varying yearly rates of changes (Tables 10–11; Figs. 17 and 18). With a 57% share in 1993, open grassland was the largest area in ONP; by 2023, it had slowly decreased to 6.67%. open grassland was the most altered with an annual rate of change -213.4 km^2/year in the first period (1993-2003) and increased at a rate of 12.4 km^2/year in the second period (2003-2013) and fell at a rate of -58 km^2/year in the third period (2013-2023). With the highest annual rate of change of 203.7 km^2/year over the first period (1993-2003), Savanna wooded grassland exhibited the strongest rise, rising from 11% in 1993 to 39% in 2023. Bushland and woodland also showed some increases, rising from 3% in 1993 to 16% in 2023 and 8% in 1993 to 18% in 2023, respectively. The percentage of forest and water bodies increased from 20% in 1993 to 21% in 2023 in a relatively steady and smaller increase, and from 1% in 1993 to 2% in 2023, respectively (Tables 12 and 13).

The assessment of land use and cover changes (LULC) in the surrounding buffer areas of the ONP, revealed that over the last thirty years, significant land cover changes had been observed in the agricultural land, which increased from 735 km^2 (10.2%) in 1993 to 2823 km^2 (39.1%) in 2023 or increased by about 2088 km^2 (284%) (Table 14). Savanna wooded grassland increased from 1715 km^2 (23.7%) in 1993 to 1968 km^2 (27.2%) in 2023, followed by water bodies, which increased from 280 km^2 (3.9%) in 1993 to 442 km^2 (6.1%) in 2023. Other LULC classes that showed a decreasing trend between 1993 and 2023 were forest land by 1906 km^2 (−73.4%), open grassland by −600 km^2 (−60.6%), woodland by −36 km^2 (−12.2%), and bushland by −39 km^2 (−6.3%) (Tables 12 and 13).

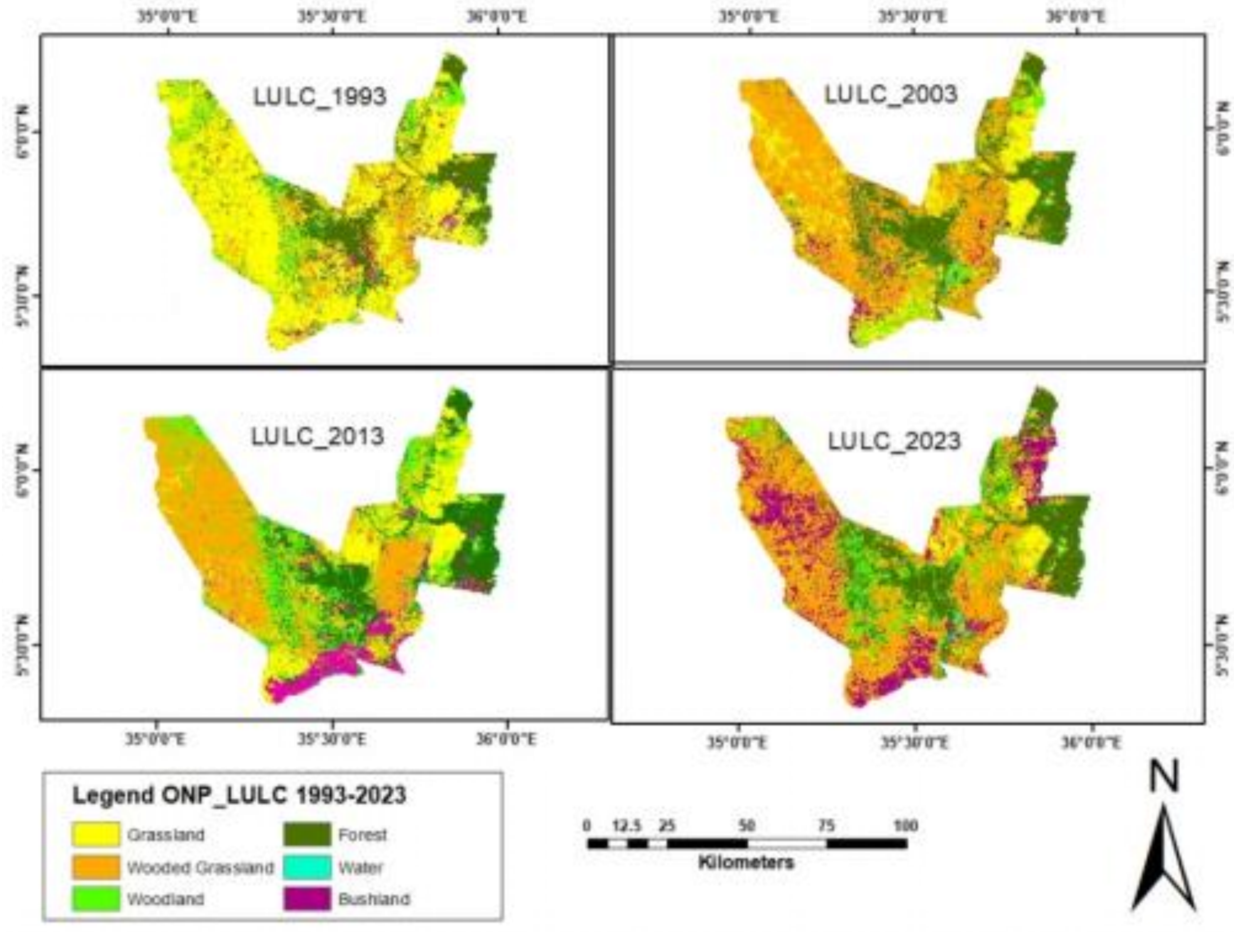


Figure 17. Comparative maps showing the LULC change from 1993 to 2023 in ONP.

Table 10. LULC type, area (in km^2) and percent coverage (%) in ONP

LULC type/Year	1993	%	2003	%	2013	%	2023	%
OGL	2940	57.01	805	15.61	929	18.01	349	6.77
SWG	549	10.65	2586	50.15	1793	34.77	2100	40.72
WL	400	7.76	319	6.19	912	17.68	564	10.94
BL	168	3.26	186	3.61	402	7.79	819	15.88
FL	1035	20.06	1196	23.18	1059	20.55	1196	23.19
WB	65	1.26	65	1.26	62	1.2	129	2.50
Total	5157	100.00	5157	100.00	5157	100.00	5157	100.00

Key:- OGL= Open Grassland, SWG =Savanna Wooded Grassland, WL=Wood Land, BL = Bush Land, FL = Forest Land, WB= Water Bodies

Table 11. LULC changes and area proportion in the three study period in ONP.

LULC type	(1993-2003) Change(km^2)	% Change	Change rate (km2/ year)	(2003-2013) Change (km^2)	% change	Change rate (km^2/ year)	(2013-2023) Change (km^2)	% change	Change rate(km^2/year)
OGL	-2135	-72.6	-213.5	124	15.4	12.4	-580	-62.43	-58
SWG	2037	371.4	203.7	-793	-30.7	-79.3	307	17	30.7
WL	-81	-0,2	-8.1	593	185.9	59.3	-348	-38.16	-34.5
BL	18	10.71	1.8	216	116.1	21.6	417	103.73	41.7
FL	161	15.56	16.1	-137	-11.5	-13.7	137	12.94	13.7
WB	0	0	0	-3	-4.62	−0.3	67	108.06	6.7

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land.

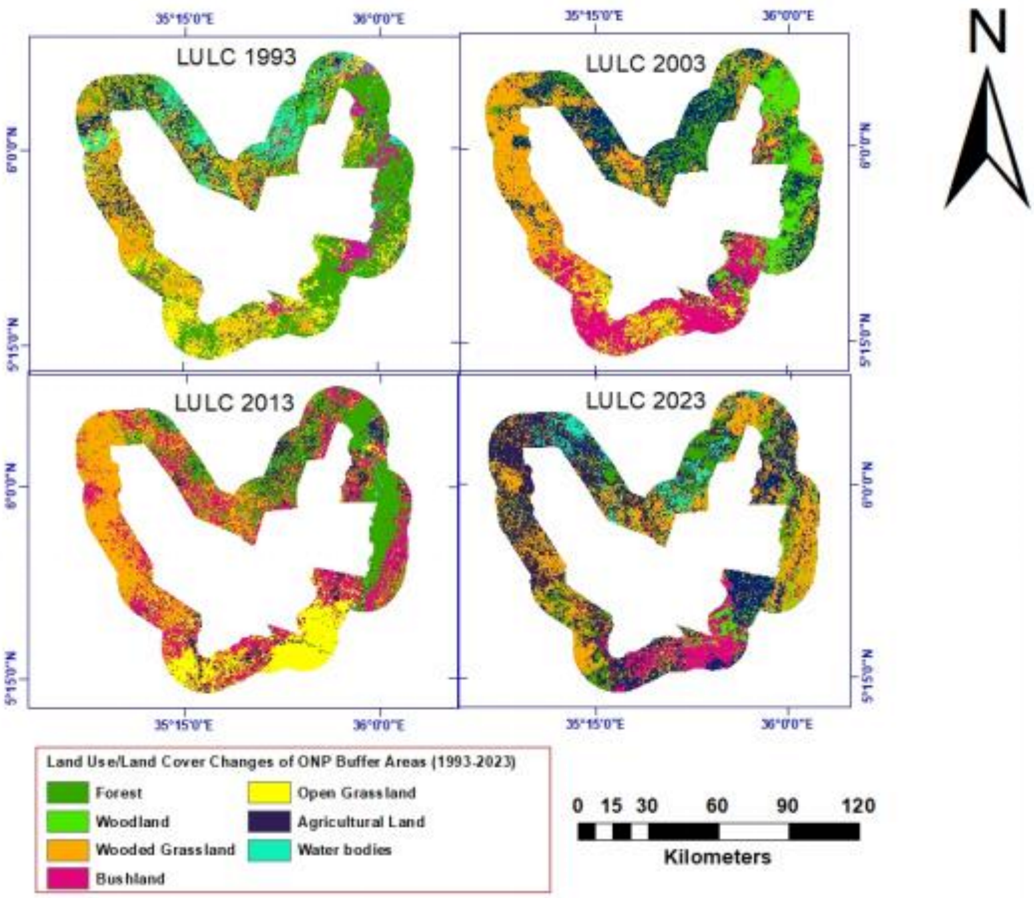


Figure 18. Comparative maps of LULC change in the buffer areas of ONP from 1993 to 2023.

Table 12. LULC type, area (in km²) and percent coverage (%) in the buffer areas of ONP.

LULC type/Year	1993	%	2003	%	2013	%	2023	%
OGL	990.2	13.7	435	6.0	402	5.6	390	5.4
SWG	1615.1	23.7	1825	25.2	995	13.8	1968	27.2
WL	94.5	4.0	504	7.0	1072	14.8	260	3.6
BL	520.2	8.6	733	10.1	1268	17.5	659	9.1
FL	2597.5	35.9	1846	25.5	949	13.1	689	9.5
AL	735.2	10.2	1708	23.6	2345	32.4	2823	39.1
WB	678.3	3.9	180	2.6	200	2.8	442	6.1
Total	7231	100	7231	100	7231	100	7231	100

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

Table 13. LULC changes and area proportion in three study periods in the buffer areas of ONP.

	(1993-2003)			(2003-2013)			(2013-2023)		
LULC type	Change (km^2)	Percent change	Change rate (km^2/ year)	Change (km^2)	Percent change	Change rate (km^2/ year)	Change (km^2)	Percent change	Change rate (km^2/year)
OGL	-555	-56.1	-5.6	-33	-7.6	0.8	-12	-3.0	-58
SWG	290	16.9	29	-1010	-50.4	-101	973	97.8	97.3
WL	208	70.3	20.8	568	112.7	56.8	-812	-75	-81.2
BL	113	18.2	11.3	535	73.0	53.5	-609	-48	-60.9
FL	-749	-28.9	-74.9	*-897*	-48.6	-89.7	-260	-27.4	-26.0
AL	973	132.4	97.3	*637*	37.3	63.7	478	20.4	47.8
Water	-100	-35.7	-10	20	11.1	2.0	242	121.0	24.2

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

4.4.3. LULC trends

Over the period 1993–2023, the ONP's forest lands stayed mostly unchanged at 76%. This was followed by savanna wooded grassland at 74.2%, woodland at 30.9%, bushland at 17%, open grassland at 9.5%, and water bodies at 6.3%. The water bodies saw the greatest conversion, with about 37% of the total area going to forest, 25.4% going to woodland, and the remaining portions going to savanna wooded grassland (16.3%), bushland (8.9%), and woodland (3.1%). savanna wooded grassland (50.2%), bushland (22.4%), forest (8.9%), woodland (8.3), and water bodies (0.7%) accounted for the majority of the open grassland's conversion. The majority of bushland habitats were transformed into open grassland (6.1%), savanna wooded grassland (34.7%), forest (29%), and woodland (10.2%). With 36.9% (24.4 km^2) more water bodies added to the forest, it altered relatively little. Bushland gained 48.6 km^2 (29%), woodland gained 51.9 km^2 (13%), Open grassland gained 260.2 km^2 (8.9%), and savanna wooded grassland 23.1 km^2 (4.2%). Nevertheless, only 279.7 km^2 (8.9%) of open grassland 's habitat remained unaltered; the rest was transformed to savanna wooded grassland 1475.5 km^2 (50.2), bushland 658.9 km^2, forest 260.2, woodland 243.4 km^2, and water bodies 21.1 km^2 (Table 14). There were comparatively more modifications made when converting open grassland to savanna wooded grassland.

However, compared to the other LULC categories, agricultural land in the surrounding buffer areas of ONP changed less over the study period (1993–2023), with 54.7% of agricultural land remaining unchanged. This was followed by water bodies with 27.2%, savanna wooded grassland with 26%, open grassland with 19.2%, forest land with 14.4%, bushland with 8.8%, and woodland with 1.8%. Consequently, the woodland habitats saw the highest conversion rate, with about 98.2% of the total area going to agricultural land (38.1%), waterbodies (22.1%), savanna wooded grassland (18.6%), open grassland (7.5%), forest land (7.7%), and bushland (4.2%) (Table 15).

Table 14. LULC change matrix of ONP between the years 1993 and 2023.

LULC Classes		Unit	2023 BL	Forest	OG	SWG	WB	WL
1993	BL	(km^2)	28.4	48.6	10.2	58.2	5.0	17.2
		%	17.0	29.0	6.1	34.7	3.0	10.2
	FL	(km^2)	62.4	786.2	12.5	72.7	7.8	93.3
		%	6.0	76.0	1.2	7.0	0.8	9.0
	OG	(km^2)	601.0	260.2	279.7	1475.5	79.0	243.4
		%	22.4	8.9	9.5	50.2	0.7	8.3
	SWG	(km^2)	24.8	23.1	22.7	407.9	1.9	69.5
		%	4.5	4.2	4.1	74.2	0.3	12.7
	WB	(km^2)	5.9	24.4	2.0	10.8	6.3	16.8
		%	8.9	36.9	3.1	16.3	9.4	25.4
	WL	(km^2)	37.8	51.9	22.5	160.2	3.7	123.4
		%	9.5	13.0	5.6	40.1	0.9	30.9

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

During the study period, a significant 91.2% of the bushland underwent conversion to various types of land cover, including agricultural land (51.9%), forest land (12.3%), savanna wooded grassland (12.2%), water bodies (6.4%), and woodland (2.7%). In terms of area, the majority of forest habitats (85.6%) were transformed into different land cover types, with approximately 34.1% becoming agricultural land, 28.4% turning into savanna wooded grassland, 9.9% converting to bushland, 7.1% changing to woodland, 4.7% shifting to water bodies, and 1.5% transitioning to open grassland. In the buffer areas of the ONP, there were relatively minor changes in agricultural land, which actually gained 836.8 km^2 (51.8%) from savanna wooded grassland, followed by forest land at 886.9 km^2 (34.1%), water bodies at 246.0 km^2 (36.2%), open grassland at 145.2 km^2 (14.7%), bushland at 269.7 km^2 (51.9%), and woodland at 36.4 km^2 (38.1%). The conversion of savanna wooded grassland and forest land to agricultural land experienced significant changes during the study period in the buffer areas of the ONP (Table 15).

Table 15. LLULC change matrix of ONP buffer area between the years 1993- 2023.

LULC Types		2023 Unit	AL	BL	FL	OG	WB	SWG	WL
1993	Al	km^2	402.0	4.6	33.8	11.1	15.5	265.3	2.9
		%	54.7	0.6	4.6	1.5	2.1	36.1	0.4
	BL	km^2	269.7	45.7	64.0	29.7	33.3	63.4	14.0
		%	51.9	8.8	12.3	5.7	6.4	12.2	2.7
	FL	km^2	886.9	256.8	373.6	38.3	121.5	737.1	183.2
		%	34.1	9.9	14.4	1.5	4.7	28.4	7.1
	OG	km^2	145.2	257.8	18.0	189.8	1.8	351.3	25.7
		%	14.7	26.1	1.8	19.2	0.2	35.5	2.6
	WB	km^2	246.0	5.0	116.6	10.7	184.9	113.2	2.8
		%	36.2	0.7	17.2	1.6	27.2	16.7	0.4
	SWG	km^2	836.8	85.4	76.1	103.0	63.8	419.1	29.9
		%	51.8	5.3	4.7	6.4	4.0	26.0	1.9
	WL	km^2	36.4	4.0	7.4	7.2	21.1	17.8	1.7
		%	38.1	4.2	7.7	7.5	22.1	18.6	1.8

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

4.4.4. Distribution of African elephant population

Research and studies conducted on African elephants have revealed a decline in their population in and around ONP over the past thirty years. Interviews and focus group discussions indicated that respondents were conscious of the impact of habitat changes on wildlife, particularly African elephants. More than 75% of the participants acknowledged that due to alterations in land cover and forest clearance, certain species of wild animals that were previously prevalent in the area disappeared, while others experienced a reduction in numbers. Approximately 98% of the respondents acknowleged about the presence of African elephants, with 64% being aware of their seasonal movements and distribution pattern across different land use and land cover types (LULCs), and around 47% being aware of the decline in the African elephant population. The changing land use conditions within ONP did not have a negative impact on the elephant population, as the extent of forest, shrubland, savannah wooded grassland, and water bodies required by the elephants somewhat increased during the study period. However, the trend of the elephant population in ONP showed a decline, indicating the presence of other factors contributing to this decrease. The analysis of LULC changes over the past 30 years in ONP suggests that the elephant population has been significantly affected, by land cover changes occurred mainly outside the current boundaries of the Park. The assessment of LULC changes in the ONP buffer areas (15 km outside the Park boundary) revealed a strong correlation between the elephant population and the season, with some areas also showing independence from seasonal variations as the elephant's home range extended beyond the current park boundary (Fig. 3; Tables 15 and 16).

The boundaries of ONP have been altered multiple times, with the most recent change in 2019 resulting in the exclusion of a significant portion of suitable habitat for African elephants due to the mega sugar development project of crucial forest habitats (optimum suitable habitats) along the Omo River were excluded from the ONP, impacting the elephants' habitats in both wet and dry seasons. Additionally, more than 50 km^2 of forest and woodland habitats on the other side of the Omo River were converted for sugar plantation command area, including some portion of the Tama wildlife Reserve (Mursi Community Conservation area). The development also blocked important elephant corridors, affecting local and seasonal migration and movement patterns. Besides, a number of big infrastructures (asphalt road and gravel roads; artificial canal crossing the park from north to sourth; housing and camping grounds, quari sites) had been devevelop without any environmental impact assessment which have affected the wildlife in the park. Lack of communication , collaboration and cooperation between the Sugar Project and the Park Authirority were another main reason for the more damage happened on the wildlife of the National Park.

4.4.5. Land cover changes and driving forces

Analysis of land cover changes within the ONP over the past three decades (1993-2023) indicates a significant transformation of open grassland into savanna wooded grassland, woodland, and bushland habitats, possibly influenced by environmental factors or driving forces such as wild fire and livestock grazing. Field observations and interviews with Park rangers and locals suggest that uncontrolled seasonal fires and livestock grazing may be the primary reasons for the loss of grassland and the rise of other land cover types. In contrast, significant changes in vegetation cover in the ONP buffer areas are expected to have substantial impacts on the African elephant population in the study area. The expansion of farms around the ONP from approximately 735 km^2 in 1993 to over 2823 km^2 in 2023 indicates that agricultural expansion has been a key driver of land cover changes in the region. African elephants require extensive natural habitats beyond the Park boundaries to sustain their population.

Based on feedback from local residents, it seems that a variety of factors are driving the expansion of agriculture at the expense of natural vegetation, which includes forests, woodlands, and bushlands crucial for wildlife, particularly African elephants. The primary forces behind this change in land cover are linked to the increasing demands of the human population and government policies in the region. In addition to the need for more agricultural land due to the growing population and livestock grazing, the implementation of the Kuraz Sugar Development project in 2010 by the government has significantly altered the natural land cover of the ONP and its surrounding buffer zones.

Conversely, in the buffer zones of the Park, the area covered by natural forests decreased from 2595 km^2 in 1993 to approximately 689 km^2 in 2023, while open grassland habitats reduced from 990 km^2 in 1993 to 390 km^2 in 2023. Consequently, the expansion of agriculture poses a significant threat to the conservation of African elephants habitats, as many of the converted natural forests surrounding the ONP serve as vital habitats and dry season refugia for the African elephant population in the study area. Furthermore, the livestock population has shown a notable increase over the past three decades in and around the ONP. The grazing patterns of livestock within the Park have expanded and now dominate the southeast and southwest regions of the Parkland, particularly among the Ngnagtom and Surma pastoral communities.

5. DISCUSSION

5.1. Dung density and elephant population estimation

Reliable and recent information on the population status and density of African elephants are not available because systematic studies have not been conducted for the last two decades in the ONP. In this study, the number of African elephants is estimated to be 306, fewer than those previously recorded in the ONP. Stephenson and Mizuno (1978) estimated the population to be 700-1000, a combined estimate from the observation of aerial survey for ONP and Mago National Park (MNP). As cited in Largen and Yalden (1987), EWCO reported 800 elephants from ONP. Hillman (1988) conducted an aerial survey and did not observe any elephant except droppings. Lamprey (1994) conducted an aerial survey that estimated 369 elephants for ONP. Chere Enawugaw (1996) performed a further systematic study based on the dung count survey targeting six elephant-suitable habitats and converted the dung density to an elephant density estimating 764 elephants for ONP. Since then, several opportunistic observations were recorded by the protected areas administration in 1992 resulting in 250 elephants; and in 2020 the outcome was 185 elephants. The current result shows an overall decline in the number of elephant populations in the Park. The elephant population decline from 1978 to 2010 could be attributed to poaching for ivory and seasonal livestock grazing pressure in the Park and poor law enforcement and Park management efforts by the government (Cheire Enawugaw, 1996; EWCA, 2015; Yirmed Demeke and Afework Bekele (2003)). Whereas elephant conservation efforts have become more difficult from the year 2010 (the beginning of the government mega sugar development project in and around the Park) as more than 100,000 hectares of natural elephant habitats have been converted to the sugarcane plantation and also most of the migration routes leading to the neighbouring protected areas (Mago National Park and Tama Wildlife Reserve) are closed (EWCA 2017). Both human population increase and agricultural land use pattern dynamics have contributed to agricultural expansion and loss of elephant habitats in the dry zone of Sri Lanka (Anuradha, 2019). Ecological studies in Babile Elephant Sanctuary (Yihew Biru and Afework Bekele; 2015; Sintayehu Dejene and Mebratu Kassaw, 2019; Taye Lema *et al.,* 2022) showed similar result that the increasing agricultural land and human settlements have become a threat to the ecological integrity of elephant habitats due to habitat fragmentation and resource competition. IUCN (2021) reported that poaching for ivory and the ongoing conversion of their habitats, primarily to agricultural and other land uses, are significant

threat for the African elephant population. On the other hand better management and proper conservation effort help to increase and maintain the population of African elephant as recent assessment in CCNP, Ethiopia disclosed (Adane Tsegaye *et al.*, 2022; 2023). Similarly, IUCN (2021) and CITES (2022) highlighted the impact of successful conservation efforts on Savanna elephant in the Kavango-Zambezi TFCA have shown increment in most countries of the Southern Africa in the last decades. The continued elephant population decline and restricted access to natural migratory route, EWCA's poor law enforcement and management combined with the growing land use for investment interests of government in the area could lead to the complete loss of ONP elephants in the near future. Currently, ONP elephants have become more seasonal and limited to be seen in the remaining Mui and Omo riverine forest areas and in the southern Sermele riverine forest areas. The northern Omo riverine forest and Sai Plain were suitable habitats for elephants have alm
ost been converted for sugarcane plantation for factory 3 (>46, 000 ha) and highly fragmented; the southern wooded and bushland and Omo riverine forest habitats and Gimwuha area have been excluded for the would-be sugarcane plantations (>60,000 ha). The current situation, the natural habitat conversion and human activities (poaching and grazing pressure) could also disrupt and impair elephant reproductive performance (Laws, 1969; Laws *et.al.*, 1975). Elephants have very low growth rates and long intervals between gestation period and births and hence very difficult and would take a longer time to recover the population decline (Kangwana, 1996a; 1996b; Lahdenperä *et al.*, 2016).

Even though the human-elephant conflict is getting worse over time, the conservation and protection of Chebera Churchura National Park is improving, so the elephant population is subject to seasonal increases (Kangwana, 1993; Girma Timer, 2005; Meseret Admasu 2006; Adane Tsegaye *et al.,* 2023). While the Babile Elephant Sanctuary's elephant population has experienced a greater decline as a result of organized poaching for ivory, local agricultural expansion, and the growing interest of illegal investors (Sintayehu Dejene 2016; EWCA, 2017; Taye and Girma Mengesha 2022). The ONP elephant population ultimate fate might lead to local extinction in the near future unless effective conservation measures are taken to ensure the elephant survival, as the situation in and around the ONP is getting worse.

The seasonal migration of elephants from the neighbouring Mago National Park through the natural Gimwuha corridor connecting the MNP and the ONP is threatened by the construction of the sugar cane command area and its Factory 5 (south of ONP). The other remaining and possibly functioning corridor between MNP and ONP is the Mui Riverine Forest connected through Omo Riverine Forest. The other important and cross-border seasonal out and back route for ONP is the Pagandilo National Park (PNP), in South Sudan. This continues to function as it is more distant and remote, with some seasonal livestock grazing impacts from pastoral local communities of both countries (EWCA, 2017).

Any seasonal fluctuations in the elephant population of ONP can therefore be explained by migration between MNP and ONP as well as PNP and ONP through their natural corridors. Elephants cover larger ranges and are reported to traverse protected areas between Chebera Churchura National Park on the north along Omo River (middle of the Omo River basin) in the south to ONP and then Pagandilo National Park (South Sudan) or upto the northern landscapes of Boma (South Sudan) and Gambela National Park (Hillman, 1993; Yirmed Demeke, 2010). At present, this situation is no longer observed in most parts of the range due to the changes in the land cover caused mainly by the expansion of agriculture and large-scale investments. The seasonal fluctuations of elephants are related to their habitat requirements (water, woody species, herbs, bushes, grasses, fruiting, barking and others) in the respective protected areas (ONP, MNP and PNP). Wanyama *et al*. (2010) stated that ecological monitoring activities would be very important to understand the seasonal requirements of elephants and to evaluate the effectiveness of conservation and management measures in the protected areas. Furthermore, the creation of a Trans-frontier Conservation Area (TFCA) would be crucial to guaranteeing the African elephant's successful conservation and protection in this area. The importance of cooperative and noncompetitive efforts in the conservation of shared migratory species is emphasized by WWF (2023). This approach is effective in preserving and growing the number of elephants in southern Africa, which includes Namibia, Zimbabwe, Botswana, Angola, and Zambia (Conservation Nambia, 2024). As a result, ONP, as it is located bordering South Sudan, has the chance to become a TFCA with at least two countries, South Sudan and Ethiopia, and receive regional and international conservation attention for the management of the migratory elephant population in particular as well as the common landscape in general.

The elephant population result in the two years (2021 and 2022) has shown significant fluctuations, with less than 43% of the 2022 elephant population were estimated in 2021. This is mainly related to the intense human activities that prevailed in and around ONP in 2021, while human activities decreased in the later years (2022 and 2023) and the visibility of elephants in the Park gradually increased. The differences in population size could also be due to the movement of elephants across national borders or between neighbouring conservation areas rather than census discrepancies or an increase in population through reproduction. This is consistent with various studies in Africa, including the national parks in Botswana and Zimbabwe (Junker 2008), where elephant numbers are subject to fluctuations due to migrations in their range. The density and growth rates of African elephant populations have fluctuated widely and in some cases the latter have exceeded the theoretical maximum annual growth rate (Hanks and McIntosh 1973; Junker 2008), largely due to the extensive movements of elephants within and between populations. The impact of poaching on populations can be severe, as noted by Burrli and Douglas-Hamilton (1987), and may have led to the low growth rates of some populations. In addition, these issues need further investigated, particularly through synchronized counts in the different protected areas (MNP, TWR, ONP) in the region and with the PNP of South Sudan on a seasonal basis

5.2. Habitat suitability and distribution of African elephants

Species distribution modelling (SDM) is used in many areas of ecology, climate change research, conservation and ecosystem management. It uses computer algorithms and environmental data to predict the spatial and temporal distribution of a species and the current and/or future suitability of its habitat and to set priorities for conservation (Cowley *et al.,* 2000; Guisan and Zimmermann, 2000; Stockwell and Peterson, 2002; Gibson *et al.,* 2004; Elith *et al.,* 2006; Pearson *et al.,* 2007; Evangelista *et al.,* 2008; Thomaes *et al.,* 2008; Baldwin, 2009; Elith *et al.,* 2009; Thorn *et al.,* 2009). SDM uses geostatistical analysis to establish relationships between species' geographic occurrence points and environmental variables to define the species' ecological niche (Elith *et al.,* 2006). According to Pearson *et al.* (2007), SDM is very important for determining the spatial and temporal distribution of suitable habitats based on the requirements of target species. Monitoring and evaluation of habitats and species distribution are essential for the appropriate management of wildlife populations and the formulation of conservation actions and strategies (Zhu *et al.,* 2020; Smeraldo *et al*., 2021; Su *et al.,* 2021). Effective wildlife management and the development of appropriate strategies and plans depend on reliable information about species distribution and the corresponding required environmental variables. Wildlife distribution patterns and habitat use depend on available abiotic and biotic components of ecosystems that influence ecological requirements in their natural geographic ranges. Several statistical modelling algorithms have been used to predict species distribution patterns (Carpenter *et al.,* 1993; Guisan and Zimmermann, 2000; Breiman, 2001; Antoine Guisan *et al.,* 2002; Phillips *et al.,* 2006; Booth *et al.,* 2014;). Maximum entropy (MAXENT) is a general method or software that has become a valuable tool for predicting or inferring species distribution (Phillips *et al.,* 2004; 2006). The MAXENT model combines presence-only data with selected environmental variables to create a probability model of species distribution. Several studies on SDMs have shown that MAXENT performs better than other similar models and is widely used to model ecological niches for many species (Elith *et al.,* 2006; Hernandez *et al.,* 2006; Evangelista *et al.,* 2008). In the present study, MAXENT algorithm was used to model the habitat suitability and distribution pattern of the African elephant (*L. africana*) in ONP ,. Understanding the drivers behind the distribution and habitat use of African elephants is fundamental to developing models of suitable habitats and describing their distribution patterns from presence-only data. This study aims to use the MAXENT model to predict the geographic extent of suitable habitats, potential corridors, and distribution of African elephants using predictor variables. The study seeks to understand how the variables affect African elephant dispersal and habitat use in the ONP landscape during both the wet and dry seasons.

As indicated by MAXENT mapping, northern, northeastern, east, southeast, and central portions of the Parkland had a higher probability of elephant presence and habitat suitability (Fig. 11 C). Due to the lack of permanent water sources and high elevation, and rugged nature of the landscape, the southwestern forested habitat and western upland slopes are relatively unsuitable habitats for elephants. The result is consistent with most studies in Africa including the recent studies by Akala, *et al.* (2023); Ntukey *et al.* (2022) where elephants showed seasonal variation in habitat utilizations in relation to water sources and vegetation.

It is fortunate that ONP has several streams and rivers that flow into the great Omo River. In the dry season, elephants prefer riverine areas because they provide water, shade, and good foraging opportunities. Elephants tend to gravitate toward water sources during the dry season, indicating that they prefer habitats near riverine forests, such as those along the Shorum, Kuma, Mui, Neruze, Kibish, and Omo Rivers, where they can access water, food, and cover. Boitani *et al.,* (2008); Dunkin *et al.,* (2013); Xu *et al.,* (2020) showed elephant movement patterns in relation to surface water indicating that they are water-dependent species. Elephants adjust their movement patterns based on seasonal shifts in rainfall (from wet to dry), as well as wet episodes that occur during the dry season (Garstang *et al.*, 2014).

The presence of water impacts the foraging habits of elephants, leading them to seek out water sources for foraging purposes during the dry seasons (de Beer and van Aarde, 2008; Pittiglio *et al*., 2011; Dunkin *et al.*, 2013). Elephants move in a way that minimizes their distance from the closest water source, drink more frequently, and are a species that depends on water, as evidenced by their movement patterns in relation to surface water (Owen-Smith, 1988; Ryan and Jordaan, 2005; Traill and Bigalke, 2006; Smit *et al.*, 2007; Dunkin *et al.*, 2013).

Because there are more resources available throughout the environment during the rainy season, most wildlife is typically more widely distributed (Jachmann, 1988; Bergstrom and Skarpe, 1999; Hema *et al.*, 2010; Fanuel Kebede *et al.*, 2012). Similarly, in ONP , the likelihood of seeing elephants during the rainy season seems to be higher in the vast herbaceous, wooded, and open grassland ecosystems that are farthest from the rivers. The Kuraz Sugar Development Project irrigation canal, which is one of the environmental variables taken into account in this study, crosses herbaceous woodland and open grassland habitats that stretch over 134 km from north to south in the Park (EWCA, 2017; ESC, 2019). Because there is abundant water during the rainy season, elephants are less selective (de Beer and van Aarde, 2008; Pittiglio *et al*., 2011; Dunkin *et al.*, 2013). Elephants travel more slowly during the dry season and more freely during the wet season, which causes their habitat to expand (Cushman *et al.*, 2005; Ashiagbor and Danquah, 2017).

There are clear ecotone ecosystems all around the Mui River and the wooded forests connections. The area is known as elephant corridors to Tama Wildlife Reserve and Mago National Park. These are the suitable habitats for elephants during both the wet and dry seasons (EWCA, 2015). Seasonal elephant movements are depicted on the MAXENT distribution map in the nearby Tama Wildlife Reserve and Mago National Park.

Significant corridors are altered, and the area's ongoing Kuraz Sugar Development Project hinders natural connectivity (EWCA, 2017). According to personal correspondence with the Chief Warden and Rangers, they have confirmed the existence of trans-boundary seasonal elephant movements in the south between ONP and the nearby Ilmi Triangle (No Man's

Land) and Badingelo and Boma National Parks in South Sudan as also demonstrated by the MAXENT map.

In Omo National Park, considerable habitat fragmentation and restriction of the species' seasonal movements have resulted in a significant reduction in viable elephant habitats, notwithstanding the lack of prior studies that bear comparison (Cherie Enawgaw, 1996; EWCA, 2017). Elephant habitats have been adversely affected by the new large-scale sugar development projects and sugar plantations located adjacent to the suitable elephant habitats, according to the results of the MAXENT model.

Elephants' favoured habitats in the recent past, throughout both the wet and dry seasons, were the northern woodland areas, the Shorum and Kuma Rivers, and the grasslands and forests of the Sai Plains. Later on, Sugarcane Farms were created out of these (EWCA, 2017). Furthermore, the Ethiopian Sugar Corporation project is currently preparing to convert an area of approximately 63 km^2 that was formerly a part of the Omo National Park (before 2010) to sugarcane fields in the southern portion of the Park (Cherie Enawgaw, 2013; EWCA, 2017). This latter area called Gimwuha area is a suitable habitat and a migration corridor to Tama Wildlife Reserve and Mago National Park, even though it is legally outside the Park. To protect this crucial environment for the benefit of local populations and elephants, continuous communication is required between the Ethiopian Sugar Corporation, the Ethiopian Wildlife Conservation Authority, and the Nagngatom local communities.

Elephant movement and dispersal are significantly influenced by their distance from water because of substantial water loss from respiration and evaporation (Western and Lindsay, 1984/; Stokke and Du Toit, 2002; Smit *et al.,* 2007). The land use land cover (open grassland and herbaceous woodland) contributed 34%, distance to water (10%), and distance to the canal (80%) during the rainy season. The Omo River was to be redirected for extensive irrigation projects in the region by the canal that was constructed from the north to the south of the National Park.

Even though the canal is still unfinished, water is already flowing through the dug section since the majority of the western perennial rivers and seasonal streams that formerly drained into the Omo River do so through the canal. Elephants in the model prefer to live in herbaceous woodland and open grassland vegetation, which is crossed by the majority of the irrigation canal during the wet season. The ecological effects of building a canal were not taken into account while designing the project, and more research is needed to identify any potential drawbacks and appropriate mitigation strategies. The other environmental variables that were incorporated into the model, which were rainfall in March during the wet season, mean-diurnal temperature range (bio 2), and isotermality (bio 3), had different effects on elephant suitable habatats depending on the season.

Ecological research has demonstrated that temperature and seasonal rainfall are two aspects of the climate that influence habitat suitability and have an impact on behavior, physiology, and species interactions (Ashiagbor and Danquah, 2017; Mole *et al*., 2016). Kinahan *et al.* (2007) claimed that, in addition to their needs for food and water, elephants' thermal physiological requirements may limit their usage of terrain. For savanna elephants, thermal stress is a significant issue that makes it difficult for them to dissipate heat in hot, dry conditions (Thaker *et al*., 2019). Elephants in the Park tend to stay near to water during the dry season, but during the rainy season they spread out and cover wide regions since there is an abundance of water. Although there are small variations in height, habitats that are suitable for elephants during both the wet and dry seasons are primarily found in lower elevation places.

Elephants tend to gather in the low-elevation areas (near water along river valleys) during the dry season and move some what uphill and spread into the herbaceous woodland and grassland areas during the wet season, indicating the influence of elevation on elephant movements and dispersal. The majority of suitable habitats in the study area are located in the lowland areas with limited slope; therefore, little can be inferred from the study of elephant data, even though we detected some input to the model that varied with the observed season in predictor variables like aspect and slope.

5.3. Feeding ecology

Elephants are megaherbivores of mixed feeders as browsers and grazers requiring a wide-ranging diet. Smith and Chafota (2012) pointed out that 230 plant species were consumed by elephants with leaves, twigs, bark and fruit in tropical forests. Guy (1976) and De Boer *et al*. (2000) pointed out that elephants feed on up to 120 plant species. In ONP, elephants were observed to forage on 91 species belonging to 34 families and 66 genera. This is higher than the results in Babile Elephant Sanctuary, in eastern, Ethiopia, and less than in Chebera Churchura National Park, in southwestern, Ethiopia, and, where elephants were observed to utilize 73 species from 34 families and 109 species from 41 families, respectively (Yihew Biru and Afework Bekele, 2012; Adane Tsegaye *et al.,* 2022).

The present results confirmed that elephants, although considered less selective and bulk feeders, preferred some plant species over others in both the wet and dry seasons. There is a difference in feeding preference between browsing (leaves), and grazing (grasses) of the main plants observed to be consumed. In general, elephants seem to forage more leaves than grasses during the dry season which is consistent with the results of previous studies (Guy 1976; Stephen, 2002; Mwambola *et al*. 2014). An elephant selects a wide range of plant species and generally forages the species in amounts proportional to their abundance in the woodlands. However, some specific species are positively selected or avoided (Guy, 1976). Yihew Biru and Afework Bekele (2012), Mwambola *et al*. (2014), and Adane Tsegaye et al., (2023) indicated that the composition of the elephant diet varies according to season and location.

Overall, elephants of ONP spent more time browsing in the prospecting wet and dry seasons than grazing, although the percentage consumption of browse species is reduced during the wet season. During the wet season, there is a marked change in feeding preference, with grazing and herbaceous species being more important to the elephants vis a vis the dry season. This situation for grass over browse preference is probably related to the nutrient content of the newly grown grass and herbaceous plants (food) and with the palatability of the plant parts. Grasses or grazing are usually preferred in both seasons, but it decreased with a parallel increase in browsing as the dry season progressed, consistent with Adane Tsegaye *et al.,* (2023) in Chebera Churchura National Park where an increase in rainfall correlated with a decrease in browsing. In some protected areas, elephant diets rely on browsing of woody species (Yihew Biru and Afework Bekele, 2012) and in some other protected areas browse is more important than graze during the wet and dry seasons (De Boer *et al*., 2000). In the present study, browse accounted for most of the diet of elephants during the wet and dry seasons and a similar result was reported for elephants in Chebera Churchura National Park, western Ethiopia (Adane Tesgaye *et al.,* 2023). Meserete Admasu, (2006) and Yihew Biru and Afework Bekele (2012) showed that nearly all of the plant species consumed by elephants during the dry season were also consumed during the wet season. Elephants consumed higher diversity of plant species during the wet season which decreased towards the dry season (Apendex A; Table 1). Adane Tesegaye *et al*., (2023) pointed out that seasonality of some species may have an influence for variations in the composition of species consumed during both seasons. Higher diversity of plant species were consumed by elephants during the wet season than the dry season (Appendix A: Table 1). The non-selective behaviour of elephants could have impacts on the ecology and changes in species richness and diversity. Generally, in the present study, elephants showed strong preference for browsing followed by debarking and fruiting apart from damaging on woody plant species as a commonly observed means of foraging in both the wet and dry seasons. Besides, elephants have shown more preference on foraging herbaceous and grass species (grazing) during the wet season.

The result of the present study is in agreement with the findings of a larger number of elephant-feeding studies (Yihew Biru and Afework Bekele, 2015), in which elephants show some degree of preference for some plant species in both wet and dry seasons. The feeding reference tendencies are mainly related with nutritional contents and palatability of the plant species consumed.

5.4. LULC changes and impacts on African elephants

The present study, on LULC clasfication and time series analysis highlight the impact and consequences of the LULC changes throughout the past three decades on wildlife conservation, mainly on the African elephant population in ONP and the surrounding areas. LULC classification is a crucial method for comprehending the spatial distribution of land features and evaluating their relationship between environment and human activity (Singh *et al*., 2021; Darem *et al*., 2023).

It is essential to comprehend and assess LULC changes and related driving forces in ONP in order to advance prospective conservation solutions. LULC changes reflect the dynamics of anthropogenic activity, which can be triggered by various factors affecting nature, with significant consequences (Houghton *et al.,* 2012; NRC, 2014; Kissinger, *et al.,* 2017; WWF, 2022). Anthropogenic activities which are directly correlated with the consumption needs of the growing population, are an important issue in the context of changes in the natural environment or LULC changes that have significant implications for biodiversity and climate change (Turner, *et al*., 1993; Meyer and Turner, 1994; Carr, 2004; Rogan and Chen, 2004; Phalan *et al.,* 2011; Pielker *et al.,* 2011; Houghton *et al.,* 2012; NRC., 2014; Pandian, 2014; Cheruto *et al.,* 2016; Patel, *et al.,* 2019; Wu, *et al*., 2022;). Anthropogenic pressure has negatively impacted wildlife habitats, particularly in corridors between protected areas (Ntukey *et al.*, 2022). LULC alteration was thought to be a sign of the loss of plant and wildlife species in Ethiopia's northern highlands (Birhan Asmame and Asefa Abegaz, 2018). The LULC alterations in the various LULC classes were identified in this study between 1993 and 2023. These changes showed that, while most of the land cover (forest land, open grassland, bushland, woodland) that was suitable for African elephants was converted to agricultural land outside of the ONP (buffer areas), considerable sections of open grassland were transformed to savanna wooded grassland, bushland and woodland within ONP. The outcome validates the possibility that modifications in land use conditions that took place beyond the present Park limits, as opposed to inside them, had an impact on the decline in African elephant population of the study area. This is in line with Kideghesho *et al*. (2013) conclusion that communities close to protected areas have long faced a variety of novel issues and difficulties that complicate their administration and put resources at risk for over exploitation and extinction. As a result, we discovered that, in comparison to the other landcover types, agricultural lands have grown at the expense of natural forests in the surrounding buffer areas of ONP. The primary cause of the annual cleaning of forests is the growth of agricultural land (John *et al*., 2013). The capacity of forests to deliver vital services is diminished by its deterioration and loss, endangering the existence of several species (Gobush and Wittemyer, 2021). Wide-ranging effects on species survival and protected areas ecological function can result from progressive deforestation and habitat loss (Newmark, 1996, 2008). Since their founding, protected areas have had challenges in their ability to function due to land use changes exacerbated by the increasing human population and demands (Redpath *et al*., 2015; Patel, *et al.,* 2019; Rechciński *et al*., 2019). This is also true globally, land degradation, wildlife habitat fragmentation and species decline, as well as the conversion of natural forests, woodlands, bushlands and water bodies to agricultural land or settlements due to LULC changes pose a major threat to biodiversity, as they directly affect the distribution and movement of wildlife species and drastically reduce ecosystem services (William, *et al.,* 1994; Powers and Jetz, 2019; Liu *et al.,* 2018; Liu *et al.,* 2020). In addition, natural connectivity (wildlife corridors) and wildlife movements between protected areas are increasingly threatened, mainly because anthropogenic activities affect the maintenance of ecosystem services and biodiversity conservation (Popp *et al.,* 2014; Trincsi *et al.,* 2014; Winkler *et al.,* 2021).

According to Himanshu and Lanjouw (2016), settlements next to protected forests are the most vulnerable since there is a convergence of wildlife and human demands there. Planning land use next to protected areas preserves low human density and lowers conflicts between local people and wildlife, in Tanzania protected areas (Newmark *et al., 1993;* Lewis, 1996). The primary competition for the usage of scarce natural resources is between African elephants and wildlife conservation landuse requirements(Kremen and Merenlender, 2018). The ecological integrity of elephant habitats in and around the ONP is seriously threatened by agricultural land expansion linked to the government-led mega sugar development project (mechanized agriculture) in the region, which has resulted in significant pressure and competition for resources, as well as access restriction of natural migratory routes and habitat fragmentation.

Agricultural expansions put African elephant populations in danger because they restrict their freedom of movement and block wildlife reserve corridors (Sintayehu Dejene, 2016; Sintayehu Dejene and Mebratu Kassaw, 2019; Breuer and Ngama, 2020). Forest reserves are converted to agricultural land, which reduces African elephant's natural habitats and corridors (Hoare, 1999; Kusena, 2009). Continual agricultural expansion at the expense of forests and woodland is widespread in most parts of Ethiopia (Temesgen Gashaw *et al*., 2014; Kiros Deribew and Desalegn Wana, 2019).

In order to support biodivesirty and the survival of several species, wildlife corridors are crucial ecological components (Kideghesho *et al*., 2013). However, in the current study area, most elephant corridors are critically threatened because of the conversation of elephant suitable habitats to sugarcane plantation coupled with lack of specific regulations and policy to protect the corridors against such unsustainable intervention. Humans should be removed from the buffer zone of the protected areas and strict laws should be implemented to safeguard wild animals and maintain their natural habitats (Kideghesho *et al*., 2013).

Elephants were mostly distributed in and around ONP and locally migrated to the Mago National Park, passing via Gimwuha, the southern Tama Wildlife Reserve (the current Mursi

Community Conservancy), and the middle Mui Riverine Forest (Cherie Enawgaw, 1996; EWCA, 2017). Currently, elephants continue to migrate seasonally to Padingilo National Park in South Sudan and vice versa. Elephants are dispersed throughout the ONP, living along the Mui, Sherma, and Kuma rivers as well as the Omo and Kibish Rivers to the south.

The earth's biodiversity has suffered due to the accelerated growth of agriculture and human habitation, which has also simplified natural ecosystems (Mariye *et al.,* 2022). Apart from the conservation areas (Tama Wildlife Reserve and Mago National Park), the riverine forests that were part of the ONP before 2010 (i.e. before the onset of mega sugar development in the area) were the preferred habitats for African elephants in the study area including the Omo, Kuma and Sherma Rivers (Cherie Enawgaw, 1996b; Cherie Enawgaw *et al*., 2011; Cherie Enawgaw 2013; EWCA, 2015, 2017). The ONP's migratory corridors and African elephants suitable habitats have been negatively impacted by the dramatic reduction in forest and woodland habitats brought about by agricultural expansion. This demonstrates that agricultural land expansion, particularly for individual farms and sugarcane plantations, pose a threat to suitable habitats for elephants (forest and woodlands). If mitigation measures are not implemented beforehand in the area, this could become a potential source of conflict between sugar projects and elephants in the near future. A large portion of crop raiding and most economic losses and human fatalities are caused by African elephants. (Parajuli, 2020; Adane Tsegaye *et al.,* 2023). Conflict between humans and elephants costs local people a great deal when they share environments with elephants (Sampson *et al*., 2019; Adane Tsegaye *et al.,* 2023). In order to support the conservation of the wildlife in ways that are also consistent with the livelihoods of the local population, elephant damage is therefore a conservation and livelihood issue that requires careful management (Tweheyo *et al.,*2013).

The ONP's condition, that of its buffer area around it, and the wildlife that resides there have all been deteriorating over time. This is especially true of the natural flora and water sources that the elephants depend on for cover and connectivity. In order to guarantee that wildlife has access to enough food and water supplies, habitat management is essential (Bhandari *et al*., 2020). Large-scale agricultural operations (sugarcane plantation) are gradually replacing the natural forests in the wildlife corridors (Mui River, Gimwuha), which are made up of a fragile ecosystem of woodland and riverine forest association. This area needs special protection to ensure the coexistence of humans and wildlife.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The current study provides up-to-date information regarding the ecology of the African elephants in ONP including population status, habitat suitability and distribution and feeding ecology as well as impcats of land use land cover change in and around the Park. The population status of the African elephant has shown decline over the last decades associated with poaching for ivory and habitat destruction and changes prevailed by the ongoing land use land cover changes in the area. The algorithm provides notable information on the habitat suitability and distribution of elephants given the current environmental constraints in the Omo National Park. The results of habitat suitability and distribution models indicate the importance of distance to rivers, canals and LULC during the wet and dry seasons. The results clearly show the reduction in elephant suitable habitats and obstruction of the natural corridors affecting the elephant movement between conservation areas in the region. The ONP elephants are not able to use most of the available home ranges, resulting in a visible population size decline over the last decades. The study on the feeding ecology of the African elephants revealed that, the riverine forest associations and woodland habitat are most utilized during the dry season. Thus, depending upon seasons and security situation, palatable plant species and water sources were visited by the African elephants.

This study also reveals that ONP and its surrounding buffer areas is facing a strong LULC changes which is very likely intensified by the mega sugar development project and climate change. The result has shown that elephant habitats and corridors in ONP and the surrounding buffer areas have been severely degraded over the last three decades. The important elephant habitats such as the northeastern (Sai plain and Omo riverine association) and southeastern (south of Elelbay plain and Gimwuha corridor) as well as the northeastern forest (between Kuma and Sherma Rivers which both drain to Omo River in the Park) were part of the parkland taken for a sugar development project in 2010. In addition, the main intact forest elephant habitats on the other sides of the Omo River (part of Tama Community Conservation Area) and the wildlife corridor linking the ONP to the Mago National Park and Tama Community Conservation Area were heavily deforested to establish sugarcane plantations.

Our findings highlight the urgent need of ensuring holistic conservation approaches, collaboration and cooperation between stakeholders to ensure the survival of the elephants in the ONP. Protected areas play critical roles in the conservation of wildlife and social development. They support a variety of species in natural ecosystems that have economic, social and ecological importance. However, there are numerous conservation challenges facing wildlife in protected areas. This paper has uncovered challenges related with LULC Changes in ONP and attempts to develop effective measures to address the problems.

6.2. Recommendations

Below, we specify some possible measures to address these challenges:

- The results highlight the urgent need to improve the protection of the habitats and natural corridors of the umbrella species through increased collaboration and cooperation between stakeholders, including the Sugar Development Project and the local community and EWCA to ensure the survival of elephants in the ONP and surrounding buffer areas.
- Human-wildlife conflicts are expected challenges and should be an important issue to get strong attention from both conservationists and the Mega Sugar Development Project in the area. Collaboration and cooperation should be practiced.Furthermore, the local communities should be actively involved in the decision-making and planning of conservation to reduce conflict.
- All development policies, projects or activities should be subjected to an Environmental and Social Management Framework (ESMF) (screening) to identify and avoid their potential risks and impacts. The result of the screening of the project and sub-project (ESMF) would be important to obtain recommendations and decisions for an Environmental Social Impact Assessment (ESIA) or Environmental Management Plan (EMP) depending on the risks and impacts of the project/sub-project. Practical efforts should be made to rehabilitate the degraded or damaged lands preceding the development activities (road and canal constructions) in and around the Park.
- A variety of mitigation and adaptation measures should be further reinforced to address climate change impacts on the Park, including reducing anthropogenic activities such as deforestation, domestic animal grazing, agricultural expansion, changing energy technologies (e.g. fuel-efficient stoves and biogas) and ensuring integrated fire management and improving local community livelihood.
- The ONP is underfunded and unable to properly manage and conduct the required management and law enforcement operations throughout the Parkland. For example,

all of the Mega Sugar Project activities (road construction, canal construction and others) were conducted without the knowledge of the Park Authority and were usually seen after they had begun. EWCA needs to plan to diversify sources of conservation funding including the introduction of shared governance or co-management arrangements for the ONP management to ensure sustainable conservation finance which is a serious bottleneck.

- The ONP law enforcement operation should be uptodated, Law Enforemcnet Standard Operation Procedure (LE-SOP) required and implemented, this operation should be supported by technologies (GPS, GIS, SMART or earth rangers)

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APPENDICES

Appendix A. Identified plant species consumed by elephants in ONP

Table 1 Wet and dry seasons total number and percentage of each of the plant species consumed by the focal group (herd) elephant (C=Climber L=leaves; F=Fruit; T=twigs; B=Bark; WP=whole part; S= seeds; B=Browse, D=Debarking, F=Fruiting)

			Parts of plant eaten/Dry season		***Parts of plant eaten/wet season***			***Season***		PlantHabit
Family	*Species Sientific name*	*Genus no*	***Total***	***Total % of feeding diet***	***Total***	***Total % of feeding diet***	***Feeding parts/ types***	*Dry*	*wet*	
ACANTHACEAE	*Blepharis linariifdlus Pers.*	*1*	*0*	*0.00*	*39*	*0.34*	*H/WP*	*0.05*	*93.0*	Herb
AMARANTHACEAE	*Achyranthes aspera*	*2*	*0*	*0.00*	*19*	*0.17*	*H/WP*			Herb
	Amaranthus Spinosa	*3*	*0*	*0.00*	*27*	*0.24*	*H/WP*			Herb
	Celosia argentea L.	4	*0*	*0.00*	*16*	*0.14*	*H/WP*			Herb
	Digera muricata (L.) Mart.	5	*0*	*0.00*	*9*	*0.08*	*H/WP*			**Herb**
	Suaeda monoica J.F. Gmel.	6	*143*	*1.26*	*121*	*1.05*	*H/WP*	1.26	3.07	Shrub/ ST
ANACARDIACEAE	Rhus natalensls Bernh. Ex	7	*81*	*0.71*	*43*	*0.37*	*LFT/BD*	*0.73*	*0.38*	Shrub
APOCYNACEAE	*Carissa spinarum L.*	*8*	*127*	*1.12*	*82*	*0.71*	*LFT/BD*	*1.70*	*0.94*	Shrub
	Saba comorensis	*9*	*66*	*0.58*	*26*	*0.23*	*F/F*			**C/Shrub**
ASCLEPIDACEAE	*Leptadenia hastata (Pers.)*	*10*	*84*	*0.74*	*12*	*0.10*	*L/B*	*0.76*	*0.11*	**C/Shrub**
ASTERACEAE	*Vernonia amygdalina Del.*	*11*	*134*	*1.18*	*66*	*0.57*	*L/B*	*1.21*	*0.59*	Shrub
BALANITACEAE:	*Balanites agyptica(L) Del.*	*12*	*201*	*1.77*	*164*	*1.43*	*LF/BDF*	*1.81*	*1.46*	Tree
BORAGINACEAE	*Cordia africana Lam.*	*13*	*402*	*3.54*	*352*	*3.07*	*LF/BDF*	*8.45*	*6.04*	Tree
	Cordia crenata Del.		*83*	*0.73*	*31*	*0.27*	*F/F*			Shrub
	Cordia sinensis Lam. (C.		*103*	*0.91*	*67*	*0.58*	*LF/BDF*			Shrub/ ST
	Stereospermum kunthianum	*14*	*371*	*3.27*	*243*	*2.12*	*LBF/BDF*			Tree
	Urlica simensis Horchst	*15*	*0*	*0.00*	*41*	*0.36*	*H/B*	*0.21*	*0.37*	Herb
BURSERACEAE	Commiphora africana	16	*101*	*0.89*	*64*	*0.56*	*LB/BD*	*0.91*	*0.57*	Shrub/ ST
CANNABACEAE	*Celtis africana Burm. F*	*17*	*108*	*0.95*	*62*	*0.54*	*LB/BD*	*0.97*	*0.55*	Tree
CAPPARACEAE	Boscia angustHoiia A. Rich.	18	*121*	*1.07*	*97*	*0.85*	*LT/BDF*	*3.95*	*3.04*	Shrub/ ST
	Boscia coriacea Pax		*98*	*0.86*	*74*	*0.64*	*F/F*			Shrub/ ST

	Cadaba arinosa	*19*	*112*	*0.99*	*84*	*0.73*	*L/B*			Shrub
	Cadaba farlnosa Forsk.		*118*	*1.04*	*94*	*0.82*	*L/B*			Shrub/ ST
	Maytenus undata	*20*	*69*	*0.61*	*27*	*0.24*	*L/BD*	*1.39*	*0.59*	Shrub/ ST
CELASTRACEAE	*Maytenus senegalensis* (Lam		*89*	*0.78*	*41*	*0.36*	*LT/BD*			Shrub/ ST
	Combretum adenogonium	21	*110*	*0.97*	*95*	*0.83*	*L/B*	*5.64*	*3.52*	Shrub/ ST
	Combretum molle		*329*	*2.90*	*187*	*1.63*	*LT/BD*			Shrub/ ST
COMBRETACEAE	*Terminalia brownie*	*22*	*201*	*1.77*	*122*	*1.06*	*LF/BDF*			Tree
COMMELINACEAE	*Commelina Africana*	*23*	*0*	*0.00*	*243*	*2.12*	*H/WP*	*0.00*	*2.94*	Herb
	Commelin aimberbis		*0*	*0.00*	*94*	*0.82*	*H/WP*			Herb
EBENACEAE	*Diospyros scabra (Chiov.) C*	*24*	*158*	*1.39*	*138*	*1.20*	*F/F*	*1.42*	*1.23*	Shrub/ ST
	Acalypha fruticosa Forssk	*25*	*188*	*1.66*	*144*	*1.25*	*FL/B*			Shrub
	Acalypha ornata A. Rich.		*0*	*0.00*	*94*	*0.82*	*wp/B*			**C/Shrub**
	Euphorbia Polycantha Boiss	*26*	*66*	*0.58*	*44*	*0.38*	*L/B*			Shrub
	Flueggea virosa (Willd.) Voi	*27*	*298*	*2.62*	*268*	*2.33*	*FL/BDF*			Shrub/ ST
	Phyllanthus Sepialis Muell	*28*	*144*	*1.27*	*102*	*0.89*	*TL/B*			Shrub
EUPHORBIACEAE	*Sapium ellipticum*	*29*	*82*	*0.72*	*35*	*0.30*	*L/B*	*6.85*	*5.98*	Shrub/ ST
	Acacia brevlsplca Hann	*30*	*284*	*2.50*	*242*	*2.11*	*FPS/BDF*			Shrub/ ST
	Acacia horrida(L.) Willd.		*214*	*1.88*	*187*	*1.63*	*LT/BD*			Tree
	Acacia melifera Benth.		*111*	*0.98*	*134*	*1.17*	*LTP/BDF*			Tree
	Acacia nilotica (L.) Wild.		*296*	*2.61*	*253*	*2.20*	*LB/BD*			Tree
	Acacia pentagona		*65*	*0.57*	*32*	*0.28*	*L/B*			**C/Shrub**
	Acacia sengal (L.) Wild.		*94*	*0.83*	*75*	*0.65*	*LP/BF*			**Shrub**
	Acacia seyal De!.		*201*	*1.77*	*174*	*1.52*	*LB/BD*	*25.00*	*20.07*	Tree
	Acacia sieberana		*262*	*2.31*	*243*	*2.12*	*LB/BD*			Tree
	Acacia tortilis (Forsk.) Hay.		*209*	*1.84*	*174*	*1.52*	*LFB/BD*			Tree
	Dalbergia lactea Vatke	*31*	*172*	*1.51*	*143*	*1.25*	*LFTB/BDF*			Shrub/ ST
	Dichrostachhys cineres (L.)	*32*	*242*	*2.13*	*148*	*1.29*	*PSLT/BDF*			**Tree**
	Erythrina abyssinica	*33*	*48*	*0.42*	*13*	*0.11*	*L/BD*			Tree
	Lonchocarpus laxiflorus	*34*	*164*	*1.44*	*126*	*1.10*	*LFP/BDF*			Tree
	Ormocarpum trichocar Pum	*35*	*89*	*0.78*	*28*	*0.24*	*L/B*			Shrub
FABACEAE	*Piliostigma thonningii*	*36*	*220*	*1.94*	*180*	*1.57*	*LFSB/BDF*			Tree

	Pterolobium stellatum	37	0	0.00	27	0.24	wp/B			**C/Shrub**
	Tamarindus indica L	38	134	1.18	87	0.76	LB/BDF			Tree
	Tylosema assoglensis (Sc	39	33	0.29	21	0.18	SLTu/B			**C/Shrub**
	Tylosema fassoglensis		0	0.00	17	0.15	WP/B			**C/Shrub**
	Leonotis ocymifolia	40	0	0.00	44	0.38	WP/B			Shrub
LAMIACEAE	Premna schimperi	41	0	0.00	27	0.24	WP/B	0.95	1.82	Shrub
	Grewia mollis	42	108	0.95	67	0.58	LT/BD			Shrub/ST
	Trichilin emetica (Forsk.) C	43	149	1.31	71	0.62	LFSB/BDF			Tree
	Ficus sur Forssk	44	332	2.92	332	2.89	LFBT/BDF	9.75	8.76	Tree
	Ficus sycomorus L.		297	2.62	278	2.42	LF/BDF			Shrub/ST
MELIACEAE	Ficus vasta Forssk		329	2.90	324	2.82	LF/BDF			Tree
PRIMULACEAE	Embellia Shimperi 1	45	184	0.92	163	1.42	LF/B	0.94	1.45	**C/Shrub**
MYRTACEAE	Syzygium guineense	46	104	0.92	94	0.82	LFB/BD	0.94	0.84	Tree
OLIACEAE	Ximenia cafjia sand.	47	127	1.12	101	0.88	FLB/BD	1.14	0.9	Shrub/ST
PHYLLANTHACEAE	Margaritaria discoidea	48	74	0.65	56	0.49	LFB	0.67	0.5	Shrub/ST
	Grass sp.	49	178	1.57	695	6.05	G			Grassess
	Panicum coloratum L.	50	46	0.41	294	2.56	G			Grassess
	Panicum maximum Jacq.		48	0.42	242	2.11	G	3.58	18.29	Grassess
	Phragmites australis (Cav.)	51	47	0.41	265	2.31	G			Grassess
	Setaria megaphyl/a (Steud.)	52	0	0.00	304	2.65	G			Grassess
POACEAE	Typha capensis (SP.)	53	88	0.78	299	2.60	G			Grassess
RHAMNACEAE	Ziziphus pubescens	54	284	2.50	189	1.65	LF/BDF	2.56	1.69	Tree
RUBIACEAE	Gardenia lutea Fres.	55	49	0.43	30	0.26	FL/BDF	0.44	0.27	Shrub
SALVADORACEAE	Salvadora persica L.	56	119	1.05	84	0.73	LT/BDF	1.07	0.75	Tree
	Allophyllus rubifolius L.	57	278	2.45	184	1.60	FL/BF			Shrub/ST
	Deinbollia kilimandscharica	58	322	2.84	296	2.58	LF/BF			Shrub/ST
	Haplocoelum loliolosum	59	92	0.81	78	0.68	F/F	7.06	6.11	Shrub/ST
	Maytenus senegalensls.	60	99	0.87	94	0.82	LT/B			Shrub/ST
SAPINDACEAE	Paullinia pinnata L.	61	11	0.10	49	0.43	F/B			**C/Shrub**
SOLANCIACE	Solanum incanum L.	62	21	0.18	60	0.52	LS	0.19	0.54	Shrub

STERCULIACEAE	*Sterculia africana* (Lour.)	*63*	*98*	*0.86*	*86*	*0.75*	*LPS/B*	*0.88*	*0.77*	**Tree**
	Grewia bicolor Juss.	64	*184*	*1.62*	*126*	*1.10*	*LF/B*			Shrub/ ST
	Grewia flavescens Juss.		*188*	*1.66*	*265*	*2.31*	*LF/B*			Shrub/ ST
	Grewia lenax (Forssk.) Fiori		*82*	*0.72*	*65*	*0.57*	*LF/B*	*5.22*	*5.04*	**Shrub**
	Grewa *tenax* (forsk.)Fieri.		*65*	*0.57*	*57*	*0.50*	*LF/B*			**Shrub**
TILIACEAE	Grewia *villosa* Willd.		*74*	*0.65*	*65*	*0.57*	*LF/B*			**Shrub**
VERBENACEAE	*Lantana trifolia L.*	*65*	*0*	*0.00*	*69*	*0.60*	*L/B*	*0.11*	*0.62*	**Shrub**
	Cissus Petiolata Hook. F	*66*	*104*	*0.92*	*91*	*0.79*	*L/B*	*2.22*	*2.22*	**C/Shrub**
VITACEAE	*Cissus rotundifolia* (Forssk)		*148*	*1.30*	*164*	*1.43*	*LF/BF*			**C/Shrub**
	Total	*66*	*11354*	*100.00*	*11479*	*100.00*				

Tabel 2. The most consumed plant species during both wet and dry seasons

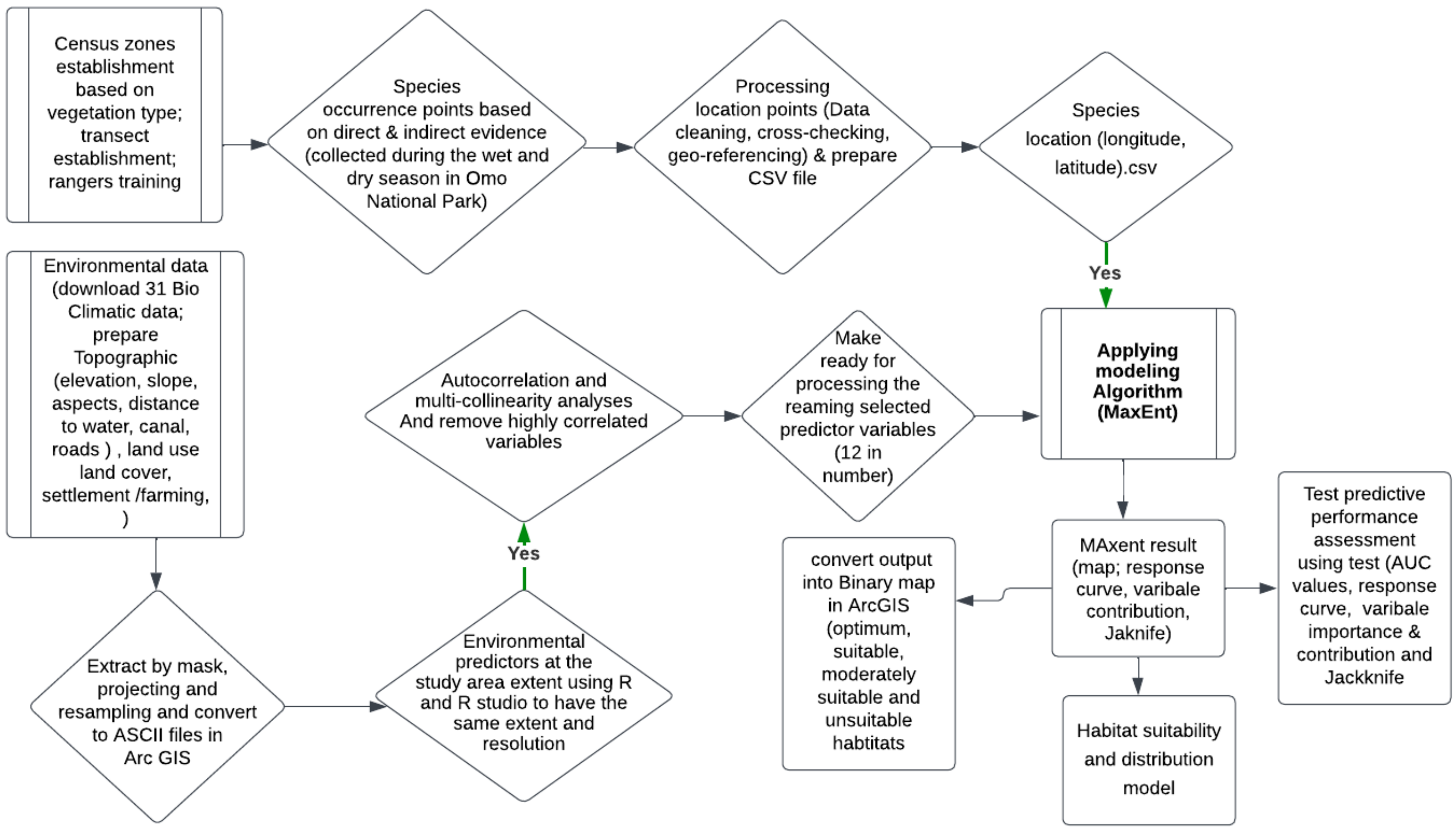
Species sintific name	Dry	wet	mode fo feeding
Cordia africana Lam.	*402*	*352*	*LF/BDF*
Stereospermum kunthianum Cham.	*371*	*243*	*LBF/BDF*
Ficus sur Forssk	*332*	*332*	*LFBT/BDF*
Ficus vasta Forssk	*329*	*324*	*LF/BDF*
Combretum molle	*329*	*187*	*LT/BD*
Deinbollia kilimandscharica Taub	*322*	*296*	*LF/BF*
Flueggea virosa (Willd.) Voigt.	*298*	*268*	*FL/BDF*
Acacia nilotica (L.) Wild.	*296*	*253*	*LB/BD*
Acacia brevlsplca Hann	*284*	*242*	*FPS/BDF*
Acacia sieberana	*262*	*243*	*LB/BD*
Dichrostachhys cineres (L.) Wight &Am.	*242*	*148*	*PSLT/BDF*
Acacia tortilis (Forsk.) Hay.	*209*	*174*	*LFB/BD*

Table 3 Herbacous and climber whole part eaten plant species in ONP

Scientific name	Dry season	Wet season	Mode of feeding
Blepharis linariifdlus Pers.	*0*	*39*	*H/WP*
Achyranthes aspera	*0*	*19*	*H/WP*
Amaranthus Spinosa	*0*	*27*	*H/WP*
Celosia argentea L.	*0*	*16*	*H/WP*
Digera muricata (L.) Mart.	*0*	*9*	*H/WP*
Suaeda monoica J.F. Gmel.	*143*	*121*	*H/WP*
Commelina Africana	*0*	*243*	*H/WP*
Commelin aimberbis	*0*	*94*	*H/WP*

Tylosema fassoglensis	*0*	*17*	*WP/B*
Leonotis ocymifolia	*0*	*44*	*WP/B*
Premna schimperi	*0*	*27*	*WP/B*
Saba comorensis	*66*	*26*	*F/F*
Leptadenia hastata (Pers.) Decne.	*84*	*12*	*L/B*
Tylosema assoglensis (Schwinj)	*33*	*21*	*SLTu/B*
Pterolobium stellatum	*0*	*27*	*wp/B*
Embellia Shimperi 1	*184*	*163*	*LF/B*
Paullinia pinnata L.	*11*	*49*	*F/B*
Cissus Petiolata Hook. F	*104*	*91*	*L/B*
Cissus rotundifolia (Forssk) Yah!.	*148*	*164*	*LF/BF*
Total	773	1209	

Appendix B. Supplementary information on habitat suitability and elephant distribution.



Supplementary Figure 1. Conceptual work flow of the methodology used to build the MaxEnt model to determine habitat suitability and distribution of the African elephant (*Loxodonta africana*) in the Omo National Park.

Table 1. The occurrence localities of African elephant (*Loxodonta africana*) in the Omo National Park recorded in 2021-22 during wet and dry season.

S.no	Species	Wet Season			information	Dry Season			Information
		Longitude	Latitude	Place (Habitat types		Longitude	Latitude	Places (Habitats)	
1	L.african	35.96624473	6.323551481	WLforest (North)	Direct	35.98992	6.389362	Sherma River	Foot prints
2	L.african	35.94059168	6.303787278	WLforest (North)	Direct	35.98025	6.386895	Sherma River	Foot prints
3	L.african	35.89627479	6.267111236	WLforest (North)	Dung pile	35.97607	6.364128	sherma River	Dung pile
4	L.african	35.8738701	6.218722878	WLforest (North)	Dung Pile	35.96621	6.345914	sherma River	Dung Pile
5	L.african	35.87029593	6.187646479	HWG	Foot prints	35.95976	6.323715	Sherma River	Direct
6	L.african	35.85807058	6.150970438	HWG	Foot prints	35.87798	6.219175	Kuma River	Direct
7	L.african	35.85807058	6.105125385	HWG	Foot prints	35.84478	6.232835	Kuma River	Foot prints
8	L.african	35.85959875	6.066921175	HWG	Dung pile	35.84554	6.25029	Kuma River	Footprints
9	L.african	35.82914455	6.036640335	HWG	Dung pile	35.86148	6.232266	Kuma river	Foot print
10	L.african	35.83667623	5.979815576	HWG	Dung pile	35.88254	6.207601	Kuma River	Dung pile
11	L.african	35.8382044	5.944667703	HWG	Footprints	35.80665	6.052615	Sai Plain (stream	Dung pile
12	L.african	35.87029593	5.907991661	HWG	Direct	35.79047	6.072603	Sai Plain (straem	Direct
13	L.african	35.85959875	5.852977599	OGL (Tingn plain)	Killed	35.8036	6.045762	Sai Plain (stream	Dung pile
14	L.african	35.8427889	5.797963536	OGL (Tingn plain)	Foot print	35.78628	6.066321	Sai Plain (straem	Dung pile
15	L.african	35.87335227	5.7949072	OGL (Tingn plain)	Dung pile	35.82645	6.045382	Sai Plain (stream)	Dung pile
16	L.african	35.89321846	5.797963536	OGL (Tingn plain)	Dung pile	35.8215	6.036054	Sai Plain (stream)	Direct
17	L.african	35.88863395	5.765872	OGL (Tingn plain)	Foot print	35.98402	5.968524	Omo River	Foot print
18	L.african	35.85042974	5.759759326	OGL (Tingn plain)	Dung pile	35.97259	5.95378	Omo River	Dung pile
19	L.african	35.81222553	5.741421305	HWG (Bushy- Elelbay)	Dung pile	35.95544	5.939337	Omo River	Direct
20	L.african	35.84737341	5.726139621	HWG (Bushy- Elelbay)	Foot print	35.97831	5.93362	Omo River	Foot print
21	L.african	35.86876776	5.684879075	HWG (Bushy- Elelbay)	Dung pile	35.96417	5.873141	East of Mui river	Dung pile
22	L.african	35.82903539	5.66959739	HWG (Bushy- Elelbay)	Dung Pile	35.92896	5.87645	East of Mui River	Dung Pile
23	L.african	35.80152835	5.684879075	HWG (Bushy- Elelbay)	Direct	35.90128	5.879158	East of Mui river	Direct
24	L.african	35.83209172	5.712386106	HWG	Footprint	35.88022	5.882468	East of Mui river	Footprint
25	L.african	35.79847202	5.729195958	HWG	Foot print	35.86096	5.880663	East of Mui river	Foot print
26	L.african	35.75415513	5.7368368	HWG	Dung pile	35.84411	5.878256	East of Mui river	Dung pile

27	L.african	35.73428894	5.7368368	HWG	Direct	35.81703	5.858397	East of Mui river	Direct
28	L.african	35.80152835	5.684879075	HWG	Dung pile	35.82034	5.846662	East of Mui river	Dung pile
29	L.african	35.77096499	5.672653727	HWG	Dung pile	35.82666	5.857494	East of Mui river	Dung pile
30	L.african	35.8542752	5.622092225	HWG	Dung pile	35.8515	5.873408	East of Mui river	Dung pile
31	L.african	35.86876776	5.684879075	HWG	Foot print	35.88202	5.871335	East of Mui river	Foot print
32	L.african	35.85348608	5.585548128	HWG	Dung pile	35.89917	5.869229	East of Mui river	Dung pile
33	L.african	35.85654242	5.562625602	HWG	Direct	35.91331	5.868928	East of Mui river	Direct
34	L.african	35.83209172	5.527477729	HWG	Dung pile	35.9425	5.863512	East of Mui river	Footprint
35	L.african	35.8091692	5.506083371	HWG	Foot print	35.76662	5.868037	Mui river around HQ	Foot print
36	L.african	35.79847202	5.529005897	HWG	Foot print	35.74963	5.894504	Mui river around HQ	Foot print
37	L.african	35.82597905	5.574850949	HWG	Foot print	35.71743	5.90654	Mui river west of HQ	Foot print
38	L.african	35.81500072	5.624238778	HWG	Foot print	35.71834	5.920381	Mui river west of HQ	Foot print
39	L.african	35.79694385	5.645146696	HWG	Dung pile	35.69848	5.931514	Mui river west of HQ	Dung pile
40	L.african	35.78062596	5.625956507	HWG	Foot print	35.70028	5.912858	Mui river west of HQ	Dung pile
41	L.african	35.74345795	5.574850949	HWG	Foot print	35.7075	5.900221	Mui river west of HQ	Foot print
42	L.african	35.73655522	5.625777501	HWG	Dung pile	35.72706	5.884274	Mui river west of HQ	Foot print
43	L.african	35.71900726	5.663484717	HWG	Dung pile	35.75173	5.857494	Mui river around HQ	Foot print
44	L.african	35.73734528	5.50761154	Neruz river (Gimwuha)	Foot print	35.7415	5.850273	Mui river around HQ	Dung pile
45	L.african	35.72970444	5.481632677	Neruz river (Gimwuha)	Foot print	35.72556	5.850273	Mui river around HQ	Dung pile
46	L.african	35.68303283	5.485969324	Neruz river (Gimwuha)	Dung pile	35.72255	5.865016	Mui river around HQ	Direct
47	L.african	35.70135988	5.455901313	Kibish Rver (south)	Direct	35.58628	5.461429	Kibish river (south)	Dung pile
48	L.african	35.65516832	5.432230198	Kibish Rver (south)	Dung pile	35.57437	5.505662	Kibish river (south)	Direct
49	L.african	35.68073375	5.419853168	Kibish Rver (south)	Direct	35.5685	5.483308	Kibish river (south)	Dung pile
50	L.african	35.65446612	5.389518471	Kibish Rver (south)	Dung pile	35.59182	5.505761	Kibish river (south)	Foot print
51	L.african	35.61775068	5.40066552	Kibish Rver (south)	Foot print	35.59142	5.535678	Kibish river (south)	Foot print
52	L.african					35.59142	5.535678	Kibish river (south)	Dung pile
53	L.african					35.57485	5.453158	Kibish river (south)	Direct
54	L.african					35.71737	5.461963	Gimwuha (Neruz River)	Dung Pile
55	L.african					35.76759	5.485905	Gimwuha (Neruz River)	Foot print
56	L.african					35.89526	6.19517	Kuma River	Direct

Table 2. Environmental variables used for Maxent model to predict habitat suitability and distribution of elephant (*L. africana*) in this study.

Variables	Code	Units	Data sources/ Remarks
Annual Mean Temperature	BIO1	Degree Celsius	
Mean Diurnal Range (Mean of monthly (max temp - min temp))	BIO2	Degree Celsius	
Isothermality (BIO2/BIO7) (×100)	BIO3	Degree Celsius	
Temperature Seasonality (standard deviation ×100)	BIO4	Degree Celsius	
Max Temperature of Warmest Month	BIO5	Degree Celsius	
Min Temperature of Coldest Month	BIO6	Degree Celsius	
Temperature Annual Range (BIO5-BIO6)	BIO7	Degree Celsius	
Mean Temperature of Wettest Quarter	BIO8	Degree Celsius	
Mean Temperature of Driest Quarter	BIO9	Degree Celsius	
Mean Temperature of Warmest Quarter	BIO10	Degree Celsius	
Mean Temperature of Coldest Quarter	BIO11	Degree Celsius	http://www.worldclim.org
Annual Precipitation	BIO12	Millimeters	
Precipitation of Wettest Month	BIO13	Millimeters	
Precipitation of Driest Month	BIO14	Millimeters	
Precipitation Seasonality (Coefficient of Variation)	BIO15	Millimeters	
Precipitation of Wettest Quarter	BIO16	Millimeters	
Precipitation of Driest Quarter	BIO17	Millimeters	
Precipitation of Warmest Quarter	BIO18	Millimeters	
Precipitation of Coldest Quarter	BIO19	Millimeters	
Elevation	Elev	Meters	
Precipitation (January)	Prec_01	Millimeters	Dry season
Precipitation (February	Prec_02	Millimeters	Dry season
Precipitation (March)	Prec_03	Millimeters	Wet season
Precipitation (April)	Prec_04	Millimeters	Wet season
Precipitation (May)	Prec_05	Millimeters	Wet season
Precipitation (December)	Prec_12	Millimeters	Dry Season

Average Temperature (January)	Tavg_01	Degree Celsius	Dry season
Average Temperature (February	Tavg_02	Degree Celsius	Dry season
Average Temperature (March)	Tavg_03	Degree Celsius	Wet season
Average Temperature (April)	Tavg_04	Degree Celsius	Wet season
Average Temperature (May)	Tavg_05	Degree Celsius	Wet season
Average Temperature (December)	Tavg_12	Degree Celsius	Dry Season
Maximum Temperature (January)	Tmax_01	Degree Celsius	Dry season
Maximum Temperature (February	Tmax_02	Degree Celsius	Dry season
Maximum Temperature (March)	Tmax_03	Degree Celsius	Wet season
Maximum Temperature (April)	Tmax_04	Degree Celsius	Wet season
Maximum Temperature (May)	Tmax_05	Degree Celsius	Wet season
Minimum Temperature (December)	Tmax_12	Degree Celsius	Dry Season
Minimum Temperature (January)	Tmin_01	Degree Celsius	Dry season
Minimum Temperature (February	Tmin_02	Degree Celsius	Dry season
Minimum Temperature (March)	Tmin_03	Degree Celsius	Wet season
Minimum Temperature (April)	Tmin_04	Degree Celsius	Wet season
Minimum Temperature (May)	Tmin_05	Degree Celsius	Wet season
Minimum Temperature (December)	Tmin_12	Degree Celsius	Dry Season
Digital elevation Model	Dem	Meters	https://earthexplorer.usgs.gov/
Slope	Slope	Degrees	Drived from DEM in ArcGIS
Aspect	Asp	Degrees	Drived from DEM in ArcGIS
Distance from the canal	dist_canal	Meters	Prepared using ArcGIS
Distance to the cultivated land/ settlements	dist_cultland	Meters	Prepared using ArcGIS
Distance to the rivers	dist_river	Meters	Prepared using ArcGIS
Distance to the roads	dist_road	Meters	Prepared using ArcGIS
Land use land cover	lulc_o	Unitless	https://earthexplorer.usgs.gov/ and ArcGIS supervised classification

Table 3. Multicollinearity test by using correlation analysis among continuous environmental variables in R and Rstudio (the below table is more visible by zoom in and out in PDF file). (yelow Highlighted varibales removed and the remianing (unhiglighted) 12 pridictors varaible used in the Maxent model for pridiction of habitata suitability and distrivution of African elephant in Omo National Park). The score of correlation is between -1 to 1, so any negative value means there is a negative correlation and in the test any variable with score 0.7(-/+) and above this value is correlated and getrid of from furhter analysis.

	aspect	bio_1	bio_2	bio_3	bio_4	bio_5	bio_6	bio_7	bio_8	bio_9	bio_10	bio_11	bio_12	bio_13	bio_14	bio_16	bio_17	bio_18	bio_19	dem	dist_canal	dist_cultland	dist_river	dist_road	elev	lulc_o	prec_01	prec_02	prec_03	prec_04	prec_05	prec_12	slope	tavg_01	tavg_02	tavg_03	tavg_04	tavg_05	tavg_12	tmax_01	tmax_02	tmax_03	tmax_04	tmax_05	tmax_12	tmin_01	tmin_02	tmin_03	tmin_04	tmin_05	tmin_12
aspect	1	-0.06	0.04	0.1	-0.03	-0.04	-0.05	-0.05	-0.04	-0.05	-0.05	-0.05	-0.05	0.02	-0.02	0.01	0.05	0.1	0.01	0.1	0.09	0.01	0.01	0.03	0.11	-0.03	-0.02	0.1	0.11	0.01	0.09	0.01	0.01	-0.06	-0.05	-0.06	-0.05	-0.1	-0.06	-0.04	-0.04	-0.04	-0.03	-0.02	-0.06	-0.06	-0.04	-0.1	-0.07	-0.1	-0.05
bio_1	-0.06	1	0.52	0.19	-0.16	0.96	0.95	1	0.98	0.99	0.99	0.99	1	-0.3	0.15	-0.54	-0.36	-0.61	-0.61	-0.74	-0.43	-0.15	0.09	-0.12	-0.74	-0.002	0.15	-0.62	-0.69	-0.28	-0.53	-0.11	-0.33	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.97	0.97	0.97	0.96	0.97	0.98	0.99	0.99	0.95
bio_2	0.04	0.52	1	-0.1	0.19	0.69	0.26	0.52	0.5	0.51	0.53	0.52	0.52	-0.36	0.03	-0.29	-0.41	-0.58	-0.16	-0.58	-0.3	-0.02	0.19	-0.07	-0.58	-0.04	0.03	-0.61	-0.61	-0.35	-0.27	-0.14	-0.49	0.52	0.51	0.55	0.57	0.54	0.49	0.69	0.61	0.62	0.7	0.65	0.66	0.27	0.7	0.33	0.41	0.41	0.25
bio_3	0.1	0.19	-0.1	1	-0.64	0.06	0.39	0.21	0.29	0.2	0.18	0.22	0.21	-0.06	-0.21	-0.36	0.1	0.33	-0.51	0.42	0.36	-0.2	0.1	0.15	0.42	-0.06	-0.2	0.4	0.39	-0.06	-0.34	-0.21	0.14	0.17	0.21	0.15	0.16	0.22	0.2	0.08	0.08	0.06	0.13	0.27	0.04	0.31	0.08	0.23	0.17	0.18	0.39
bio_4	-0.03	-0.16	0.19	-0.64	1	-0.01	-0.29	-0.16	-0.19	-0.13	-0.11	-0.18	-0.16	0.16	0.29	0.28	0.09	-0.09	0.26	-0.23	-0.39	0.13	0.17	-0.32	-0.25	-0.01	0.29	-0.12	-0.17	0.17	0.24	0.2	0.03	-0.12	-0.14	-0.11	-0.13	-0.2	-0.15	-0.01	-0.01	0.01	-0.08	-0.19	-0.03	-0.24	-0.01	-0.2	-0.18	-0.2	-0.3
bio_5	-0.04	0.96	0.69	0.06	-0.01	1	0.84	0.97	0.93	0.96	0.97	0.96	0.97	-0.35	0.14	-0.51	-0.42	-0.69	-0.53	-0.8	-0.47	-0.11	0.13	-0.13	-0.81	-0.01	0.16	-0.71	-0.67	-0.33	-0.5	-0.11	-0.41	0.97	0.96	0.98	0.98	0.96	0.96	0.99	0.99	0.99	0.99	0.97	0.99	0.85	0.99	0.89	0.93	0.93	0.84
bio_6	-0.05	0.95	0.26	0.39	-0.29	0.84	1	0.95	0.95	0.95	0.94	0.95	0.95	-0.24	0.11	-0.56	-0.25	-0.43	-0.69	-0.54	-0.31	-0.17	0.07	-0.08	-0.55	-0.01	0.12	-0.42	-0.5	-0.22	-0.55	-0.11	-0.18	0.94	0.95	0.93	0.92	0.94	0.95	0.84	0.84	0.83	0.85	0.89	0.86	0.99	0.85	0.98	0.96	0.96	0.99
bio_7	-0.05	1	0.52	0.21	-0.16	0.97	0.95	1	0.98	0.99	0.99	0.99	1	-0.31	0.15	-0.55	-0.36	-0.61	-0.62	-0.73	-0.43	-0.15	0.1	-0.12	-0.74	-0.01	0.16	-0.62	-0.69	-0.29	-0.54	-0.11	-0.33	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.97	0.97	0.97	0.96	0.97	0.98	0.99	0.99	0.95
bio_8	-0.04	0.98	0.5	0.29	-0.2	0.93	0.95	0.98	1	0.98	0.98	0.98	0.98	-0.36	0.07	-0.62	-0.39	-0.59	-0.7	-0.66	-0.37	-0.18	0.1	-0.12	-0.67	-0.01	0.09	-0.58	-0.65	-0.34	-0.61	-0.2	-0.32	0.97	0.98	0.98	0.97	0.98	0.98	0.94	0.94	0.93	0.94	0.96	0.94	0.95	0.94	0.96	0.97	0.97	0.95
bio_9	-0.05	0.99	0.51	0.2	-0.13	0.96	0.95	0.99	0.98	1	0.99	0.99	0.99	-0.29	0.17	-0.53	-0.34	-0.6	-0.61	-0.74	-0.45	-0.15	0.11	-0.14	-0.74	-0.01	0.18	-0.61	-0.69	-0.27	-0.52	-0.09	-0.31	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.96	0.97	0.97	0.96	0.97	0.98	0.99	0.99	0.95
bio_10	-0.05	0.99	0.53	0.18	-0.11	0.97	0.94	0.99	0.98	0.99	1	0.99	0.99	-0.3	0.16	-0.53	-0.36	-0.61	-0.61	-0.75	-0.45	-0.14	0.11	-0.14	-0.75	-0.01	0.18	-0.62	-0.7	-0.28	-0.52	-0.1	-0.33	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.97	0.97	0.98	0.95	0.97	0.97	0.99	0.99	0.94
bio_11	-0.05	0.99	0.52	0.22	-0.18	0.96	0.95	0.99	0.98	0.99	0.99	1	0.99	-0.3	0.15	-0.54	-0.35	-0.6	-0.61	-0.73	-0.42	-0.15	0.09	-0.12	-0.73	-0.01	0.16	-0.61	-0.68	-0.29	-0.53	-0.11	-0.33	0.99	0.99	0.99	0.99	0.99	0.99	0.96	0.96	0.95	0.97	0.97	0.97	0.96	0.962	0.98	0.99	0.99	0.95
bio_12	-0.05	1	0.52	0.201	-0.16	0.97	0.95	1	0.98	0.99	0.99	0.99	1	-0.31	0.15	-0.51	-0.36	-0.61	-0.62	-0.73	-0.43	-0.15	0.1	-0.12	-0.74	-0.01	0.16	-0.62	-0.69	-0.29	-0.54	-0.11	-0.33	0.99	0.99	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.97	0.97	0.97	0.96	0.97	0.98	0.99	0.99	0.95
bio_13	0.02	-0.3	-0.36	-0.06	0.16	-0.35	-0.24	-0.31	-0.36	-0.29	-0.3	-0.3	-0.31	1	0.74	0.89	0.95	0.75	0.62	0.23	-0.23	0.2	0.07	-0.15	0.22	0.09	0.74	0.67	0.57	0.99	0.88	0.91	0.38	-0.28	-0.29	-0.3	-0.34	-0.3	-0.27	-0.34	-0.34	-0.33	-0.35	-0.39	-0.29	-0.2	-0.35	-0.3	-0.31	-0.3	-0.22
bio_14	-0.02	0.15	0.03	-0.21	0.29	0.14	0.11	0.15	0.07	0.17	0.16	0.15	0.15	0.74	1	0.6	0.72	0.3	0.31	-0.35	-0.66	0.01	0.23	-0.47	-0.36	0.12	0.99	0.18	0.01	0.76	0.6	0.8	0.12	0.19	0.16	0.17	0.14	0.13	0.19	0.15	0.15	0.16	0.13	0.03	0.22	0.19	0.14	0.18	0.15	0.2	0.13
bio_16	0.01	-0.54	-0.29	-0.36	0.28	-0.51	-0.56	-0.55	-0.62	-0.53	-0.53	-0.54	-0.55	0.89	0.6	1	0.81	0.64	0.9	0.23	-0.18	0.29	0.02	-0.08	0.23	0.09	0.6	0.54	0.51	0.88	0.99	0.87	0.29	-0.51	-0.54	-0.52	-0.54	-0.6	-0.52	-0.51	-0.51	-0.48	-0.52	-0.59	-0.46	-0.51	-0.51	-0.5	-0.55	-0.5	-0.55
bio_17	0.05	-0.36	-0.41	0.1	0.09	-0.42	-0.25	-0.36	-0.39	-0.34	-0.36	-0.36	-0.36	0.95	0.72	0.81	1	0.87	0.52	0.37	-0.18	0.14	0.11	-0.18	0.37	0.07	0.71	0.8	0.7	0.95	0.82	0.83	0.42	-0.34	-0.34	-0.36	-0.4	-0.4	-0.32	-0.41	-0.41	-0.4	-0.41	-0.43	-0.37	-0.23	-0.41	-0.3	-0.37	-0.3	-0.24
bio_18	0.1	-0.61	-0.58	0.33	-0.09	-0.69	-0.43	-0.61	-0.59	-0.6	-0.61	-0.6	-0.61	0.75	0.3	0.64	0.867	1	0.41	0.77	0.27	0.13	0.02	0.04	0.77	0.01	0.29	0.99	0.66	0.74	0.65	0.5	0.49	-0.61	-0.59	-0.63	-0.65	-0.6	-0.58	-0.67	-0.67	-0.67	-0.67	-0.63	-0.68	-0.46	-0.67	-0.5	-0.61	-0.6	-0.42
bio_19	0.01	-0.61	-0.16	-0.51	0.26	-0.53	-0.69	-0.62	-0.7	-0.61	-0.61	-0.61	-0.62	0.62	0.31	0.9	0.52	0.41	1	0.21	0.02	0.33	-0.04	0.09	0.21	0.05	0.31	0.33	0.37	0.59	0.9	0.68	0.16	-0.59	-0.62	-0.59	-0.59	-0.6	-0.61	-0.53	-0.53	-0.5	-0.52	-0.6	-0.51	-0.65	-0.54	-0.6	-0.64	-0.6	-0.68
dem	0.1		-0.58	0.42	-0.23	-0.8	-0.54	-0.73	-0.67	-0.74	-0.75	-0.73	-0.73	0.23	-0.35	0.23	0.37	0.77	0.21	1	0.74	0.12	-0.11	0.32	0.99	-0.07	-0.35	0.83	0.7	0.21	0.24	-0.05	0.44	-0.75	-0.72	-0.76	-0.77	-0.7	-0.73	-0.78	-0.78	-0.79	-0.77	-0.67	-0.83	-0.62	-0.78	-0.7	-0.74	-0.7	-0.54
dist_canal	0.09	-0.43	-0.3	0.36	-0.39	-0.47	-0.31	-0.43	-0.37	-0.45	-0.45	-0.42	-0.43	-0.28	-0.76	-0.18	-0.18	0.27	0.02	0.74	1	0.24	-0.25	0.62	0.75	-0.13	-0.75	0.36	0.51	-0.31	-0.14	-0.39	0.11	-0.48	-0.43	-0.46	-0.44	-0.4	-0.46	-0.45	-0.45	-0.46	-0.42	-0.31	-0.54	-0.41	-0.45	-0.4	-0.44	-0.5	-0.31
dist_cultla	0.01	-0.15	-0.02	-0.2	0.13	-0.11	-0.17	-0.15	-0.18	-0.15	-0.14	-0.15	-0.15	0.2	0.01	0.29	0.14	0.13	0.33	0.12	0.24	1	-0.27	0.24	0.11	0.06	0.01	0.11	0.14	0.17	0.33	0.23	0.03	-0.15	-0.15	-0.13	-0.14	-0.2	-0.14	-0.1	-0.1	-0.07	-0.12	-0.15	-0.11	-0.19	-0.1	-0.2	-0.16	-0.2	-0.17
dist_river	0.01	0.09	0.19	0.1	0.17	0.13	0.07	0.096	0.1	0.11	0.11	0.09	0.1	0.07	0.23	0.02	0.11	0.02	-0.04	-0.11	-0.25	-0.27	1	-0.24	-0.11	-0.04	0.23	0.01	-0.06	0.07	0.01	0.07	0.04	0.12	0.11	0.1	0.1	0.1	0.1	0.13	0.13	0.13	0.14	0.1	0.12	0.09	0.13	0.06	0.06	0.09	0.07
dist_road	0.03	-0.12	-0.07	0.15	-0.32	-0.13	-0.08	-0.12	-0.12	-0.14	-0.14	-0.12	-0.12	-0.15	-0.47	-0.08	-0.18	0.04	0.09	0.32	0.62	0.24	-0.24	1	0.32	-0.01	-0.47	0.07	0.19	-0.19	-0.05	-0.19	0.03	-0.15	-0.13	-0.13	-0.11	-0.1	-0.13	-0.13	-0.13	-0.12	-0.09	-0.02	-0.17	-0.13	-0.13	-0.1	-0.14	-0.2	-0.08
elev	0.11	-0.74	-0.58	0.42	-0.25	-0.81	-0.56	-0.74	-0.67	-0.74	-0.75	-0.73	-0.74	0.22	-0.36	0.23	0.37	0.77	0.21	0.99	0.65	0.11	-0.11	0.32	1	-0.07	-0.36	0.84	0.68	0.2	0.24	-0.06	0.4	-0.76	-0.73	-0.77	-0.77	-0.7	-0.74	-0.79	-0.79	-0.8	-0.77	-0.68	-0.84	-0.63	-0.79	-0.7	-0.75	-0.7	-0.55
lulc_o	-0.03	-0.01	-0.034	-0.06	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.09	0.12	0.09	0.07	0.01	0.05	-0.06	-0.13	0.06	-0.04	-0.1	-0.07	1	0.12	-0.01	-0.03	0.09	0.09	0.09	0.02	0.01	-0.01	0.01	-0.01	-0	0.01	-0.02	-0.02	-0.01	-0.02	-0.03	0.01	0.01	-0.02	0.01	0.01	0.01	-0.01
prec_01	-0.02	0.15	0.03	-0.2	0.29	0.16	0.12	0.16	0.09	0.18	0.18	0.16	0.16	0.74	0.99	0.6	0.71	0.29	0.31	-0.35	-0.66	0.01	0.23	-0.47	-0.36	0.12	1	0.18	0.02	0.76	0.6	0.79	0.11	0.19	0.17	0.17	0.15	0.13	0.19	0.15	0.15	0.16	0.14	0.04	0.22	0.19	0.15	0.18	0.16	0.21	0.13
prec_02	0.1	-0.62	-0.61	0.4	-0.12	-0.71	-0.42	-0.62	-0.58	-0.61	-0.62	-0.61	-0.62	0.67	0.18	0.54	0.8	0.99	0.33	0.83	0.36	0.11	0.01	0.07	0.84	-0.01	0.18	1	0.68	0.66	0.55	0.41	0.5	-0.61	-0.59	-0.63	-0.66	-0.6	-0.58	-0.68	-0.68	-0.68	-0.68	-0.63	-0.69	-0.45	-0.7	-0.5	-0.62	-0.6	-0.4
prec_03	0.11	-0.69	-0.61	0.39	-0.18	-0.67	-0.5	-0.69	-0.65	-0.69	-0.7	-0.68	-0.69	0.57	0.013	0.51	0.7	0.66	0.37	0.7	0.51	0.14	-0.06	0.19	0.68	-0.03	0.02	0.68	1	0.56	0.52	0.32	0.48	-0.69	-0.67	-0.7	-0.73	-0.7	-0.66	-0.74	-0.74	-0.75	-0.74	-0.68	-0.77	-0.54	-0.74	-0.6	-0.7	-0.7	-0.48
prec_04	0.01	-0.28	-0.35	-0.06	0.17	-0.33	-0.21	-0.29	-0.34	-0.27	-0.28	-0.29	-0.29	0.99	0.76	0.88	0.95	0.74	0.59	0.21	-0.31	0.17	0.07	-0.19	0.2	0.09	0.76	0.66	0.56	1	0.86	0.9	0.38	-0.26	-0.28	-0.28	-0.32	-0.3	-0.25	-0.33	-0.33	-0.31	-0.34	-0.38	-0.27	-0.18	-0.33	-0.2	-0.29	-0.3	-0.21
prec_05	0.02	-0.53	-0.27	-0.34	0.24	-0.5	-0.55	-0.54	-0.61	-0.52	-0.52	-0.53	-0.54	0.88	0.6	0.99	0.82	0.65	0.9	0.24	-0.14	0.33	0.01	-0.05	0.24	0.09	0.6	0.55	0.52	0.86	1	0.87	0.28	-0.51	-0.53	-0.51	-0.53	-0.5	-0.51	-0.5	-0.5	-0.47	-0.5	-0.57	-0.46	-0.5	-0.5	-0.5	-0.55	-0.5	-0.54
prec_12	0.01	-0.11	-0.14	-0.21	0.2	-0.11	-0.11	-0.11	-0.2	-0.09	-0.1	-0.11	-0.11	0.91	0.79	0.87	0.83	0.5	0.68	-0.05	-0.39	0.23	0.07	-0.19	-0.06	0.09	0.79	0.41	0.32	0.9	0.87	1	0.22	-0.09	-0.11	-0.1	-0.12	-0.1	-0.09	-0.13	-0.13	-0.1	-0.12	-0.19	-0.06	-0.07	-0.13	-0.1	-0.12	-0.1	-0.11
slope	0.01	-0.32	-0.49	0.14	0.03	-0.41	-0.18	-0.33	-0.32	-0.31	-0.33	-0.33	-0.33	0.38	0.12	0.29	0.42	0.49	0.16	0.44	0.11	0.03	0.04	0.03	0.4	0.02	0.11	0.5	0.48	0.38	0.28	0.22	1	-0.31	-0.31	-0.34	-0.36	-0.3	-0.3	-0.4	-0.4	-0.4	-0.41	-0.38	-0.39	-0.18	-0.4	-0.3	-0.3	-0.3	-0.17
tavg_01	-0.06	0.99	0.52	0.17	-0.12	0.97	0.94	0.99	0.97	0.99	0.99	0.99	0.99	-0.28	0.19	-0.51	-0.34	-0.61	-0.59	-0.75	-0.48	-0.15	0.12	-0.15	-0.76	0.01	0.19	-0.61	-0.69	-0.26	-0.51	-0.09	-0.31	1	0.99	0.99	0.99	0.99	0.1	0.97	0.97	0.96	0.97	0.96	0.98	0.96	0.97	0.98	0.99	0.99	0.94
tavg_02	-0.05	0.99	0.51	0.21	-0.14	0.96	0.95	0.99	0.98	0.99	0.99	0.99	0.99	-0.29	0.16	-0.54	-0.34	-0.59	-0.62	-0.72	-0.43	-0.15	0.11	-0.13	-0.73	-0.01	0.17	-0.59	-0.67	-0.28	-0.53	-0.11	-0.31	0.99	1	0.99	0.99	0.99	0.99	0.97	0.97	0.96	0.97	0.97	0.97	0.96	0.97	0.98	0.99	0.99	0.95
tavg_03	-0.06	0.99	0.55	0.15	-0.11	0.98	0.93	0.99	0.97	0.99	0.99	0.99	0.99	-0.3	0.18	-0.52	-0.36	-0.63	-0.58	-0.76	-0.48	-0.13	0.1	-0.13	-0.77	0.01	0.17	-0.63	-0.7	-0.28	-0.51	-0.1	-0.34	0.99	0.99	1	0.99	0.99	0.99	0.98	0.98	0.97	0.98	0.97	0.98	0.94	0.98	0.97	0.98	0.98	0.93
tavg_04	-0.05	0.99	0.57	0.16	-0.13	0.98	0.92	0.99	0.97	0.99	0.99	0.99	0.99	-0.34	0.14	-0.54	-0.4	-0.65	-0.59	-0.77	-0.44	-0.14	0.1	-0.11	-0.77	-0.01	0.15	-0.66	-0.73	-0.32	-0.53	-0.12	-0.36	0.99	0.99	0.99	1	0.99	0.99	0.98	0.98	0.97	0.98	0.98	0.98	0.93	0.98	0.96	0.98	0.98	0.92
tavg_05	-0.05	0.99	0.54	0.22	-0.19	0.96	0.94	0.99	0.98	0.99	0.99	0.99	0.99	-0.33	0.13	-0.56	-0.38	-0.61	-0.62	-0.72	-0.4	-0.15	0.1	-0.09	-0.73	-0.01	0.13	-0.61	-0.67	-0.31	-0.54	-0.14	-0.34	0.99	0.99	0.99	0.99	1	0.99	0.97	0.97	0.96	0.97	0.98	0.97	0.95	0.97	0.97	0.98	0.98	0.94
tavg_12	-0.06	0.99	0.49	0.2	-0.15	0.96	0.95	0.99	0.98	0.99	0.99	0.99	0.99	-0.27	0.19	-0.52	-0.32	-0.58	-0.61	-0.73	-0.46	-0.14	0.1	-0.13	-0.74	0.01	0.19	-0.58	-0.66	-0.25	-0.51	-0.09	-0.3	0.99	0.99	0.99	0.99	0.99	1	0.96	0.96	0.95	0.96	0.96	0.97	0.97	0.96	0.98	0.99	0.99	0.95
tmax_01	-0.04	0.97	0.69	0.08	-0.01	0.99	0.84	0.97	0.94	0.97	0.97	0.96	0.97	-0.34	0.15	-0.51	-0.41	-0.67	-0.53	-0.78	-0.45	-0.1	0.13	-0.13	-0.79	-0.02	0.15	-0.68	-0.74	-0.33	-0.5	-0.13	-0.4	0.97	0.97	0.98	0.98	0.97	0.96	1	1	0.99	0.99	0.97	0.99	0.86	1	0.9	0.93	0.93	0.85
tmax_02	-0.04	0.97	0.61	0.08	-0.01	0.99	0.84	0.97	0.94	0.97	0.97	0.96	0.97	-0.34	0.15	-0.51	-0.41	-0.67	-0.53	-0.78	-0.45	-10	0.13	-0.13	-0.79	-0.02	0.15	-0.68	-0.74	-0.33	-0.5	-0.13	-0.4	0.97	0.97	0.98	0.98	0.97	0.96	1	1	0.99	0.99	0.97	0.99	0.86	1	0.9	0.93	0.93	0.85
tmax_03	-0.04	0.96	0.62	0.06	0.01	0.997	0.83	0.96	0.93	0.96	0.96	0.95	0.96	-0.33	0.16	-0.48	-0.4	-0.67	-0.5	-0.79	-0.46	-0.07	0.13	-0.12	-0.8	-0.01	0.16	-0.68	-0.75	-0.31	-0.47	-0.1	-0.4	0.96	0.96	0.97	0.97	0.96	0.95	0.99	0.99	1	0.99	0.97	0.99	0.84	0.99	0.88	0.92	0.91	0.83
tmax_04	-0.03	0.97	0.7	0.13	-0.08	0.99	0.85	0.97	0.94	0.96	0.97	0.97	0.97	-0.35	0.13	-0.52	-0.41	-0.67	-0.53	-0.77	-0.42	-0.12	0.14	-0.09	-0.77	-0.02	0.14	-0.68	-0.74	-0.34	-0.5	-0.12	-0.41	0.97	0.97	0.98	0.98	0.97	0.96	0.99	0.99	0.99	1	0.98	0.98	0.87	0.99	0.9	0.93	0.93	0.85
tmax_05	-0.02	0.97	0.65	0.27	-0.2	0.97	0.89	0.97	0.96	0.97	0.97	0.97	0.97	-0.39	0.03	-0.59	-0.43	-0.63	-0.6	-0.67	-0.31	-0.15	0.1	-0.02	-0.68	-0.03	0.04	-0.63	-0.68	-0.38	-0.57	-0.19	-0.38	0.96	0.97	0.97	0.98	0.98	0.96	0.97	0.98	0.97	0.98	1	0.96	0.89	0.97	0.91	0.93	0.93	0.89
tmax_12	-0.06	0.97	0.66	0.04	-0.03	0.99	0.86	0.97	0.94	0.97	0.98	0.97	0.97	-0.29	0.22	-0.46	-0.37	-0.68	-0.51	-0.83	-0.54	-0.11	0.12	-0.17	-0.84	0.01	0.22	-0.69	-0.77	-0.27	-0.46	-0.06	-0.39	0.98	0.97	0.98	0.98	0.97	0.97	0.99	0.99	0.99	0.98	0.96	1	0.88	0.99	0.92	0.95	0.95	0.86
tmin_01	-0.06	0.96	0.27	0.31	-0.24	0.85	0.99	0.96	0.95	0.96	0.95	0.96	0.96	-0.2	0.19	-0.51	-0.23	-0.46	-0.65	-0.62	-0.41	-0.19	0.09	-0.13	-0.63	0.01	0.19	-0.45	-0.54	-0.18	-0.5	-0.07	-0.18	0.96	0.96	0.94	0.93	0.95	0.97	0.86	0.86	0.84	0.87	0.89	0.88	1	0.86	0.99	0.97	0.98	0.99
tmin_02	-0.04	0.97	0.7	0.08	-0.01	0.99	0.85	0.97	0.94	0.97	0.97	0.96	0.97	-0.35	0.14	-0.52	-0.41	-0.67	-0.54	-0.78	-0.45	-0.1	0.13	-0.13	-0.79	-0.02	0.15	-0.68	-0.74	-0.33	-0.5	-0.13	-0.4	0.97	0.97	0.98	0.98	0.97	0.96	1	1	0.99	0.99	0.97	0.99	0.86	1	0.9	0.93	0.93	0.85
tmin_03	-0.07	0.98	0.33	0.23	-0.22	0.89	0.98	0.98	0.96	0.98	0.97	0.98	0.98	-0.25	0.18	-0.53	-0.3	-0.54	-0.64	-0.68	-0.43	-0.18	0.06	-0.13	-0.69	0.01	0.18	-0.53	-0.62	-0.23	-0.52	-0.09	-0.25	0.98	0.98	0.97	0.96	0.97	0.98	0.9	0.9	0.88	0.9	0.91	0.92	0.99	0.9	1	0.99	0.99	0.98
tmin_04	-0.07	0.99	0.41	0.17	-0.18	0.93	0.96	0.99	0.97	0.99	0.99	0.99	0.99	-0.31	0.15	-0.55	-0.37	-0.61	-0.64	-0.74	-0.44	-0.16	0.06	-0.14	-0.75	0.01	0.16	-0.62	-0.7	-0.29	-0.55	-0.12	-0.3	0.99	0.99	0.98	0.98	0.98	0.99	0.93	0.93	0.92	0.93	0.93	0.95	0.97	0.93	0.99	1	0.99	0.96
tmin_05	-0.07	0.99	0.41	0.18	-0.17	0.93	0.96	0.99	0.97	0.99	0.99	0.99	0.99	-0.27	0.2	-0.52	-0.32	-0.58	-0.62	-0.73	-0.47	-0.16	0.09	-0.16	-0.74	0.01	0.21	-0.59	-0.68	-0.25	-0.51	-0.08	-0.28	0.99	0.99	0.98	0.98	0.98	0.99	0.93	0.93	0.91	0.93	0.93	0.95	0.98	0.93	0.99	0.99	1	0.96
tmin_12	-0.05	0.95	0.25	0.39	-0.3	0.84	0.99	0.95	0.95	0.95	0.94	0.95	0.95	-0.22	0.13	-0.55	-0.24	-0.42	-0.68	-0.54	-0.31	-0.17	0.07	-0.08	-0.55	-0.01	0.13	-0.4	-0.48	-0.21	-0.54	-0.11	-0.17	0.94	0.95	0.93	0.92	0.94	0.95	0.85	0.85	0.83	0.85	0.89	0.86	0.99	0.85	0.98	0.96	0.96	1

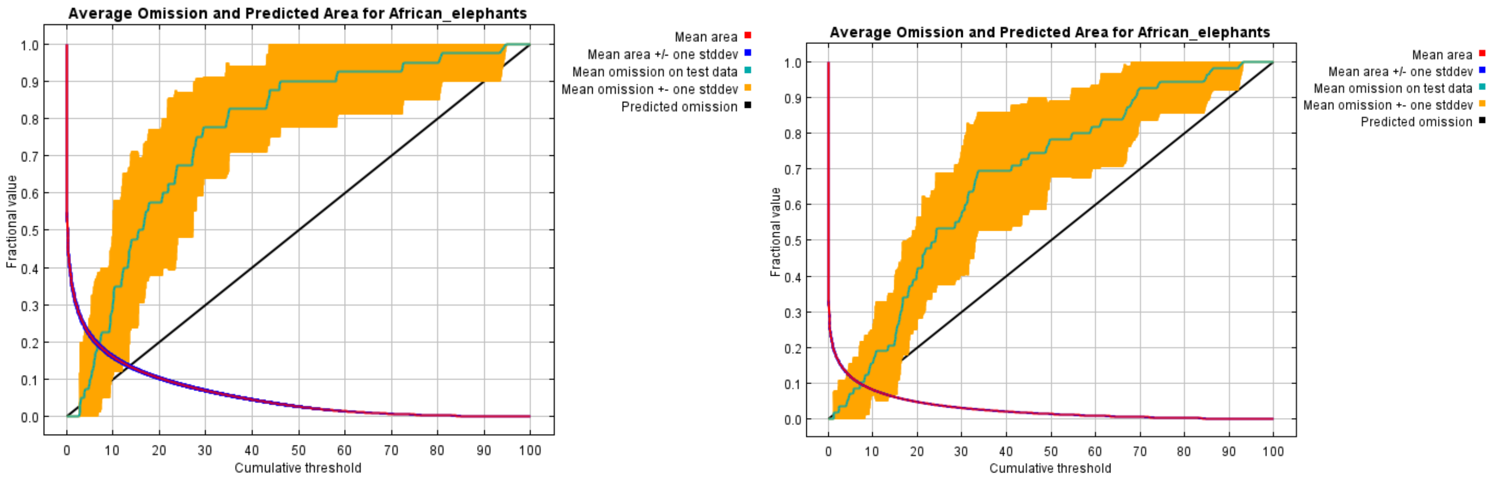


Figure 2. The test omission rate and predicted area as a function of the cumulative threshold for the current predictor variables used for modelling in wet (left) and dry(right) seasons.

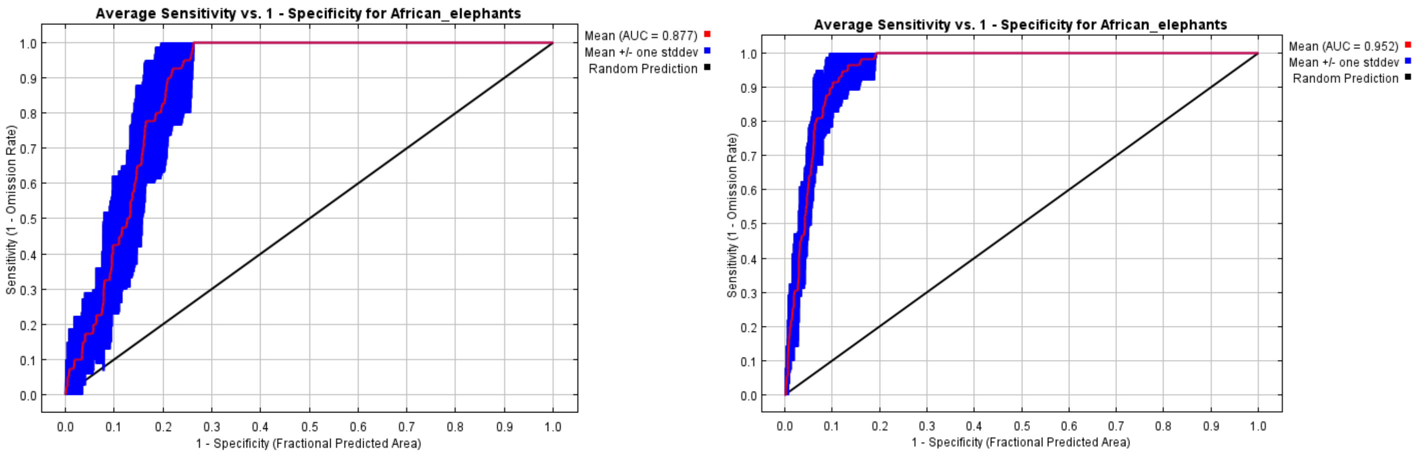
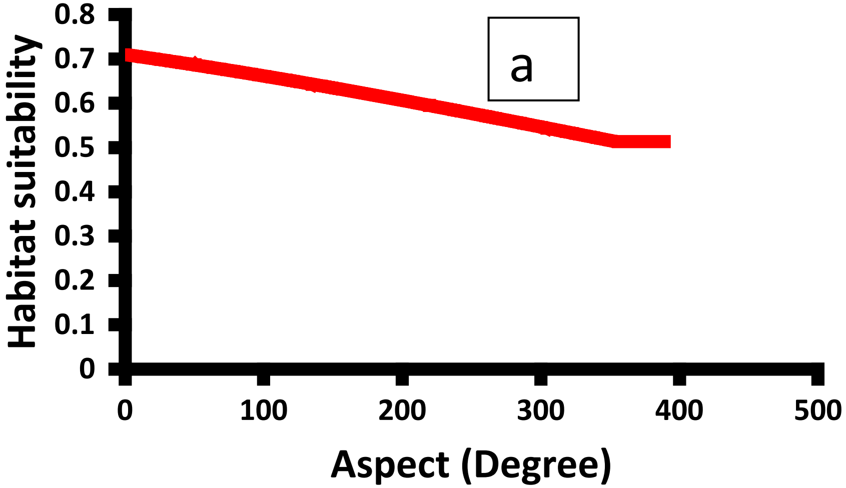
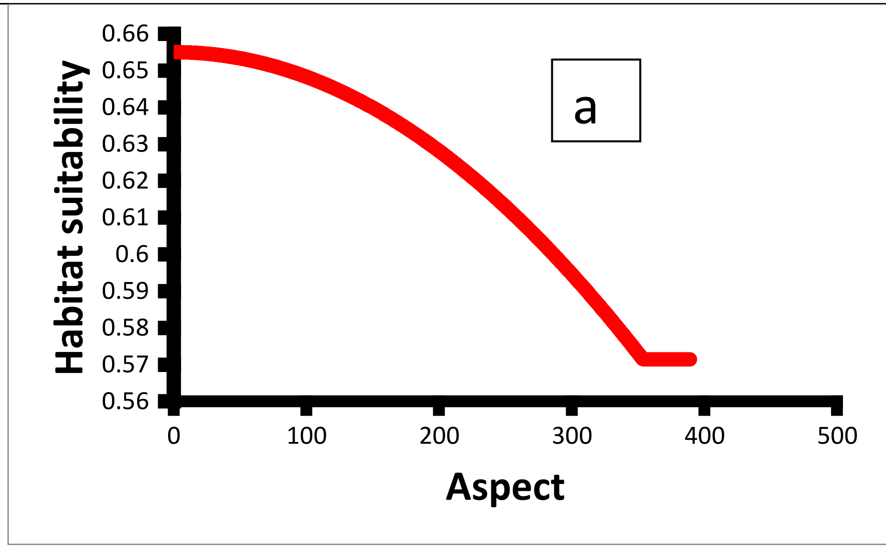
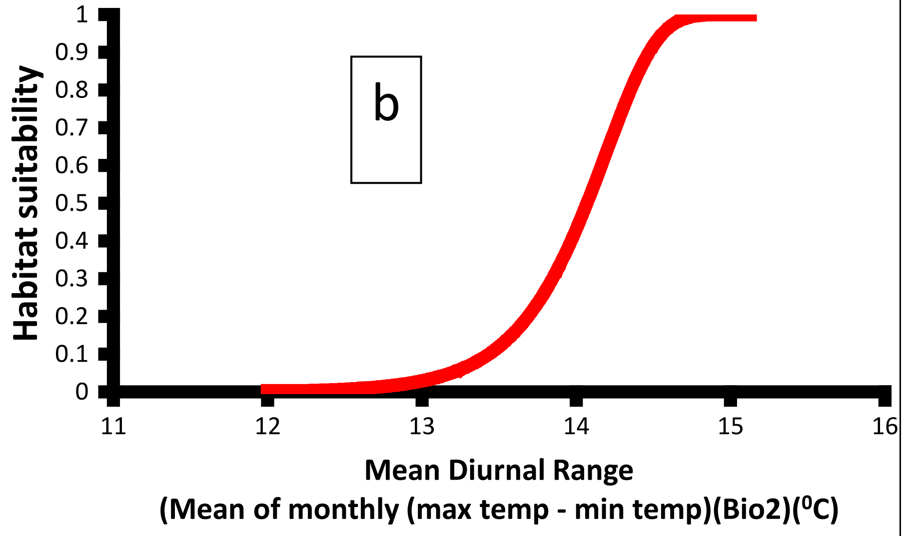
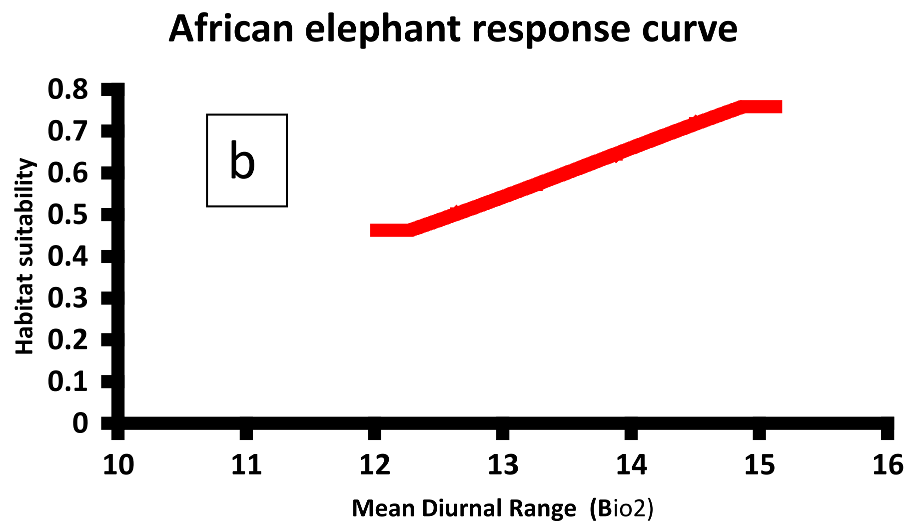


Figure 3. The Receiver Operating Characteristics Curve (ROC) and the value of Area under Curve (AUC) for predicted habitat suitability and distribution of African elephant (*Loxodonta africana*) in the Omo National Park. Red colour indicates the mean of area under curve averaged over 10 replicate runs, blue colour shows the mean+/- standard deviation, and black colour represents random prediction with AUC of 0.5 in wet (left) and dry(right) seasons.

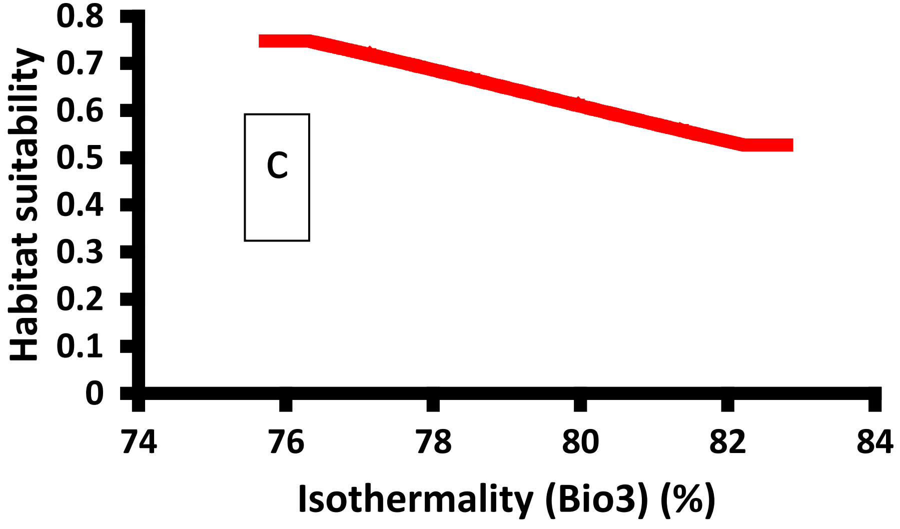
Wet season	Dry season
	

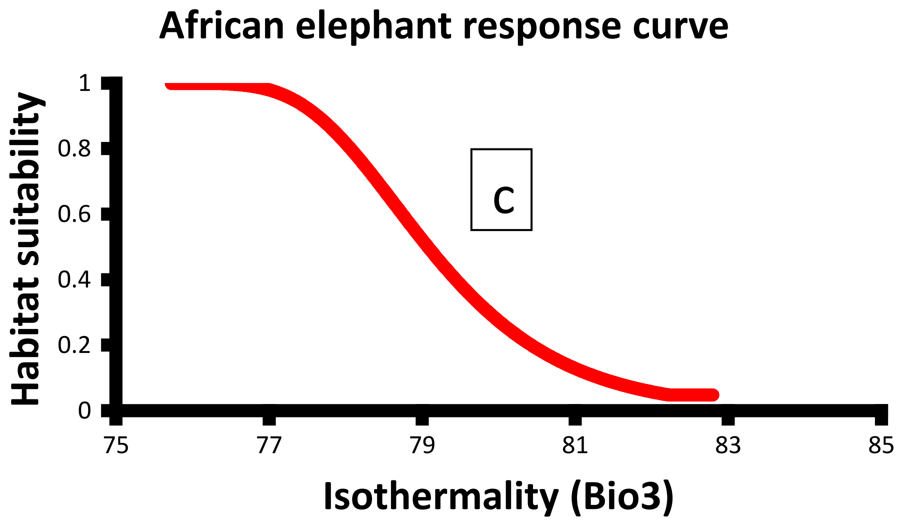


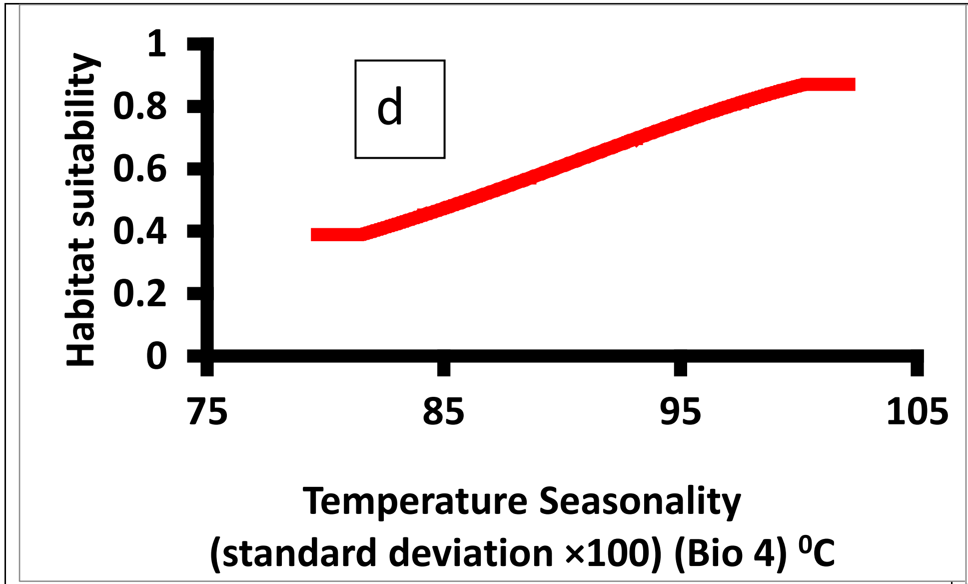
Habitat suitability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
b
11
12
13
14
15
16
Mean Diurnal Range
(Mean of monthly (max temp - min temp)(Bio2)(⁰C)

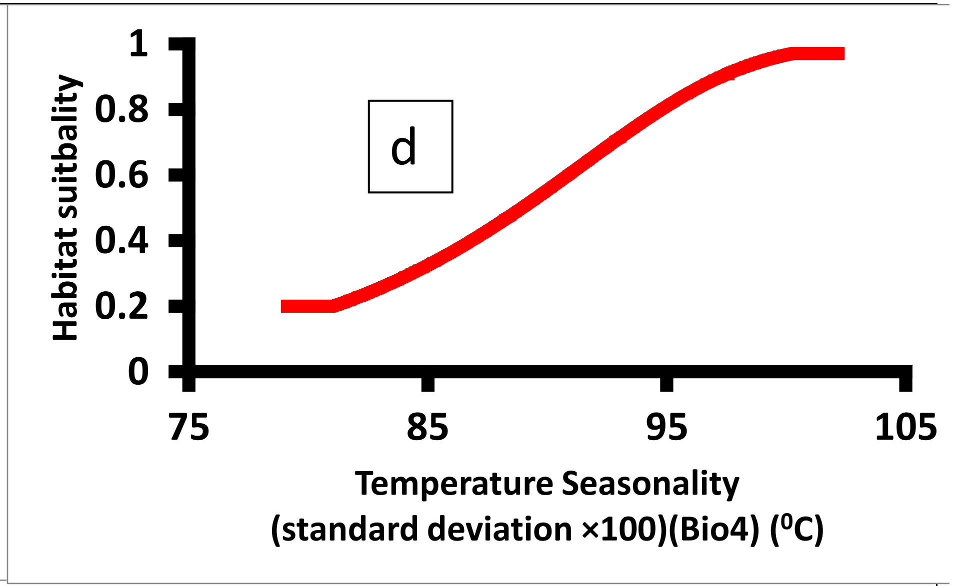


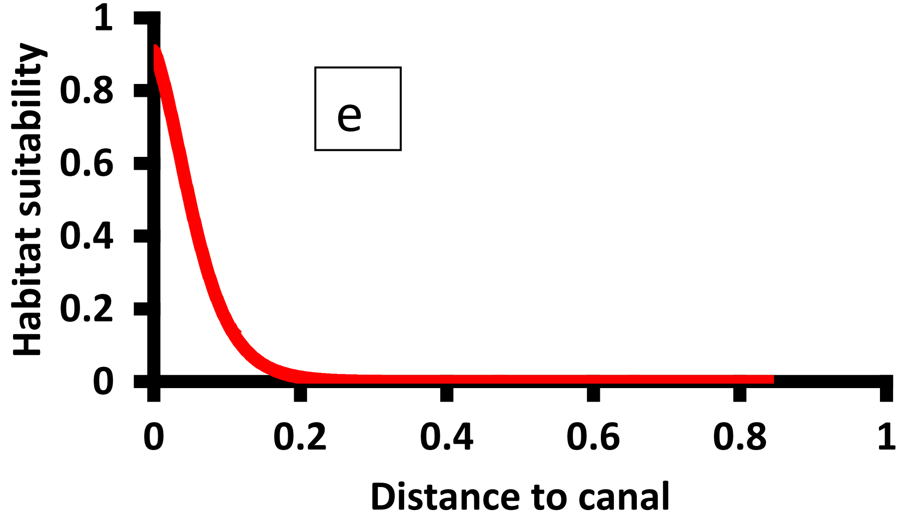
African elephant response curve
Habitat suitability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
b
10
11
12
13
14
15
16
Mean Diurnal Range (Bio2)


C
Habitat suitability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
74
76
78
80
82
84
Isothermality (Bio3) (%)

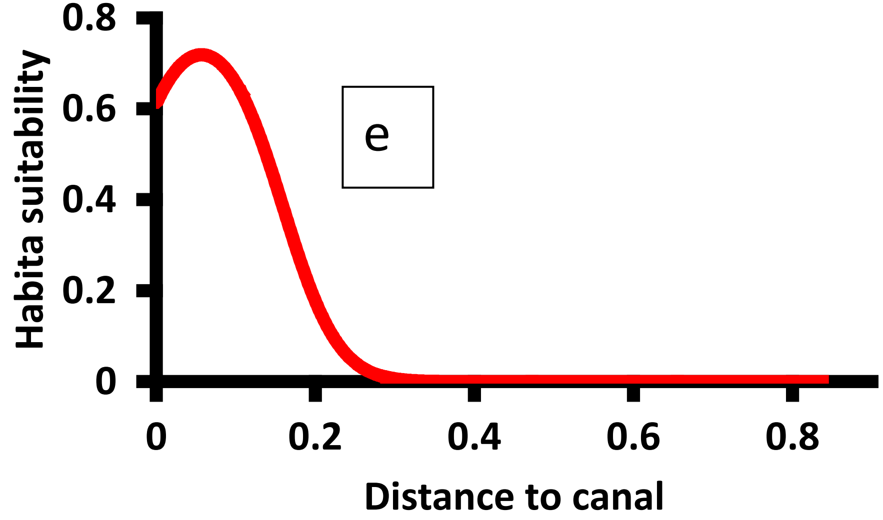

African elephant response curve
C
Habitat suitability
1
0.8
0.6
0.4
0.2
0
75
77
79
81
83
85
Isothermality (Bio3)


d
Habitat suitability
1
0.8
0.6
0.4
0.2
0
75
85
95
105
Temperature Seasonality
(standard deviation ×100) (Bio 4) ⁰C

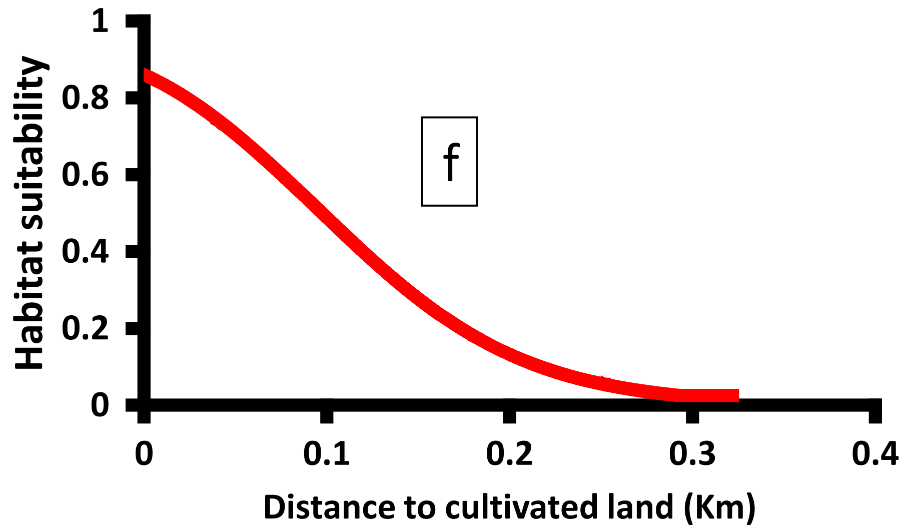

d
Habitat suitbality
1
0.8
0.6
0.4
0.2
0
75
85
95
105
Temperature Seasonality
(standard deviation ×100)(Bio4) (⁰C)



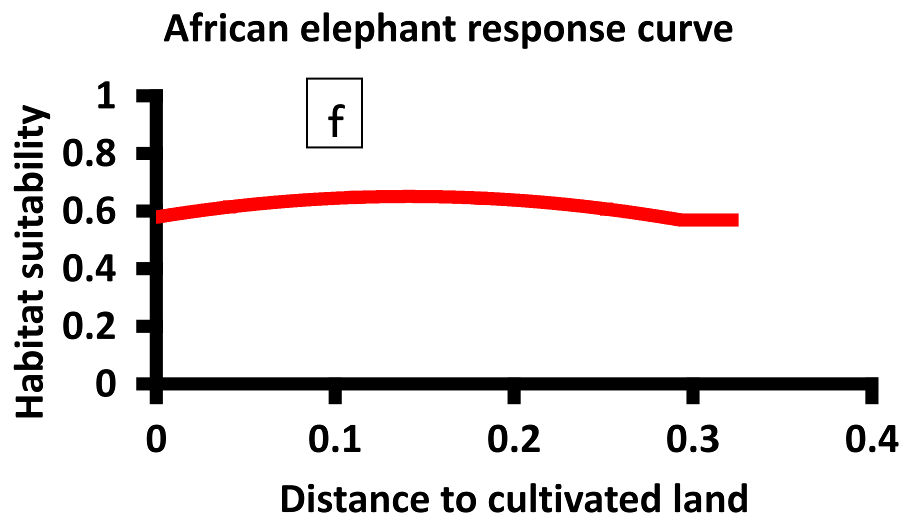
Habitat suitability
1
0.8
0.6
0.4
0.2
0
e
0
0.2
0.4
0.6
0.8
1
Distance to canal



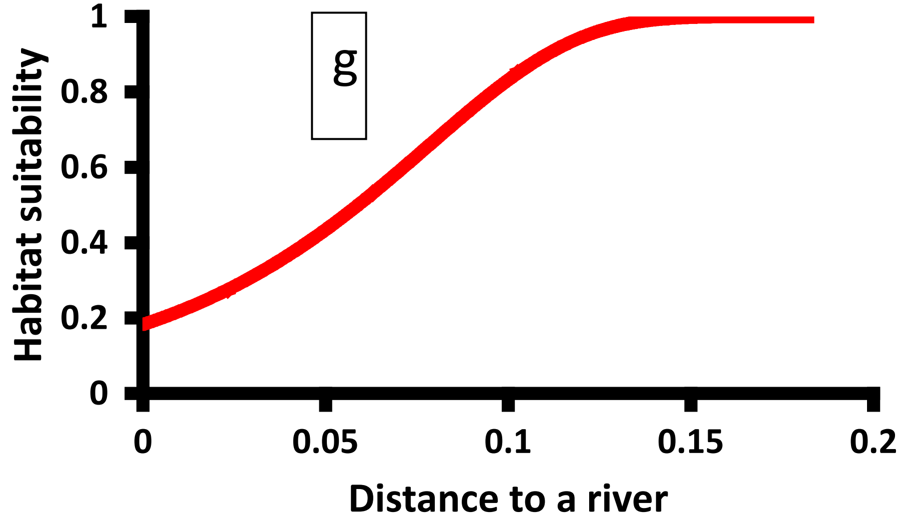
Habita suitability
0.8
0.6
0.4
0.2
0
e
0
0.2
0.4
0.6
0.8
Distance to canal

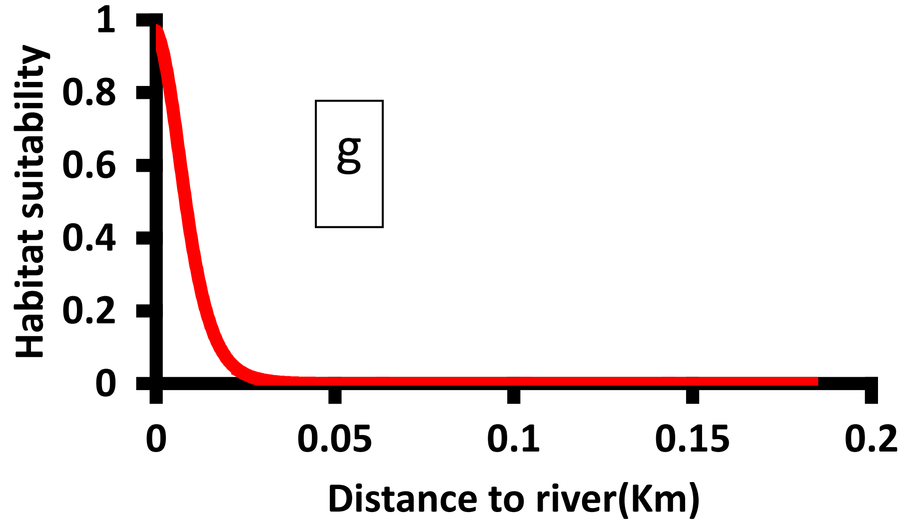


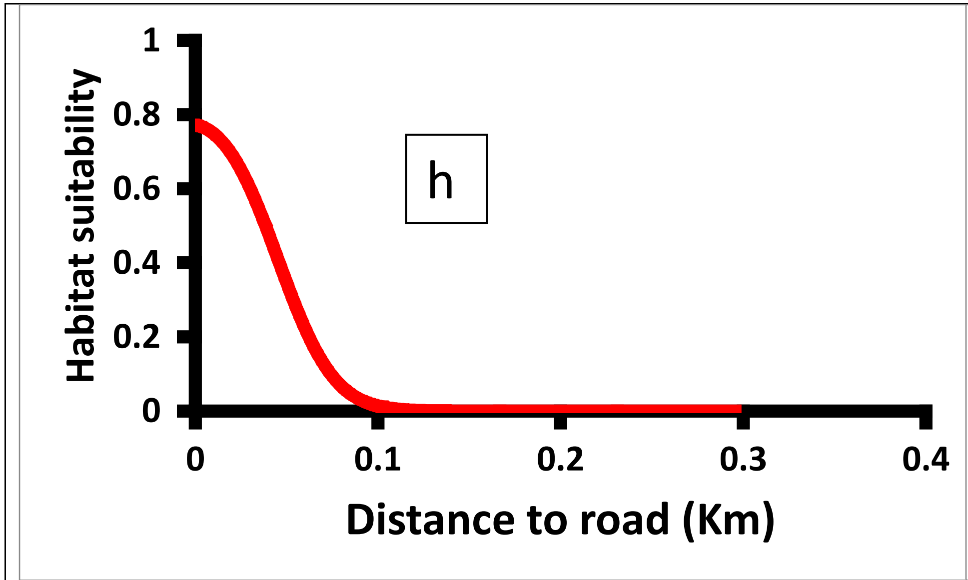
f
Habitat suitability
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
Distance to cultivated land (Km)

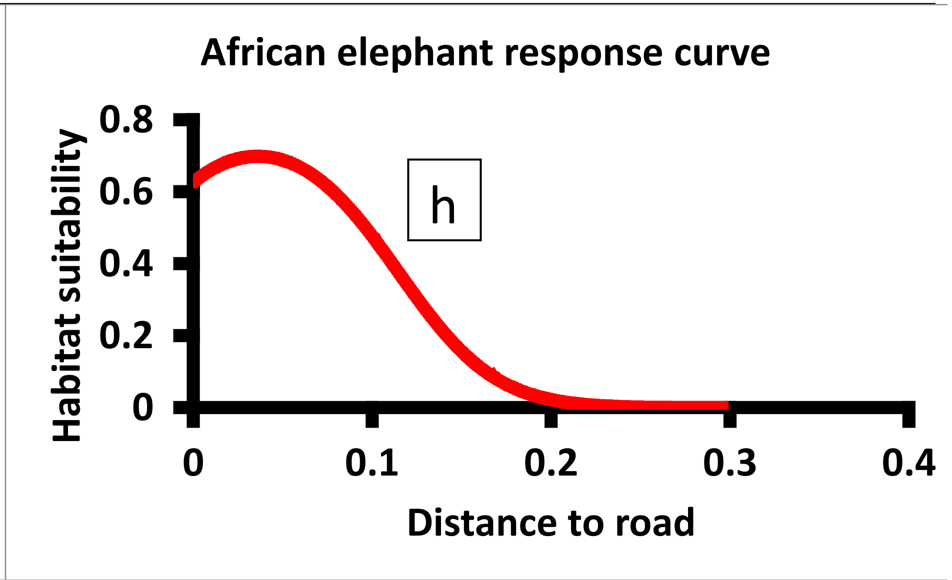


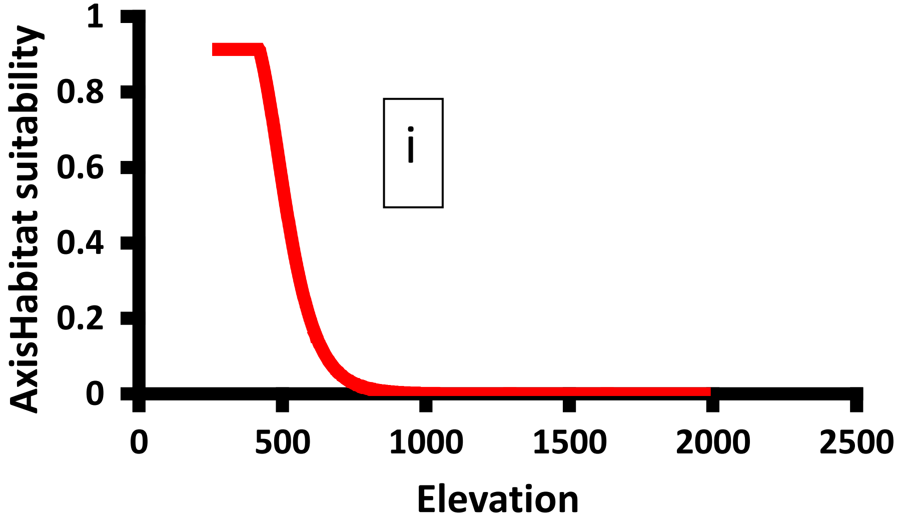
African elephant response curve
f
Habitat suitability
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
Distance to cultivated land


g
Habitat suitability
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
Distance to a river

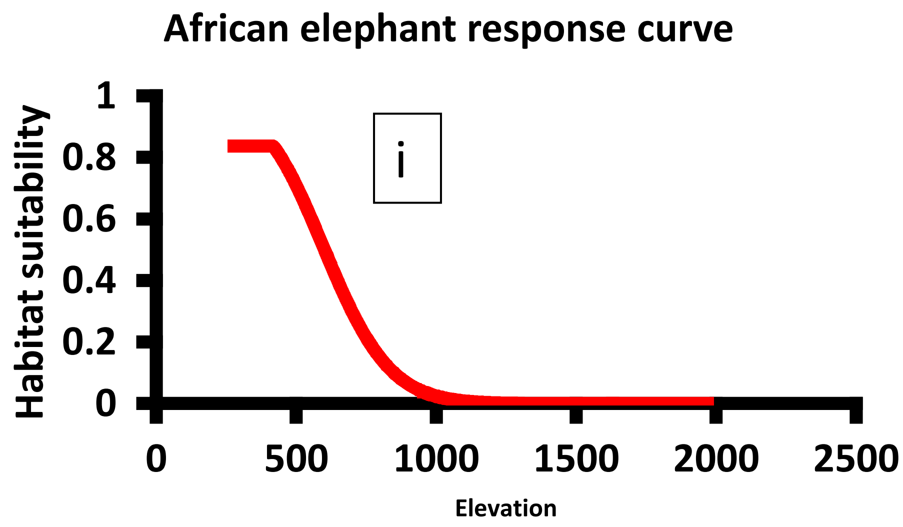

g
Habitat suitability
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
Distance to river(Km)


h
Habitat suitability
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
Distance to road (Km)

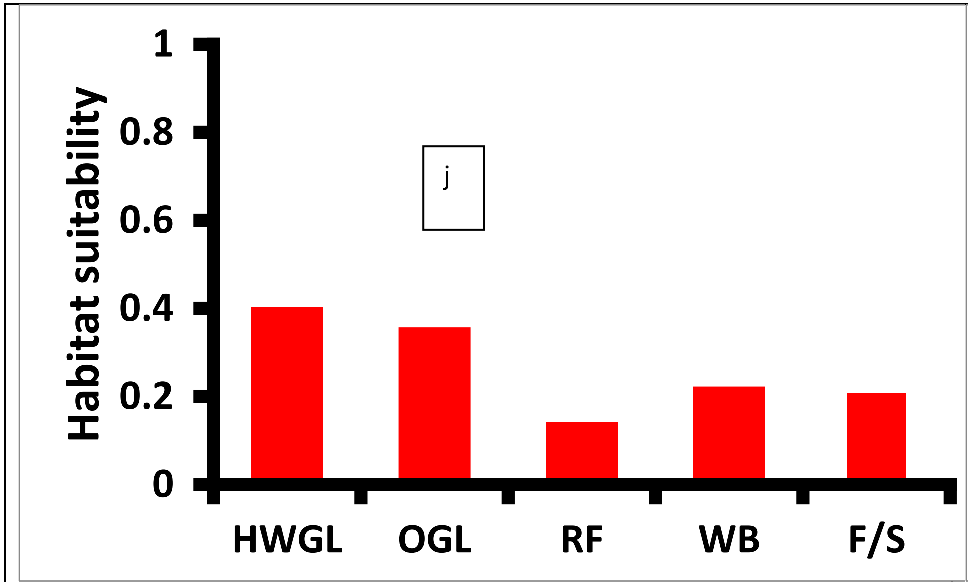

African elephant response curve
h
Habitat suitability
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
Distance to road



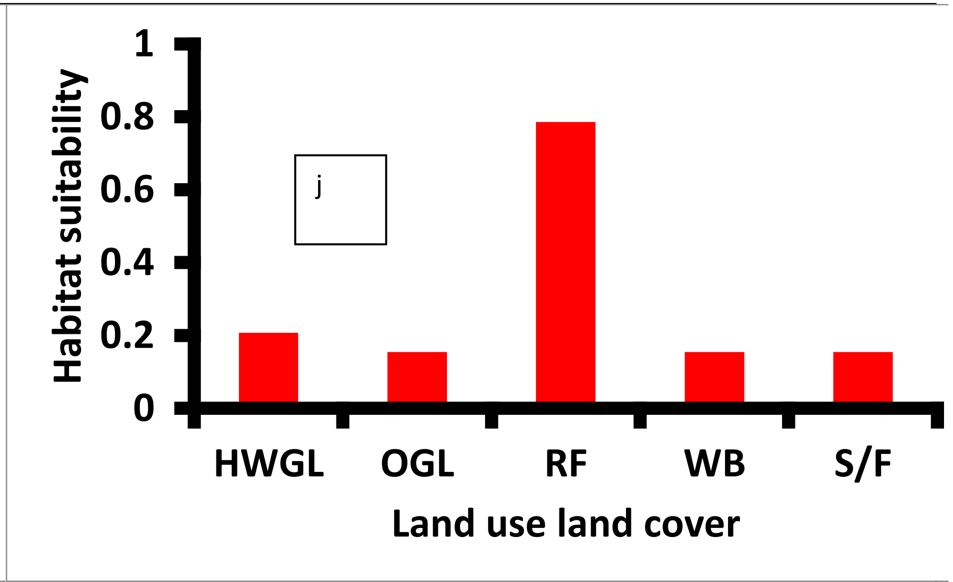
AxisHabitat suitability
1
0.8
0.6
0.4
0.2
0
i
0
500
1000
1500
2000
2500
Elevation



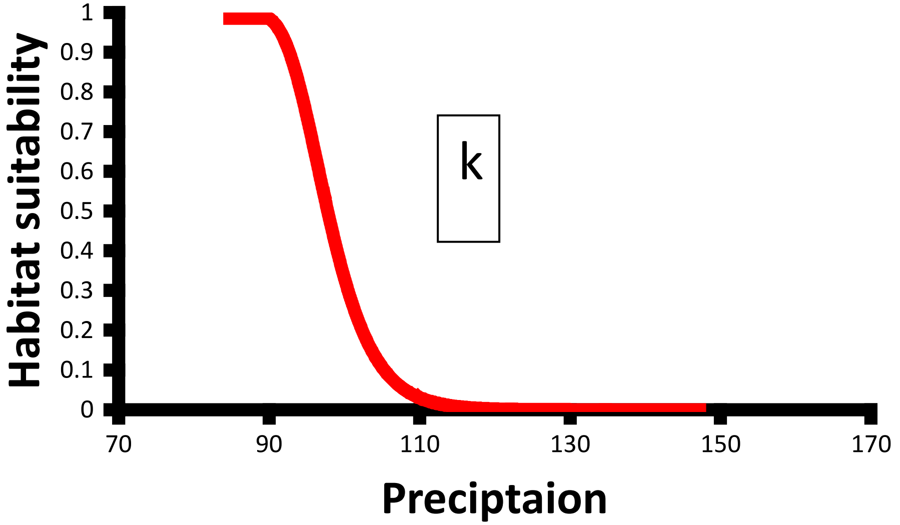
African elephant response curve
Habitat suitability
1
0.8
0.6
0.4
0.2
0
i
0
500
1000
1500
2000
2500
Elevation



Habitat suitability
1
0.8
0.6
0.4
0.2
0
j
HWGL
OGL
RF
WB
F/S



Habitat suitability
1
0.8
0.6
0.4
0.2
0
j
HWGL
OGL
RF
WB
S/F
Land use land cover



k

Dry season precipitation removed as found not useful for the model prediction

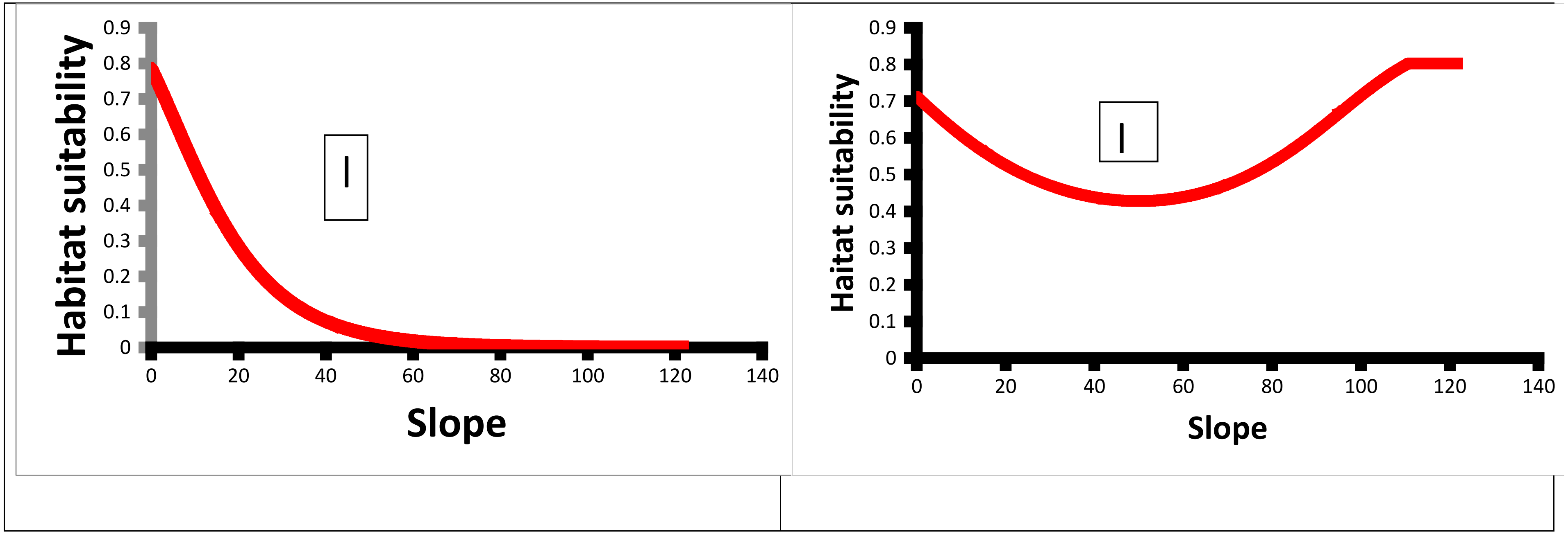
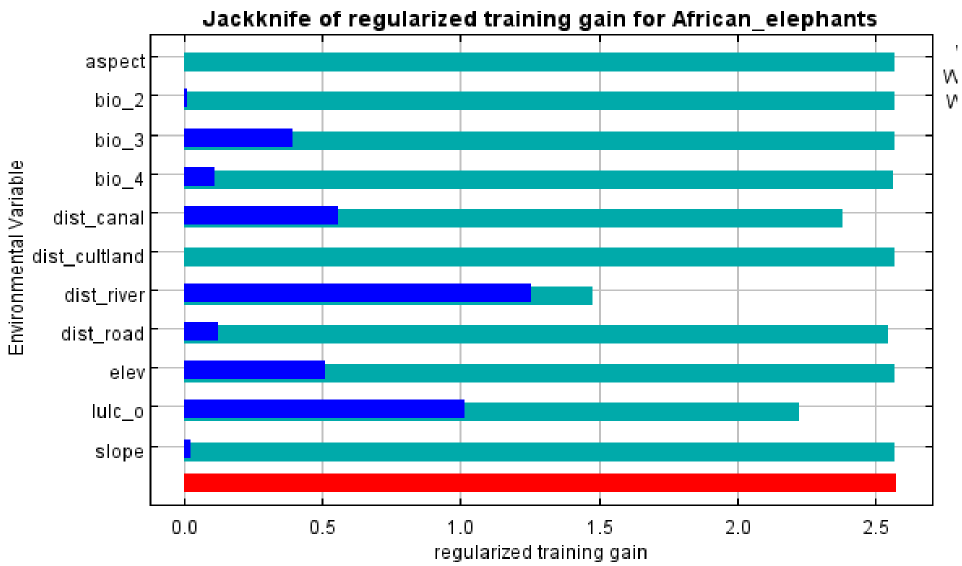
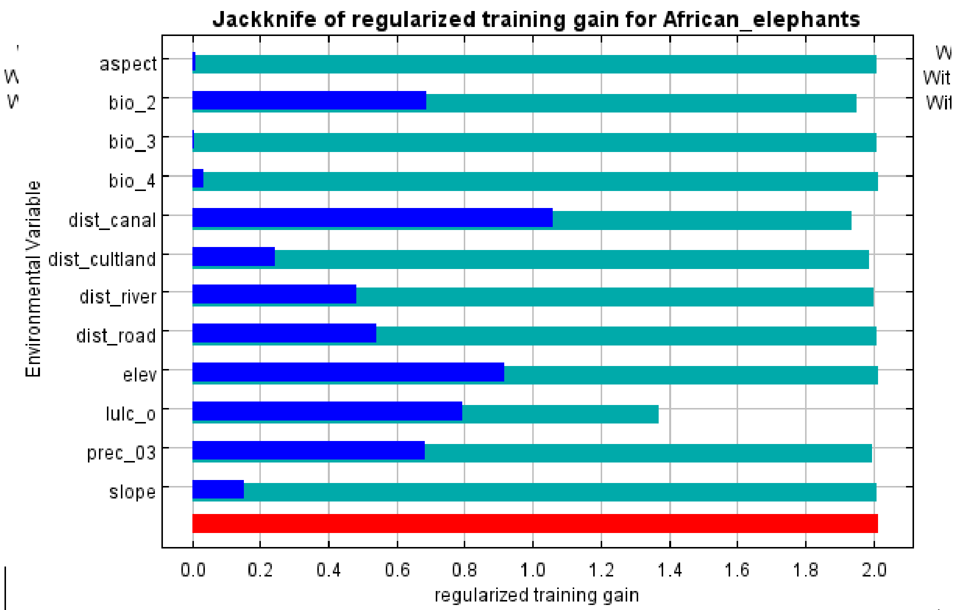
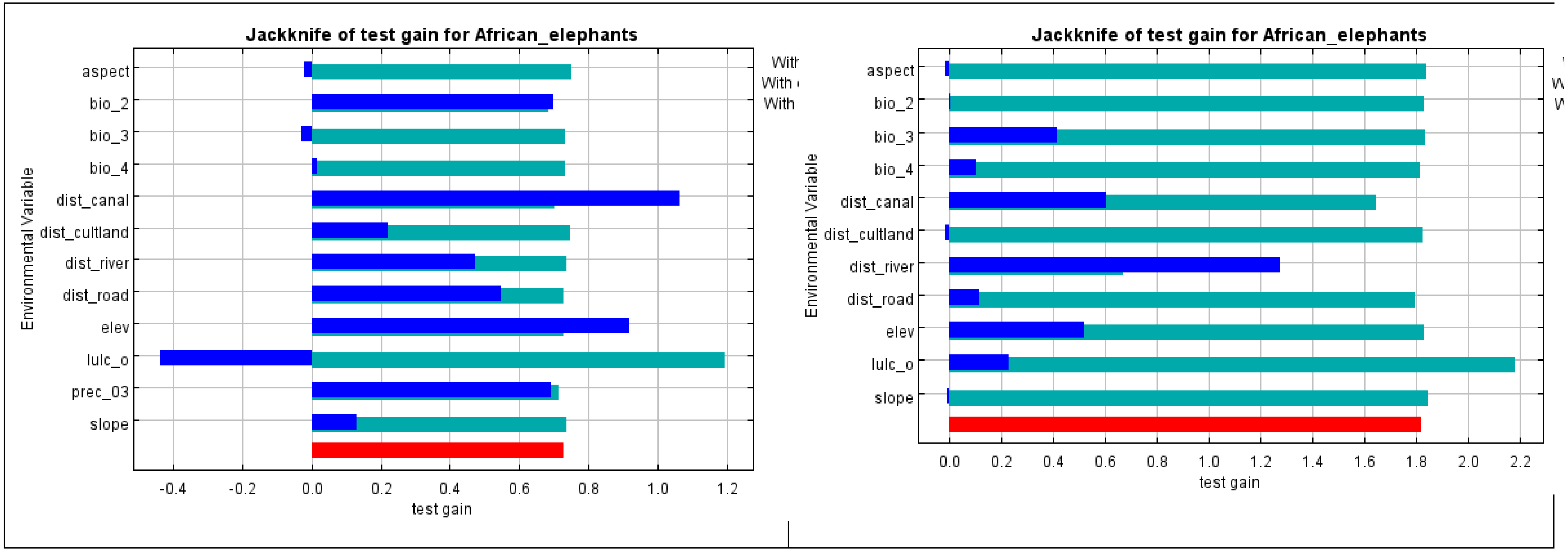


Figure 4. MAXENT model result of African elephant habitat suitability response curve (from a - l) for wet and dry seasons showing variables impacts on habitat suitability of Africa elephants *(Loxodonta africana).* HWGL: Herbaceous Wooded Grassland; OGL: Open Grassland; RF: Riverine Forest; WB: Water Bodies; F/S: Farming and Settlement. The **Response curves:-**Show how the habitat suitability influenced by the environmental variables. For categorical variables:-bar graph and for continuous variable's:- response curve.

Wet season Jackknife test	Dry season Jackknife test
	


Jackknife of test gain for African_elephants
Environmental Variable
aspect
bio_2
bio_3
bio_4
dist_canal
dist_cultland
dist_river
dist_road
elev
lulc_o
prec_03
slope
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
test gain
Jackknife of test gain for African_elephants
Environmental Variable
aspect
bio_2
bio_3
bio_4
dist_canal
dist_cultland
dist_river
dist_road
elev
lulc_o
slope
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
test gain

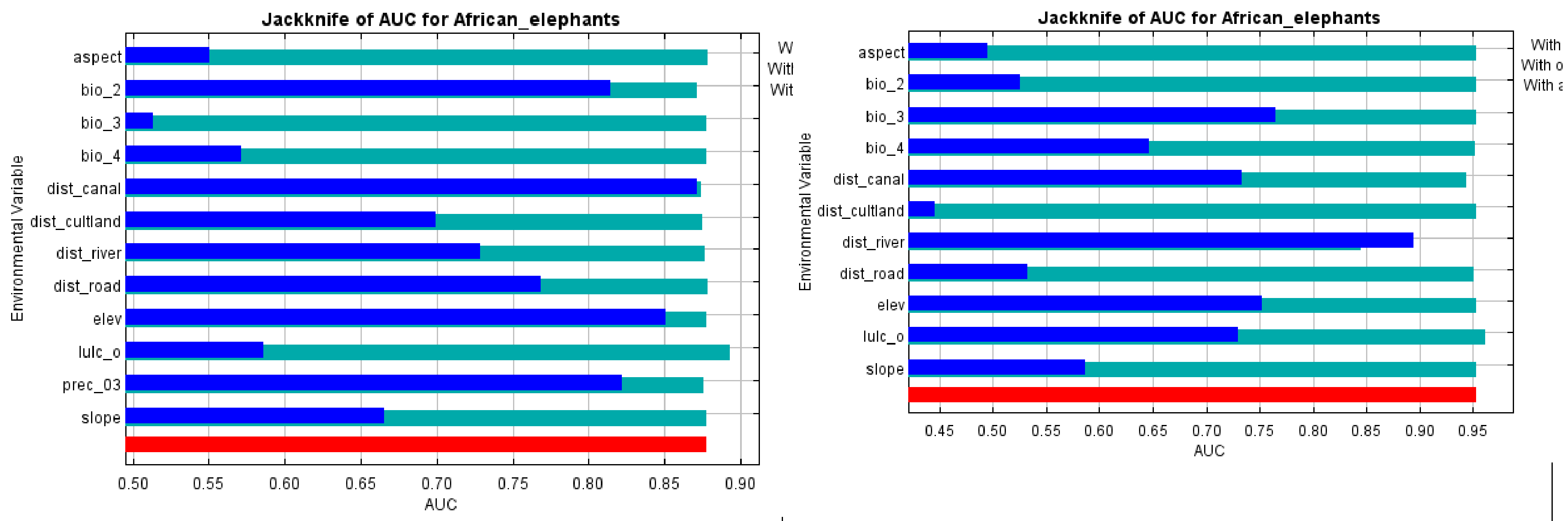


Figure 5. Jackknife results of variable importance in the regularized training gain(top), test gain (middle) and AUC test data(bottom) show the importance of all predictor variables in the MaxEnt Model of African elephant *(Loxodonta africana)* habitat suitability calculated from 10 replicates for wet season (left) and dry season (right) . (green bars: model performance – train gain – without variable; blue bars: model performance with variable only and red bars: model performance with all variables).. Bio2:Mean Diurnal Range; Bio3: Isothermality, Bio4:Temperature Seasonality;Dist_canal: distance from the canal; dist_Cultland: distance to the cultivated land; dist_river: Distance to the rivers; dist_road: distance to the roads; elev: elevation; lulc_o: land use land cover.

Table 4. African elephant range in Omo National Park (Optimum. Suitable, Moderately suitable and unsuitable habitats prepared using seasonal MaxEnt output maps in ArcGIS10.8)

Habitat suitability /seasons	Wet (AREA,N,19,11) km^2	Percent ,N,19,11 %	Dry(Area, N,19,11) km^2	Per cent ,N,19,11 %	Both season(Area,N, 19,11) km^2	Percent, N,19,11 %	Wet season km^2	Dry season km^2	Both season km^2
Optimum	311.88	6.2	29.0	0.6	364.67	7.19	311.9	28.9	364.7
Suitable	427.89	8.4	59.	1.2	747.79	14.74	427.9	59.3	747.8
Moderately Suitable	475.64	9.4	102.3	2	886.16	17.46	475.5	102.3	886.2
Unsuitable	3855.88	76.0	4945.9	96.3	3075.62	60.61	1215.4	190.6	1998.6
Total Area	5071.29	100	5136.5	100	5074.24	100			

Appendix C. Supplementary information on Land Use Land Cover change detection and species of mammals in ONP

Table 1. USGS earth explorer used to download Satellite images for the LULC changes analysis.

Date, Month and Year of acquisition	**Type**	**Landsat**	**Path**	**Row**	**Resolution**
21, Dec 1993	Collection 2 and Level 2 science products	Landsat 05	170	056	30 m x 30 m
28, Dec 2003		Landsat 07	170	056	30 m x 30 m
31, Dec 2013		Landsat 08	170	056	30 m x 30 m
19, Dec 2023		Landsat 09	170	056	30 m x 30 m

Tabel 2 LULC classification accuracy assessment ONP (1993, 2003, 2013 and 2023)

Accuracy assessment							
LULC 1993							
	OG	SWG	WL	BL	F	WB	Total user
OG	15	2	0	0	0	0	17
SWG	0	17	0	0	0	0	17
WL	0	1	16	0	1	0	17
BL	0	1	0	16	0	0	17
F	0	0	2	0	15	0	17
WB	0	0	0	0	1	16	17
Total producer	15	21	18	16	17	16	102
User Accuracy	88.2	100	94.1	94.1	88.2	94.1	
Producer Accuracy	100	80.9	88.9	100	88.2	100	
Over all accuracy	0.93						
Kapa Coeffecient	TS=	102	TS*TCS	9690	CT-RT	1751	
	TCS=	95					
			up value	7939	KC =	91.75	
	TS^2 =	10404	Down value	8653			
Accuracy assesment							
LULC 2003							
	OG	SWG	WL	BL	F	WB	Total user

OG	12	1	1	1	0	0	15
SWG	1	13	1	0	0	0	15
WL	0	0	13	1	1	0	15
BL	0	1	1	14	0	0	15
F	0	3	0	0	12	0	15
WB	0	0	0	0	0	15	15
Total producer	13	18	16	16	13	15	90
User Accuracy	80	86.7	86.7	93.3	80	100	180
Producer Accuracy	92.31	72.2	81.3	87.5		92.3	
Over all accuracy	0.9					26	
Kapa Coeffecient (KC)	TS=	90	TS*TCS	7110	CT-RT	1365	
	TCS=	79					
			up value	5745	KC =	85.3	
	TS^2 =	8100	Down value	6735			

Accuracy assessment

LULC 2013

	OG	SWG	WL	BL	F	WB	Total user
OG	16	0	1	1	0	0	18
SWG	1	16	1	0	0	0	18
WL	0	0	17	0	1	0	18
BL	0	1	0	17	0	0	18
F	0	3	0	0	15	0	18
WB	0	0	0	0	0	18	18
Totla prodcuer	17	20	19	18	16	18	108
User Accuracy	88.9	88.9	94.4	94.4		83.3	100
Producer Accuracy	94.1	80	89.5	94.4		93.8	100
Over all accuracy	0.92						
Kapa Coeffecient (KC)	TS=	108	TS*TCS	10692	CT-RT		3744
	TCS=	99					

			up value	6948	KC =	87.73	
	TS^2 =	11664	Down value	7920			
Accuracy assessment							
LULC 2023							
	OG	SWG	WL	BL	F	WB	Total user
OG	17	0	0	1	0	0	18
SWG	1	16	1	0	0	0	18
WL	0	0	17	0	1	0	18
BL	0	1	0	17	0	0	18
F	0	0	3	0	15	0	18
WB	0	0	0	0	0	18	18
Total producer	18	17	21	18	16	18	108
User Accuracy	94.4	88.9	94.4	94.4		83.3	100
Producer Accuracy	94.4	94.1	81	94.4		93.8	100
Over all accuracy	0.92						
Kapa Coeffecient (KC)	TS=	108	TS*TCS	10800	CT-RT	3744	
	TCS=	100					
			up value	7056	KC =	89.1	
	TS^2 =	11664	Down value	7920			

Key:- Kapa Coeffcient =(TS x TCS) -∑ CT*TR/TS2--∑ CT*TR; TS= Total Sample; CT= Column Total
TCS= Total Corrected Sample; RT + Row Total; KC=Kapa Coeffecient
Key :WB=water bodies ; F=Forest, OG=Open grassland, BL=Bush land, SWG=Savanna wooded grassland; WL= Woodland

Table 3. Large mammal fauna of ONP

Order	Scientific name	English name
Primate	*Gelato senegalensis*	Bush baby
	Papio cynocephalus	Savanna baboon
	Cercopithecus *aethiops*	Vervet Monkey
	Cercopithecus *neglectns*	DeBraza’s Monkey
	Ceropithecus *initis*	Blue/Sykes monkey
	Colobus gureza	Gureza
Artiodactyls	*Phacochoerus africanus*	Warthog
	Hylochoerus mein ertzhageni	Giant forest hog
	Hippoptamus amphibious	Hippopotamus
	Syncerus coffer	African Buffalo
	Tragelapus strepsiceros	Greater kudu
	Tragelapus scriptuss	Bushbuck
	Potamochoerus larvatus	Bush pig
	Kobus ellipsipprymus	Waterbuck
	Otocyon megaloties	Bat eared fox
	Giraffa ***Camelopardalis***	Giraffe
	Sy/ vicapra oreotragus	Common Duiker
	Alcelaplms buselophus lelwel	Lelwel Hartebeest
Proboscideans	*Loxodanta africana*	Savanna Elephant
Carnivora	*Cams mesomelas*	Blacked backed Jackal
	Canis aureus	Golden Jackal
	Mellovora capensis	Honey Badger (Ratel)
	Civettictis civetta	African Civet
	Genetta spp	Genet cat
	Ichneumia albicaucla	White tailed mongoose
	Galerellaflavescens •	Black slender mongoose
	Croatia crocuta	Spotted Hyena
	Panthera paradns	Leopard
	Panthera leo	Lion
	Felis silvestris	African wild cat
	Leptailurus serval	Serval Cat
	Ictonyx strktius	Striped polecat
	Acinonyx jubatus	Cheetah
	Lycaon pictus	Hunting dog
	Taurotragus oryx	Common eland
	Nanger granti	Grant’s gazelle
	Caracal caracal	Caracal
Tubulidentata	*Orycteropus afer*	Aardvark
Pholidota	*Manis temmincki*	Pangolin

Rodentia	*Hystrix cristata* *Xerus erythropus* *Helosciurus gambianus*	Porcupine Ground squirrels Gambian sun squirrel
Hyracoidea.	*Procavia capensis*	Rock hyrax
Odd-toed ungulates	*Diceros bicornis*	Black Rinoceros (suspected around)

Table 4. List of cross-border elephant populations across Africa (source: Lindsay, *et al.,* 2017).

Region/s	Transboundary population name	Countries	Popu.Est.	Appendix
West	Djambamakrou-Bia Cote d'Ivoire-	Ghana	176	I/I
	Ziama-Wenegisi	Guinea-Liberia	114	I/I
	Gola transfrontier area	Liberia-Sierra Leone	450	I/I
	Gourma	Mali-Burkina Faso	304	I/I
	WAP complex	Niger-Benin-Burkina Faso	8936	I/I
	Kainji Lake + Benin border	Nigeria-Benin	7	I/I
	Oti-Keran-Mandori -	Togo-Benin-Burkina Faso	10	I/I
W-C	Takamanda-Cross River	Nigeria-Cameroon	20	I/I
W-C	Waza - Chad Basin	Nigeria-Cameroon	496	I/I
W-C	Cross River NP - Mbe Mtns./Korup	Nigeria-Cameroon	84	I/I
Central	Bouba N'djida - Sena Oura - Benoue -	Cameroon-Chad	107	I/I
	Sangha Tri-National Landscape	Cameroon-Congo-CAR	14,372	I/I
	Rio Campo-Campo Ma'an Landscape	Cameroon-Equa. Guinea	839	I/I
	Tridom	Cameroon-Gabon-Congo	25,572	I/I
	Binder-Léré, Waza	Chad-Cameroon	132	I/I
	Dembo+ CAR	border Chad-CAR	20	I/I
	Conkouati-Mayumba-	Mayombe Congo-Gabon	1306	I/I
	Mount Fouari	complex Congo-Gabon	200	I/I
	Ogooue-Leketi - Bateke	Congo-Gabon -	537	I/I
	Birougou + Mayoko	Gabon-Congo	556	I/I
	Southwest Chad	Chad-Cameroon	64	I/I
	Monte Alen - Monts de Mitra	Equatorial Guinea-Gabon	3300	I/I
C-E	Garamba Ecosystem	DRC-South Sudan	1924	I/I
C-E	Greater Virunga	DRC- Uganda-Rwanda	3105	I/I
C-S	Angola S DRC	DRC-Angola	20	I/I
C-S	Swa Kibula I	DRC-Angola	20	I/I
	Gash-Setit - Kafta-Sheraro	Eritrea-Ethiopia	400	I/I

East	Gambella NP/Boma NP	Ethiopia-South Sudan	606	I/I
	Omo NP, Mago NP/Loelle NP	Ethiopia-South Sudan	491	I/I
	Lamu - Lag Badana	Kenya-Somalia /	60	I/I
	Amboseli - Kilimanjaro-Magadi-	Kenya-Tanzania	3098	I/I
	Mara-Serengeti	Kenya-Tanzania	7615	I/I
	Tsavo-Mkomazi	Kenya-Tanzania	11,217	I/I
	Boma-Badingilo	South Sudan-Ethiopia	606	I/I
	Nimule-Otze	South Sudan-Uganda	124	I/I
	Kidepo complex	South Sudan-Uganda-Kenya	621	I/I
E-S	Selous-Niassa	Tanzania-Mozambique	21,640	I/I
South	KAZA Angola-Zambia-Namibia-	Botswana-Zimbabwe	201,977	I/I/II/II*/II
	Greater Mapungubwe TFCA	Botswana-S.A-Zimbabwe	1449	II*/II/II
	Nyika + Zambia border	Malawi-Zambia	47	I/I
	Maputo-Tembe	Mozambique-South Africa	568	I/II
	Limpopo TFCA	Mozambique-Zimbabwe-S.A	33,785	I/II/II
	Songimvelo-Malolotja	South Africa-Swaziland	108	II/I
	Lower Zambezi - Mana Pools	Zambia- Zimbabwe	12,782	I/II
	Nyatana - Tete	Zimbabwe-Mozambique	634	II/I
			360,499	

Appendix D. Publications

Girma Timer Jeza, and Afework Bekele, (2023). Seasonal distribution model of African elephants (*Loxodonta africana*) under a changing environment and land use in Omo National Park, Ethiopia. *Journal of Wildlife and Biodiversity* **7(3):** 96–117. DOI: 10.5281/zenodo.7783039

Girma Timer Jeza and Afework Bekele (2024). Land covers changes and impact on the African elephant conservation in Omo National Park, Ethiopia. *Journal of Wildlife and Biodiversity* **8(2):** 103-121. DOI: https://doi.org/10.5281/zenodo.11108561

Girma Timer Jeza and Afework Bekele (2025). Feeding ecology of African elephant (*Loxodonta africana*) in Omo National Park, Ethiopia. (*n) in press)*