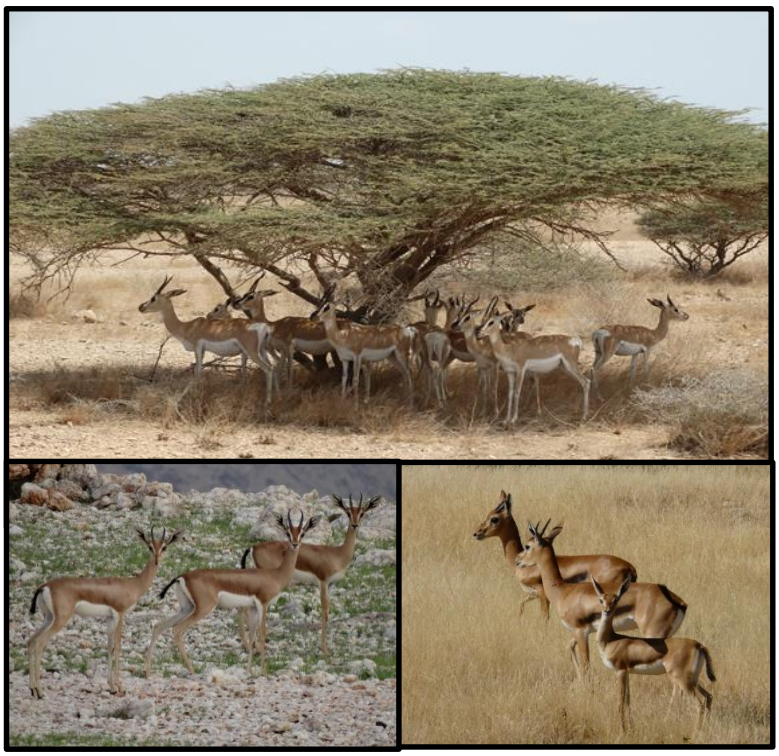
Università di Pavia

Department of Earth and Environmental Sciences

Ecological Distribution, Abundance and Conservation Status of the Three Indigenous Species of Gazelles: *Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura* in Eritrea

By Futsum Hagos



Thesis submitted to the Department of Earth and Environmental Sciences, University of Pavia in partial fulfillment of the requirements for a degree of Doctorate of Science (Biology of Conservation).

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Declaration

This thesis is my original work and has not been presented for a degree in any other University to the best of my knowledge. No part of this thesis should be reproduced without prior permission of the author and/or the University of Pavia.

Signature ፍጹምሓጎስ Date 5/09/2023

Dedication

This thesis dedicated to my beloved parents, my father the late Keshi Hagos Gebremariam and my mother Tiberh Gebremichal for their inexhaustible love and support. May the almighty God rest the soul of my father in peace and let his prayers remain with us? Amen!

I also dedicate it to my brothers and sisters together with their family for continuous support, prayers and encouragement. I truly value their support and encouragement, which has been immense.

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List of Acronyms

BCM	Billion Cubic Meters
CBD	Convention on Biological Diversity
CITES	Convention on International Trade for Endangered Species
CLT	Cultivation Land
CoP	Conference of Parties
CPCs	Climatic principal components
DoE	Department of Environment
DOWR	Department of Water Resource
EPI	Elephant Protection initiatives
EPHS	Eritrea Population and Health Survey
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographical Information system
GLM	Generalized Linear Model
GM	General Manager
GoE.	Government of Eritrea
GWA	Global Wildlife Association
HDI	Highest density intervals
HSM	Half sample mode
IBA	Important Bird Area
ICAM	Integrated Coastal Area Management
IUCN	International Union for conservation of nature
LCCS	Land Cover Classification System

LPC	Livestock composition
MoA	Ministry of Agriculture
MoLWE	Ministry of Land Water and Environment
MoMR	Ministry of Marine resources
MoT	Ministry of Tourism
NAP	National Action Plan
NBSAP	National Biodiversity Strategic Action Plan
NEMP-E	National Environment Management Plan for Eritrea
N_{max}	observed maximum count
NSO	National Statics office
NUEW	National Union of Eritrean Women
OGR	Open grassland
OSG	Open shrub grassland
PA	Protected area
PCA	Principal Component Analysis
SCRS	Scrubland on rocky and stony ground
SCR	Scrubland
SHC	Closed shrubs
SPSS	Statistical Package for Social Sciences
SSG	Species special Group
UNCCD	United Nation Convention to Compact Desertification
URB	Urban areas
Urb	Urban / settlement
VEG	Vegetation
WRB	Riverbanks
ZIP	Zero-Inflated-Poisson

Chapter 1 Introduction

Recurrent droughts and chronic armed conflicts in the Horn of Africa have significantly influenced the abundance and distribution of terrestrial wildlife in the region (Bauer et al., 2020). This is the case in Eritrea too, where assessment reports from the nineties after the country emerged from a 30-year-long war (1961-1991) as an independent state in 1991, recognized that habitat degradation, war and drought had caused serious loss of wildlife. During the war of the independence, a large numbers of wild animals were killed for food and others who were forced to live primarily off the land. Moreover, during the Italian colonial era, hunting licenses used to be issued subsequently a number of terrestrial wildlife species had gone locally extinct while others were reduced to the brink of extinction (GoE, 1995). The extirpated species included black rhinoceros (*Diceros bicornis*), African buffalo (*Syncerus caffer*), beisa (*Oryx gazella*), Grevy's zebra (*Equus grevyi*) and giraffe (*Giraffa camelopardalis*) (Yalden, 1984; DoE, 2008; Bekele, &Yalden, 2013 and Gippoliti (2020)). Other species including the populations of the three gazelle species indigenous to the region, i.e. Soemmerring's gazelle (*Nanger soemmerringii*), Dorcas gazelle (*Gazella dorcas*), and Eritrean gazelle (also known as Heuglin's gazelle; *Eudorcas tilonura*), were found to be in severe decline (IUCN, 2017).

With the establishment of peace after the independence, policies and practices were adopted, including restrictions on hunting, the establishment of protected areas, and preparation of a national environmental management plan (NEMP-E) that emphasized community engagement. These measures are credited with the restoration of biodiversity (GoE, 1995). The intervention had remarkable contribution on the revival of global threatened iconic species such as African elephant (*Laxodanta africana*), African wild ass (*Equus africanus somaliensis*) and the three gazelle species (IUCN, 2002; DoE, 2015; and Hagos, 2019).

Populations of the three-gazelle species in some parts of the country are still roaming. However, detailed information on their conservation status, their current ranges, abundance and the ecology of their habitats are lacking. So far, various attempts carried out to establish the status of *Nanger soemmerringii* in coastal and island areas are now in place (DoE, 2010). However, there have been no studies on the status of mainland populations of the three species represent evidence of gap of knowledge.

The study organisms

This study targeted three threatened gazelle species, namely: Soemmerring's gazelle (*Nanger soemmerringii*), Dorcas gazelle (*Gazella dorcas*) and Eritrean gazelle (*Eudorcas tilonura*).

Soemmerring's gazelle (*Nanger soemmerringii*) (Cretzschmar, 1828)

Kingdom	Phylum	Class	Order	Family	Subfamily	Tribe	Genus
Animalia	Chordataur	Mammalia	Artiodactyla	Bovidae	Antilpinae	Antilopini	Nanger

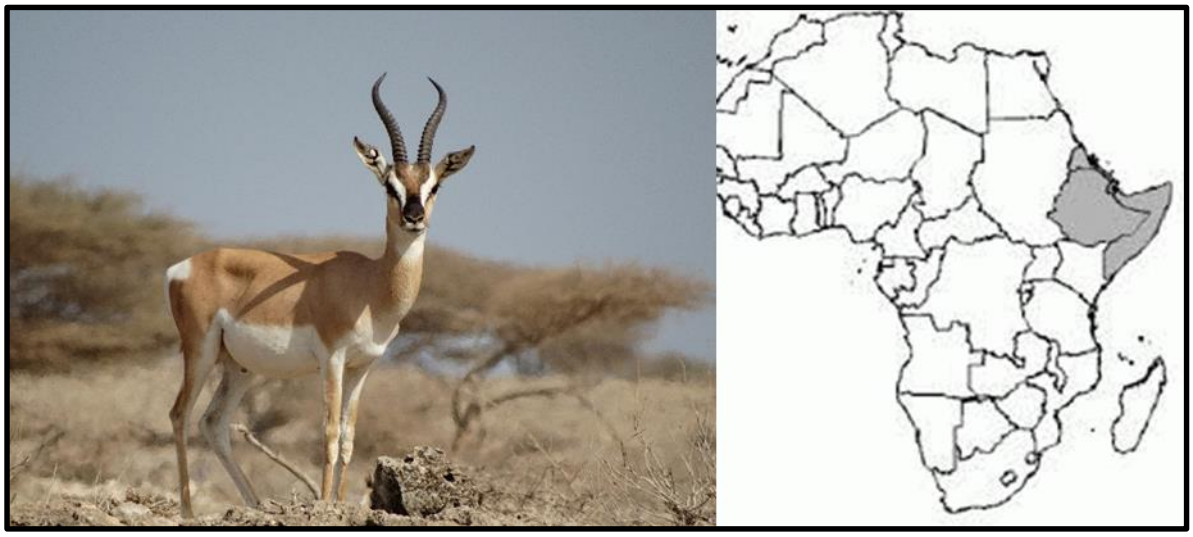

Figure 1.1 Soemmerring's gazelle and its geographical distribution

The Soemmerring's gazelle *Nanger soemmerringii* is one of the few remaining understudied species of the order Artiodactyla. It inhabits savannas, scrublands and grasslands in Eritrea, Ethiopia, Djibouti and Somalia and Sudan (Yalden et al., 1984; IUCN 2017); the Sudanese population has probably been extirpated (Schloeder and Jacobs, 2013). The remaining populations dwell in five separate areas: 1) Somalia; 2) the Ogaden region in southeastern Ethiopia; 3) the western lowlands of Eritrea; 4) the Afar Triangle (Ethiopia, Djibouti and Eritrea); 5) the Dahlak Archipelago (IUCN, 2016). Slight morphological differences prompted the description of a number of subspecies, of which only three are now recognized (Wilson and Reeder, 2005; Schloeder and Jacobs, 2013). East (1999) estimated the total population at about 14,000 but a decline has occurred recently in Ethiopia (Gebremedhin and Yirga, 2005) and elsewhere, to give a recent estimate of a total population below 4,500 adults (IUCN, 2016), coupled with a fragmented range. Consequently, the species is classified as vulnerable (IUCN, 2016). In Eritrea, the species is still present in the Danakil region, on Dahlak Kebir Island, and in some areas of the western lowlands (Nile River catchment). The species is legally protected, as any hunting of wild animals in the country is forbidden. Eritrean rangers patrol some areas, but enforcement is facing several bottlenecks.

These gazelles are particularly abundant in Dahlak Kebir Island, probably due to the lack of terrestrial predators and the benign attitude of the local Dahlik and Afar peoples, who have

conservation ethics and respect the gazelles. The local people in the coastal and Island believe that God sends the rain for the sake of wild animals, not for humans and killing the gazelles would mean God would prevent the rain from falling (Yohannes, 2001; Hagos. 2016), thus such attitude could help conservation measures towards the species. As suggested byYohannes (2001) estimated a population as high as 4,000-4,500 individuals on this island but a recent estimate is missing (Mallon, 2014). The origin of the island population of the species is still a mystery (Masseti et al., 2015). Gazelles have been reported for Dahlak Kebir since the end of the 18th century. They might have colonized the island during the Last Glacial Maximum when the sea level was lower. Other sources claim that periodical droughts extirpated the gazelles in the past and that people trans located specimens from the continent in order to re-establish the insular population a hundred years ago (Masseti et al*.,* 2015).

It was reported that the Dahlak Kebir gazelles are smaller than those of the mainland, an example of insular dwarfism (Lomolino, 2005) and the females sport smaller and more irregularly shaped horns (De Marchi *et al*., 2013). In addition, it was suggested that dwarfism of the Dahlak gazelles may result from directional selective pressures favoring the survival of small and less food demanding individuals (Masseti *et al.,* 2015). Or else it may be the result of phenotypic plasticity related to nutrient deficiency, an explanation suggested for the Arabian gazelles of the Farasan Islands of Saudi Arabia (Lerp et al., 2014). It was also speculated that there is limited interspecific competition and predation affecting the Dahlak Kebir gazelles and that this has led to a reduction in their body size over generations (Ibrahim *et al,.* 2020). Furthermore, study that is more recent hypothesized that, the up normality could be also resulted from phenotypic plasticity related to nutrient deficit (Chiozzi *et al*., 2021).

Little is known on the ecology of the insular population. Interestingly, during periods of high-temperature, Dahlak Kebir gazelles sometimes wade into the sea (Pers.obser. 2020). This behavior might be for thermoregulation, but Schloeder and Jacobs (2013) reported that when grass is lacking during the dry season, the gazelles move from the interior open-scrublands to forage on the mudflats on algae growing in the shallow coastal waters. Whether this thermoregulatory or foraging behavior is present also in the continental coastal population is currently unknown. More generally, it is not known whether the dwarf gazelles of Dahlak Kebir have different foraging habits and diet or a different social structure compared to the mainland populations. The coastal area population of gazelles also appears viable because the population size and structure remain stable (Yohannes, 2001). However, the status of the population in the

southwestern part of Eritrea remains unknown. Nonetheless, currently Eritrea is a stronghold for the conservation of the Soemmerring's gazelle (Mallon, 2014).

Dorcas gazelle (*Gazella dorcas)* (Linnaeus, 1758)

Kingdom	Phylum	Class	Order	Family	Subfamily	Tribe	Genus
Animalia	Chordataur	Mammalia	Artiodactyla	Bovidae	Antilpinae	Antilopini	Gazella

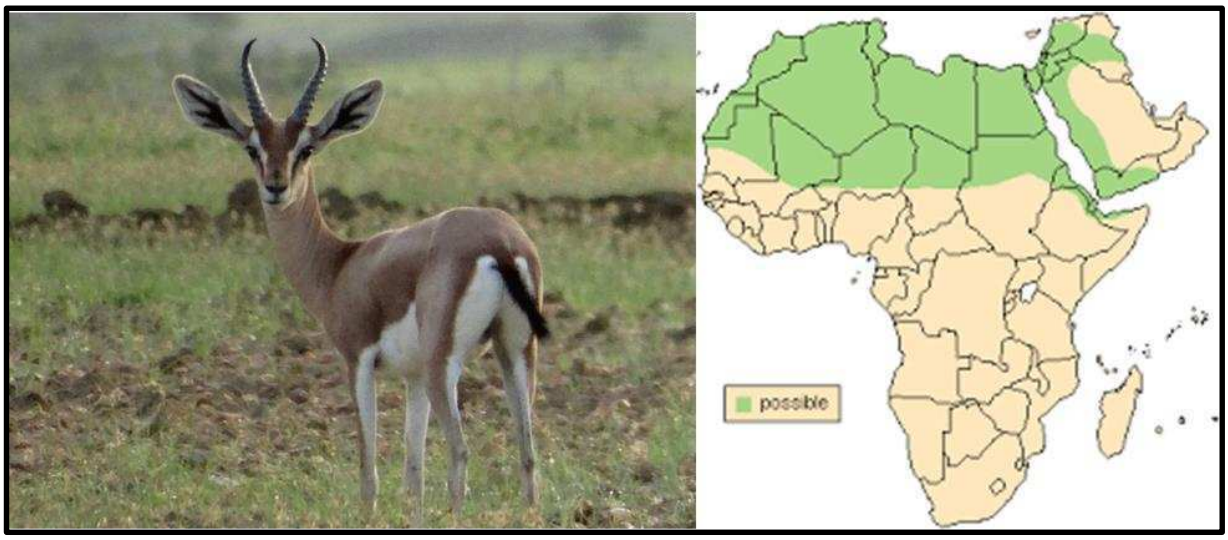

Figure 1.2. Dorcas gazelle and its geographical distribution

The species has a Sahelian distribution in sub-Saharan Africa. The native distribution of Dorcas gazelle includes parts of Algeria, Burkina Faso, Chad, Djibouti, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Sudan, Syria, Eritrea, Ethiopia, Israel, Senegal, Jordan and Tunisia (Abaigar *et al*., 2013)

The Dorcas gazelle previously had the most extensive distribution of any African gazelle, but a recent study revealed that the species no longer exists in several of its former areas (Frost, 2014). As Abaigar (2013) stated in Senegal, the species was considered extinct from the mid-1970s until it was reintroduced in 2007. Likewise, as Frost (2014) suggested the status of Dorcas gazelle in Mauritania, Burkina Faso and Nigeria is not known, and is assumed that it may be extinct in these countries. According to IUCN (2017), the decline of the species was estimated to be more than 30% over a period of about 15 years up to April 2016 and fewer than 25% of those remaining at that time lived in protected areas. Currently, Dorcas gazelle is categorized as a globally vulnerable species (IUCN, 2017).

Eritrea harbors one of the most southern ranges of the species (Fig 1. 2). The species occurance was reported from the coastal areas, southwestern and northern parts of the country (Yalden,

1984; Bekele & Yalden, 2013). However, information on the species distribution and status does not exist

Eritrean gazelle (*Eudorcas tilonura)* (Heuglin, 1863)

Kingdom	Phylum	Class	Order	Family	Subfamily	Tribe	Genus
Animalia	Chordataur	Mammalia	Artiodactyla	Bovidae	Antilpinae	Antilopini	Eudorcas

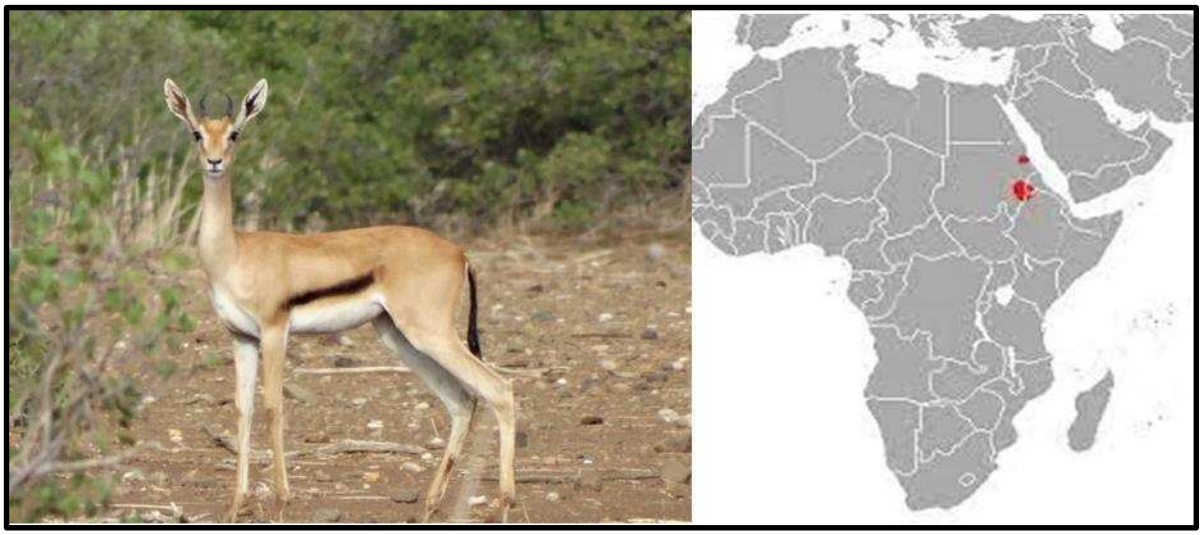

Figure 1.3. Eritrean gazelle and its geographical distribution

The Eritrean gazelle, also known as Heuglin's gazelle, is endemic to the Horn of Africa, specifically to W Eritrea, NE Ethiopia and SE Sudan. It was considered a subspecies of the red-fronted gazelle (*E. rufifrons*) or conspecific with Thomson's gazelle (*E. thomsonii*) and Mongalla gazelle (*E. albonotata*) by some authors in the past. Other authors consider Heuglin's gazelle an independent species (Groves, 2013; Hashim, 2013) and this treatment was provisionally followed on the IUCN Red List (IUCN SSC Antelope Specialist Group, 2017).

According to the IUCN Red List, *Eudorcas tilonura* is classified as Endangered (IUCN, 2017), and across its range it is under the threats of hunting, competition with domestic livestock and habitat degradation. It is believed that populations of the species might have fallen by 20% in roughly nine years since 2008. Currently it is estimated that 2,500 to 3,500 individuals remain in small fragmented groups, with fewer than 2,500 adults (IUCN, 2017).

The status and distribution of the species in Eritrea are not well known. As reported by Global Wildlife Conservation (GWC, 2019), for more than 80 years no Eritrean gazelles had been reported in the country. There have been no scientifically confirmed sightings of the species

since the 1930s. Similarly, there have been no confirmed sightings by professionals until 2019, when a small group observed and photographed in the Gash Barka region specifically in sub regions of Dige and Gonge (Hagos, 2019). For this reason, the species is not included in the list of threatened species that require special attention in the Forestry and Wildlife Conservation and Development Proclamation No. 155/2006 (GoE, 2006).

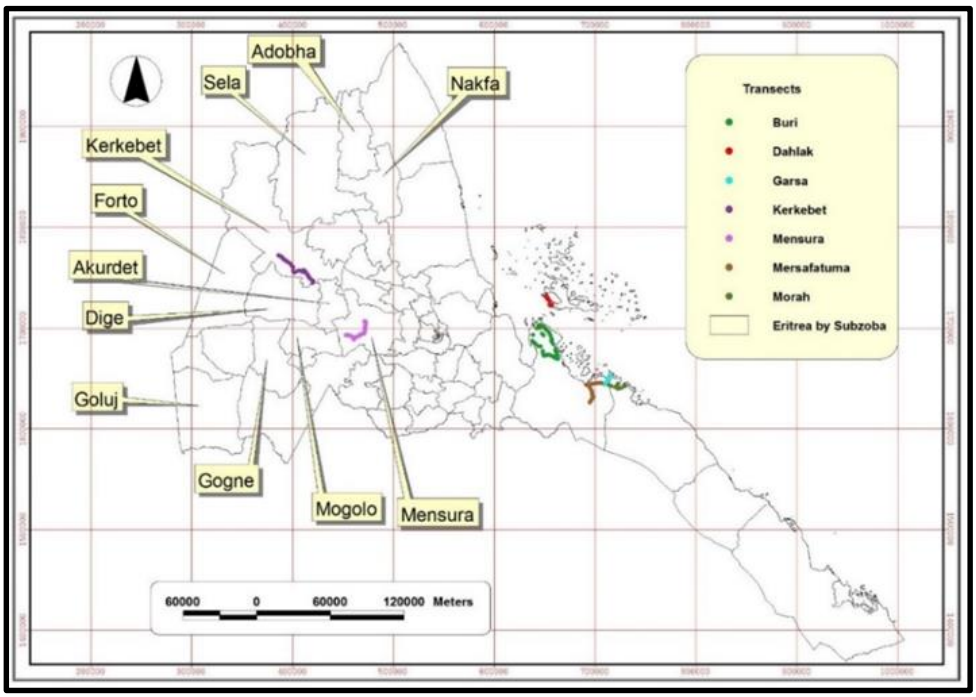

Figure 1.4. Location of the sample transects and reference sub regions

Geographical setting of Eritrea

Eritrea is situated in the Horn of Africa and lies north of the equator between 12°22'N and 18°02'N latitude, and 36°26'E and 43°13'E longitude. It has an area of 124,300 square kilometers with a mainland and island coastline of more than 3,300 km (DoE, 1999). To the east, the country is bordered by the Red Sea, extending 1,212 kilometers from Ras Kasar in the north to Dar Elwa in the south, including over 350 islands, the most prominent of which is the Dahlak Archipelago. To the north and west, it is bordered by Sudan and to the southeast by Djibouti and Ethiopia in the south (Fig. 1.5). The country has a wide range of elevations from -160 up to 330 meter above sea level (Fig 1.6).

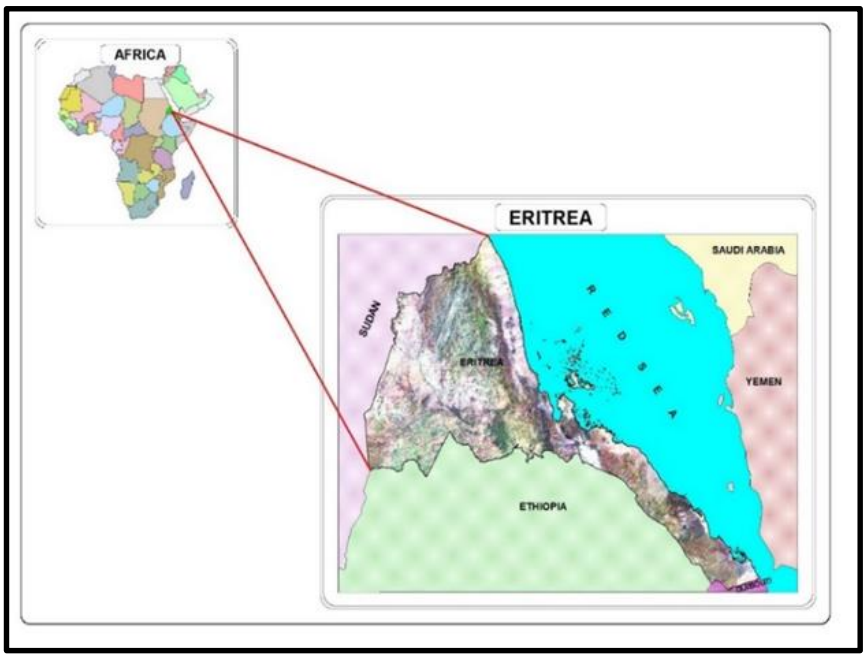

Figure 1.5. Map of the location of the country of study area.

Population and settlement

According to the Eritrea Population and Health Survey (EPHS), the total human population of Eritrea is around 3.2 million (NSO, 2013). Settlement patterns and distribution have been influenced by several factors such as history, infrastructure, landscape, productivity, climate, water supply and economic activities. Therefore, the majority of the people (~60%) live in the high lands as many of these conditions are met there.

There are nine ethnic groups, of which the Tigrigna and Tigre constituting 50% and 31% of the total population respectively. The rest of the population are Afar, Bilen, Hidareb (Bdawiet), Kunama, Saho, Nara, and Rashaida, found scattered mainly in the eastern and western lowlands. These ethnic groups differ in language and customs. The majority of the people adhere to two major religions, Christianity and Islam, each constituting roughly half of the total population.

Agriculture and pastoralism are the main sources of livelihood for about 80% of Eritrea's population (MoA, 2002). The agricultural sector depends mainly on rain, with less than 10% of the arable land currently irrigated. Consequently, productivity is low. The agricultural sector accounts for only one-fifth of the Gross Domestic Product (GDP).

The coastal areas are sparsely populated with approximately 5% of the national population, the majority residing in the two main coastal cities of Massawa and Asseb. Shortage of fresh water is a characteristic feature of the coasts and island areas. In most cases, wells are the primary sources of fresh water supply. Due to the scarcity of annual precipitation and extremely harsh

weather conditions, the principal agricultural activity remains in small ruminant livestock herding. The majority of the coastal communities' livelihoods depend on fisheries activities coupled with trade in fishery products and other goods with the neighboring Saudi Arabia and Yemen (MoMR, 2007).

Topography and Climate

The Eritrean landmass can be classified into three major physiographic regions namely: highland/plateau, eastern and western escarpments, and eastern and western lowlands (GoE, 1995). It has varied topography and climate with an altitude that ranges from 150 m below sea level (Denakil Depression) to over 3,000 m above sea level (Mt. Soira). The climate ranges from hot and arid adjacent to the Red Sea to temperate in the highlands and sub-humid in isolated areas of eastern escarpment (the Green Belt). Most parts of the country (70%) are classified as 'hot to very hot' with mean annual temperature of more than 27^{o}C; about (25%) as 'warm to mild' with a mean temperature of about 22^{0}C, and the remaining parts (5%) as 'cool' with a mean annual temperature of less than 19^{o}C (DoE, 2001).

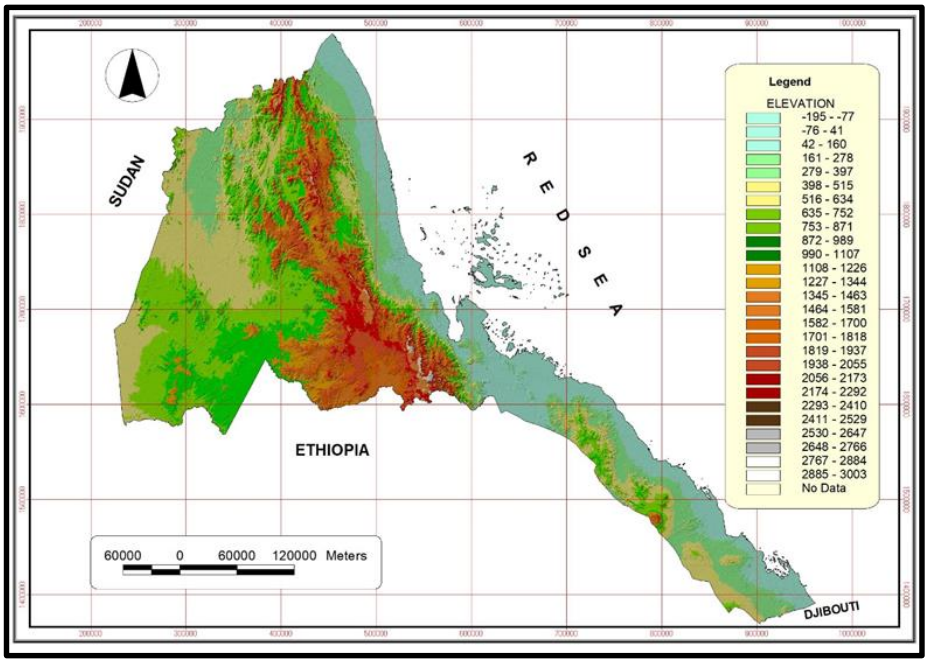

Figure 1.6. Digital Elevation Model of Eritrea

The terrain and the changes occurring from the Central Highlands towards the Eastern Lowlands and Western Lowlands characterize the physiography of the country. The elevation changes of the western part are not as pronounced as in the eastern part of the country. The slope to the west of Asmara averages approximately 8.3 meters per kilometer, while the slope towards the Red Sea coast averages about 29.2 meters per kilometer. These abrupt and varied

physiographic characteristics are the basis for the highly variable hydrometeorology of the country resulting in a temporal and spatial distribution of rainfall (DoWR, 1999).

The Central highland plateau extends from Senafe, 14.5 degrees north and 2,667m elevations to Nakfa and Hager mountains, 16.4 degrees North about 1,833 m above sea level (DoE, 2001). The plateau narrows and descends slowly toward the north sloping more steeply to the East, and moderately toward the Western Gash Barka Region. As reported by many authors including David et al., (1996), altitude and topography play major roles in determining climate in general and temperature. This also applies to Eritrea; the land shape, continental pressure changes (affecting winds) and other factors provide a range from a moderate temperate climate in the highlands to hot dry coastal plains in the lowland regions (DoE, 1999). The same report emphasized that the elevation variation of 2,300 meters plus the effects of pressure changes in central Asia, Western and Southern Africa, produces the countries unique wind pattern.

Temperature

The mean annual temperature in Eritrea ranges from temperate comfortable 18^0C in the highlands around Asmara, to extreme high temperature along the Red Sea coastal area and reaches about 35^0C around port of Assab. Based on temperature and type of vegetation, Eritrea is classified into three distinct agro-ecological zones, namely the plateau, the Eastern and Western escarpment and the lowlands. Precipitation and temperature fluctuates with altitude. Moving westward from the Red Sea towards Asmara, temperature reduces about 1.8^0C every 310m of elevation gain (DoE, 2001). Similarly, temperature increases with decreasing elevation between the extreme western low land and Asmara.

The climate regime is highly variable and, is affected by the expanding Sahel-Saharan desert, the proximity to the Red Sea and the land's physical features (DoE, 1999). The mean annual daily temperature is approximately 25-35 °C. However, in coastal and island areas during the hot months of the year (July and August), maximum temperature can reach up to 50°C (DoE, 2001). In coastal areas, November to April are the coldest months with some rainfall. The dry hot season lasts May to October (Hagos, 2016). The mainland eco-region has a tropical climate with a hot and dry season, as well as short and long rainy seasons in the summer rainfall regime

Agro-ecological zone

When climate, soil types and other parameters are taken into account, Eritrea is divided into six agro-ecological zones (GoE, 1995). Three quarters of the country (more than 74%) fall in the arid or semi-deserts zones (Negassi *et al*., 2002). The Semi-Desert agro-ecological zone

occupies a large part of the northwestern lowlands and the whole Red Sea coastal plain (Fig 1.7). A summary of the agro ecological zones including rainfall, temperature and proportion

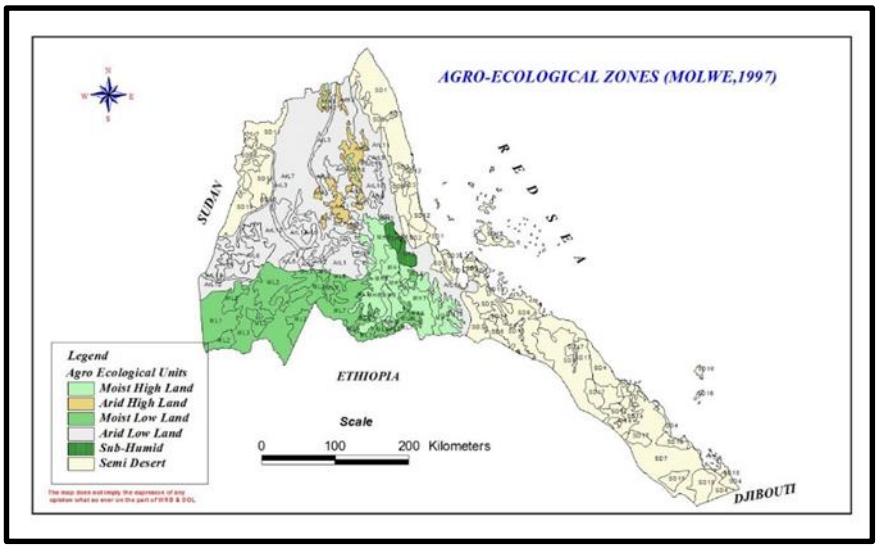

Figure 1.7. Agro-ecological zone of Eritrea (DoE, 1999)

Table 1.1.Summary of weather conditions per agro-ecological Zones of Eritrea

Zone	Elevation (m)	Annual rainfall (mm)	Mean annual temperature (°C)	Proportion of Eritrea's total area (%)
Moist Highland	600-3018	500-700	15-21	7
Arid highland	1600-2820	200-500	15-21	3
Sub humid	600-2625	700-1100	16-27	1
Moist lowland	500-1600	500-700	21-28	16
Arid lowland	400-1600	200-500	21-29	34
Semi desert	-100-1355	<200	24-32	39

Source. DoE, 2001.

Rainfall

Rainfall is erratic and unreliable, and its amount and season varies with the location of the study area. There are two major periods of precipitation in Eritrea. The first, from June to September, covers both the western lowlands and highlands. The second occurs between October and March and covers the eastern escarpments and lowlands. Despite of the occurrence of the two major rainy seasons in Eritrea, it is uncommon for large areas of the country to enjoy two rainy seasons in any one year, with the exception of a narrow strip between the highlands and the eastern escarpment called the Greenbelt.

Topographic variations have considerable effect on the rainfall pattern of the country, with annual rainfall varying from about 100 mm in the lowlands to about 700 mm in the southern part of the central highlands and southwestern lowlands. Some parts on the eastern escarpment get more than 900 mm. Rainfall in the central highland and the western lowlands is caused by south-westerly monsoon winds and occurs mainly between June and September, peaking in August. The eastern lowland and its escarpments receive rainfall between November and March due to the northeast continental winds over the Red Sea. As to areas covered by the different rainfall regimes, about 50% of the country receives less than 300 mm, 40% between 300 and 600 mm and about 10% more than 600 mm of rain per annum. Irregular rain patterns and the recurrent drought are intrinsic features of arid and semi-arid lands in Eritrea (FAO, 1994).

In the Eastern part of the country, the rainfall ranges from 200 mm in the coastal area to 1000 mm along the escarpment. Most of the runoff originating in this part of the country drains into the Red Sea. In the highlands and western lowlands, rainfall ranges from 400-700 mm and from 300-400 mm in the Southern Western and Northern part of the country respectively (Fig 8). Most runoff on the plateau flows west and north towards the Sudan. Rainfall over the highlands is relatively uniform, slightly decreasing as one moves north towards lower elevation around Nakfa (DoWR, 1999). On the other hand, towards the Western lowlands near the border of Sudan the elevation significantly decreases and the rainfall also. The northern part of the Western Lowlands is quite arid, whereas the South and Southeast parts of the Western lowlands receive relatively higher rainfall during June-September.

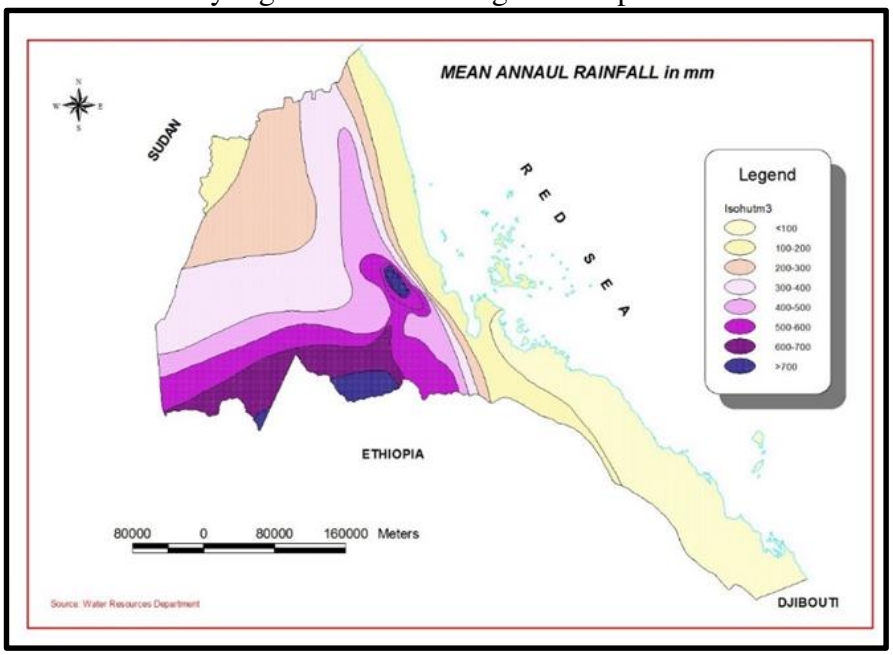

Figure 1.8. Isohyet map of Eritrea (Source DoWR, 1999)

Hydrology

Eritrean surface water resources have been divided into five major River Basin systems namely Setit, Mereb-Gash; Barka-Anseba, Red Sea Basin and Danakil Basin (Fig.1.9). Due to inadequate published rainfall and stream, flow data, the runoff of various River Basins has been estimated either from modeling (for ungauged catchments) or from simulation (for catchments with short period of data) values. Therefore, its dependability for major water resources development is questionable. The estimated runoff yield of the river basins is summarized in Table1.2

Table 1.2. Major drainage basins of Eritrea
Their estimated runoff yield in Billion Cubic Meters (BCM)

Basin	Area (km^2)		Average Annual runoff Yield (BCM)	Source or Estimation Method
	Eritrea	Total		
Setit	7,300	68,800	6.28	Measured at Omhajer 1968-69, 1971-1987 (Sector Study, 1998).
Gash-Mereb	16,730	23,200	0.48-0.76 0.89-1.44	• Measured at Kessela 1907-29 and 1982-86 (Sector Study, 1998). • Simulation (FAO, 1994).
Barka-Anseba	44,376	44,376	0.753 0.360	• Simulated (Sector Study, 1998). • Modeled (FAO, 1994). • Catchment includes small streams draining and join in Sudan
Red Sea	41,920	41,920	0.730 0.445	• Estimates from six major catchments north of the Gulf of Zula (NRCE, 1996). • Simulated (Sector Study, 1998).
Danakil Depression	10,530		0.136	• Modelled (Ramod & Regale) catchments (Sector Study, 1998).
Total			8.80 - 9.40	

Source: Agricultural Sector Review and Project Identification (FAO, 1994) and Sector study on National Water resources and Irrigation Potential (DoE, 1998)

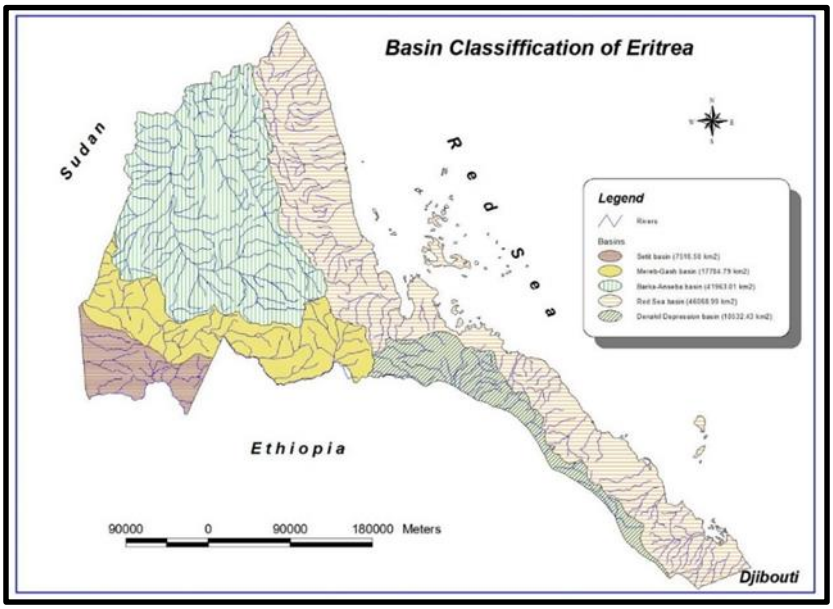

Figure 1.9. Major Surface water basins of Eritrea (Source DoWR, 1998)

Soils

Based on the Harmonized World Soil Database (FAO, 2012), the soils of Eritrea could be in a more general way can be classified into 13 soil types out of which Leptosols and Arenosols cover most parts of the country (Fig.1.10). Solonchak, soils with high salinity, are mostly found along the coastal regions. Likewise, in southern part of Danakil plains saline soils dominate, besides regosols and lithosols. Soils of western plain belong to yermosols, regosols, chromic vertisols, Cambisols, luvic, xerosols and fluvisols.

Soils in the high land areas especially in the depression areas with some alluvial materials, the soils are relatively deep and in many places, soils are shallow due to severe erosion. In general, soils are of sandy texture including sandy loam where parent materials are derived from granite, genies, sandstone and quartize. Soils of the lowlands are shallow, gravelly, and stony soils with coarse or very coarse texture occur. Generally, soils in this area are classified as chromic luvisols, eutric, cambisols lithosols and haplic xerosols.

In general, soils with the highest agricultural potential are found in the southern central highlands and southwestern parts of the country where the three indigenous species of gazelle exist.

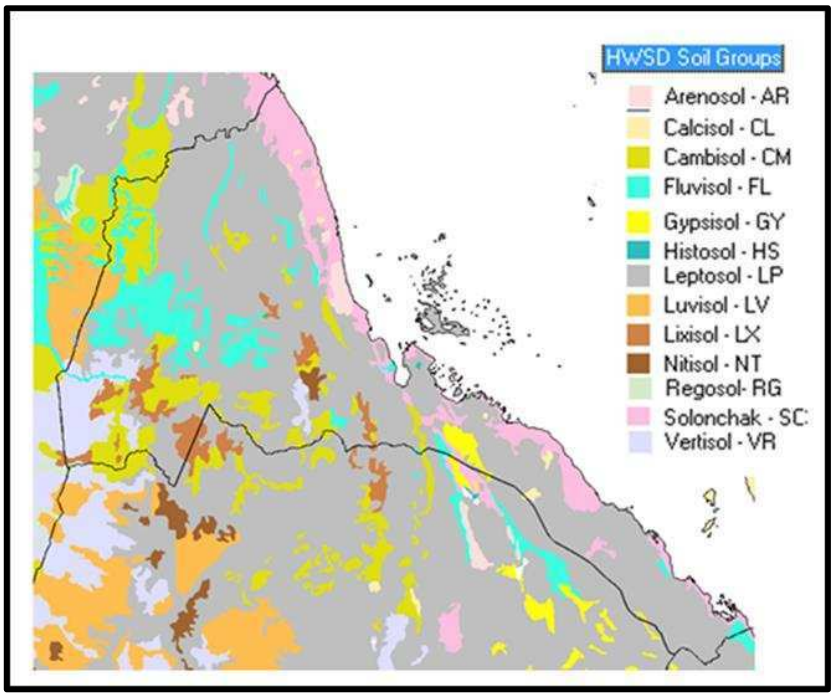

Figure 1.10. Soil map of Eritrea (Source Harmonized World Soil Database, FAO, 2012)

The soils in adjacent to coastal are mainly basaltic lava fields and sandy plains are generally very poor, highly saline solonchaks (Hagos, 2016), Thus on the most saline soils, patchy *Sueada monoica* bushes with *Dipterygium glaucum* and *Cenchrus ciliaris* grass cover are found (DoE, 1999). On the richer loamy sands found Wangobo, the grass cover is more extensive, comprising mostly *Cenchrus ciliaris* and *Cenchrus setigerus, Dactyloctenium scindicum* and very occasional stunted Acacia tortilis trees, and is still under considerable grazing &or browsing pressure.

Biodiversity

The Eritrea Biodiversity Stocktaking Assessment Report (DoE, 1999) and the National Biodiversity Strategy and Action Plan (NBSAP) (DoE, 2001), categorized the Eritrean biodiversity under three core areas: namely the natural terrestrial habitats characteristic of the region, the diverse agro-ecosystems region (agro diversity), and the coastal marine and island ecosystems of Red Sea.

Terrestrial Biodiversity

So far, very few studies on ecosystem biodiversity were carried out and serves as the base of the classification of Eco-geographical, agro-ecological, and vegetation cover (DoE, 2001). These classifications capture the main regional ecological variations within the country but provide little detailed information about the species diversity, which exists within these

regions. In almost all cases, the level of ecological/biodiversity information about ecosystems and habitats appears incomplete and is unlikely to reflect the current situation.

The studies made so far indicated that Eritrea is home to a number of globally iconic and endangered species such as the African wild Ass (*Equus Africanus somalensis*) and Nubian Ibex (*Capra ibex nubiana*). The current data are limited on Nubian wild ass (*Equus africanus africanus*), but it is believed that the species still exists in the Nubian desert of northeast Sudan into northern Eritrea (IUCN, 2002). Of the seventeen mammal taxa (species/sub-species) listed in 2013 IUCN Red List of Endangered Animals, which appear on the Eritrean checklist, only the Eritrean sub-species of the warthog (*Phacochoerus africanus aeliana*), and Dugong (*Dugong dugon*) can be ranked as Common in Eritrea taking in to consideration the exiting situation of the species (DoE, 2010). The Dorcas gazelles (*Gazella dorcas*) and Soemmerring's gazelle (*Gazella soemmerringi*) were listed as Vulnerable and Eritrean gazelle (*Eudorcas tilonura*) which is not in the national list but it is endangered species (IUCN, 2017). Black Rhinoceros (*Diceros bicornis*), African Wild Dog (*Lycaon pictus*), and Lion (*Panthera leo*) are extinct. Nubian Ibex (*Capra ibex nubiana*) are considered Endangered; and two mammals: Elephant (*Loxodonta africana*), African Wild Ass (*Equus africanu*) are considered Rare and Hartebeest (*Alcelaphus buselaphus*) although it is listed as rear species but its existence in the country is still not confirmed. At national level, the Forestry and Wildlife Conservation and Development Proclamation No. 155/2006, indicated a list of mammals that require special attention, notably African elephant, African wild ass, Greater kudu, African civet, Dorcas gazelle, Soemmerring's gazelle, Salt dik-dik, Klipspringer, Aardvark, Leopard, Warthog, Common or Grey duiker, and Bushbuck are recognized as species threatened with extinction. However, the national listing requires updating in a way that can reflect the exiting situation of the wildlife status in the country because population of some of the listed species are appearing climbing up such as Soemmerring's gazelle, leopard, Warthog etc.

In terms of avian diversity, Eritrea has records around 610 bird species that encompasses resident, Palearctic migrants and intra-African migrants. It is also very important, for migratory birds, providing migration route and stop-over location for many species. Fourtenn Important Bird Areas (IBA) have been identified in Eritrea. There are 12 species of global conservation concern recorded from Eritrea (Redman *et al.,* 2009).

Knowledge of biodiversity of reptiles and amphibians is extremely poor. A recent checklist could improve data. A total of 90 reptiles and 19 amphibian species have been recorded for

Eritrea (DoE, 2019) out of which 13 were recorded in Eritrea for the first time (Dr.Theodore Papenfus Pers.com).

Vegetation

A number of regional vegetation descriptions are exist and they are summarized in the Eritrea Biodiversity Stocktaking Assessment Report. In the absence of a national checklist, a number of site-specific checklists are included in this report. One list of almost 700 species indicates that considerable plant diversity may persist in human-altered landscapes (DoE, 1999). So far 33 tree species have been listed as endangered in the proclamation of forestry and wildlife conservation and development (GoE, 2006), but the quantitative basis for this status is not clearly documented.

The natural vegetation map of Africa includes 20 major regional centers of endemism, out of which five are represented in Eritrea. These are Afromontane region, Sudanian region, Somali-Masai region, the Sahelian region and the Sahara regional transitional zone (White, 1983, Ogbazghi & Bein, 2005). These centers give rise to distinct vegetation types rich in biodiversity.

Three major forest/woodland types are eminent in Eritrea, namely highland forests, Acacia woodlands and Riverine forests (FAO, 1997). Originally, the highland forests of *Juniperus procera* and *Olea africana* would have extended over much of the plateau, but have been largely destroyed or degraded; only remnants now survive. In the lowlands and lower escarpments, Acacia woodlands occupy about a quarter of the surface of the country. Riverine fringe in river systems of the Mereb/Gash, Setit and Barka in the lowlands, where Doum palm (*Hyphaen ethebaica*) is an important constituent. On the coastal plains, tree cover becomes increasingly sparse towards the sea. In certain places, mangroves border the coast, the main species being *Avicennia marina*. More specifically, the natural forest cover has been classified to the following six major vegetation types following international methodology (FAO, 1997). These are:

1. Highland forest, (closed to medium closed and open forest) composed of a mixture of coniferous species (Junipers procera) and broad-leafed species African olive (Olea africana) and associated species;
2. Mixed woodlands of Acacia (closed, medium closed and open woodlands) and associated species, occurring mainly in the south-western lowlands, but also in restricted areas elsewhere in the country;

3. Bush or shrub vegetation, which is the dominant cover in Eritrea
4. Grasslands to wooded grasslands, which occur in many parts of the country;
5. Riverine forest, composed essentially of Doum palm, which is common in the western lowlands and is frequent in the eastern lowlands; and
6. Mangrove occurring in many spots along the coast and concentrated mainly around port of Assab and areas found between Tio and port of Massawa.

Furthermore, According to White (1983), the vegetation of Eritrea is classified into nine categories. These are (i) undifferentiated Afromontane Forest, (ii) Ethiopian undifferentiated woodland, (iii) East African evergreen and semi-evergreen bush land and thicket, (iv) Somalia Masai Acacia-Commiphora deciduous bush land and thicket, (v) Sahel (Acacia) wooded grassland and Sahel (Acacia) deciduous bush land, (vi) Sahel semi-desert grassland and the transition to the Sahara, (vii) Somalia-Masai semi-desert grassland and shrub land, viii) the Red Sea coastal desert and (ix) Wadis and open bare desert (Fig 1.11).

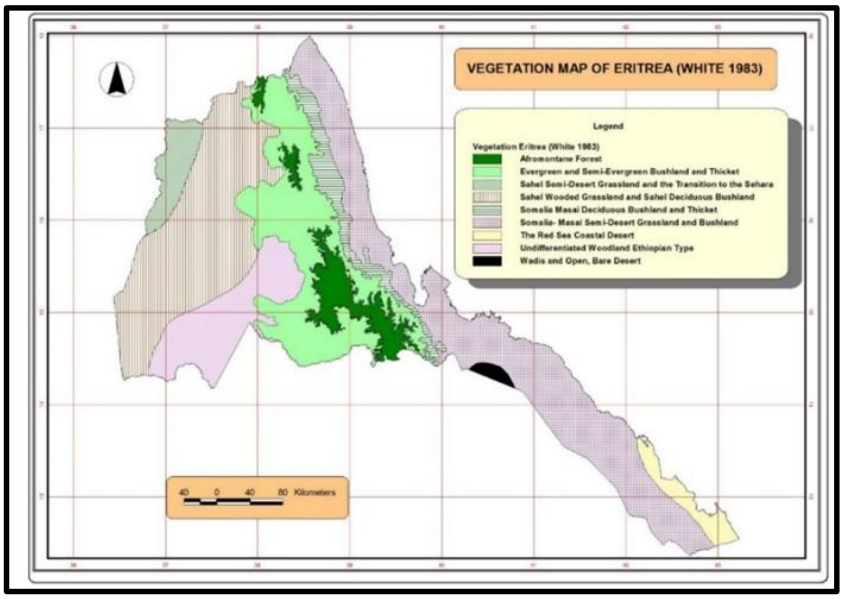

Figure 1.11. Vegetation classification of Eritrea (white, 1983)

The overview of White's vegetation classification

Undifferentiated afromontane forest

This type of vegetation runs from the Ethiopian border northwards along the highland plateau of Eritrea and escarpment to the east of the Adi Keih-Asmara road, broadens around Semenawi Bahri, Mount Bizen and other eastern escarpments and then tapers to two isolated patches north of Keren, Nakfa and the Hager Plateau (Northern part of the country). Typical Undifferentiated

Afromontane Forest usually includes the following species: *Apodytes dimidiata, Halleria lucida, Ilex mitis, Kiggelaria africana, Nuxia congesta, N. floribunda, Ocotea bullata (including O. kenyensis), Podocarpus falcatus (including gracilior), P. latifolius, Prunus africana, Rapanea melanophloeos* and *Xymalos monospora*.

Ethiopian undifferentiated woodland

This vegetation type is marked as extending into Eritrea from Ethiopia and running through eastern Gash-Barka south of Barentu and almost up to Keren (Zoba Anseba). Dominated by *Anogeissus leiocarpus* and *Combretum hartmannianum* with sporadic *Sterculia setigera*

East African evergreen and semi-evergreen bush land and thicket

This type of vegetation occupies a large area in the southern part of the country specifically around Senafe and Adi Keih and then run along the east and west escarpments to the east of Keren as far north as the border with Sudan. It often forms an altitudinal ecotone between montane forest, especially Juniperus forest above, and deciduous Acacia/Commiphora bush land and understory vegetation. This forest is commonly dominated by Carissa edulis, *Dodonaea angustifolia* (viscosa), Olea europaea ssp.africana, Tarchonanthys camphoratus, species of Acokanthera, Euclea, Sansevieria and Teclea, and succulent species of Aloe and Euphorbia exist

Somalia Masai Acacia-Commiphora deciduous bush land and thicket

This type of vegetation is mainly distributed in western lowlands. The majority of these species are multiple-stemmed bushes or small bushy trees, which are branched near the base. The dominant Acacia spp. and some of the Commiphora spp. are spinous and so impede progress even in the more open types except along game and cattle tracks. In higher-rainfall areas, especially on rocky hills, the emergent trees occur closer together, are a little taller, though scarcely ever more than 10 m., and might be considered woodland. In some Commiphora species several massive more or less prostrate branches radiate from a common base. Terminalia orbicularis has a similar habit and forms impenetrable thickets up to 12 m across and 5 m tall

Sahel (Acacia) wooded grassland and Sahel (Acacia) deciduous bush land

This covers the entire western lowlands with the exception of a small region found near the Sudanese border. It covers all the land to the west and north of a line running from the town

Om Hajer and the town of Barentu to Keren area and then north along the edge of the western escarpment to the Sudanese border.

Sahel (Acacia) wooded grassland

This is the most widespread type where annual rainfall is between 250 and 500 mm. The density of the larger woody plants varies greatly, especially in relation to water supply and the amount of human interference. The grassland is more or less continuous and is no more than 60 cm tall. It mostly consists of annual species, principally *Cenchrus biflorus, Schoenefeldia gracilis, Aristida stipoides* and *Tragus racemosus.* Perennial grasses are localized, but *Andropogon gayanus* sometimes occurs in almost pure stands on deeper sands towards the south. Where rainfall is between 280 and 450 mm. the most characteristic tree on sandy soils is *Acacia senegal*, which often occurs in almost pure stands

Sahel deciduous bush land

It is dominated by *Acacia mellifera* and *Commiphora africana,* with *Boscia senegalensis* and *Dichrostachys cinerea* usually present. This has persisted in the principal valleys and on basalt lava flows that widely distributed adjust to the coastal area, but elsewhere has been replaced by wooded grassland. The most frequent thicket species are *C. africana*, *A. mellifera* and *E. candelabrum*

Sahel semi-desert grassland and the transition to the Sahara

This is the driest vegetation type found in the western lowlands and should show strong affinities with the vegetation of Sudan. Commonly observed in area with rainfall is less than 250 mm per year and grassland is the prevalent vegetation on deep sandy soils. The chief woody species are *Acacia tortilis*, *Commiphora africana*, *Balanites aegyptiaca*, *Boscia senegalensis, Leptadenia pyrotechnica,* and *Acacia laeta*.

The dominant grasses are all annual species, notably *Cenchrus biflorus, Schoenefeldia gracilis, Aristida stipoides* and *Tragus racemosus*. They are equally characteristic of the southern Sahel. In the northern Sahel, however, certain desert grasses, principally *Panicum turgidum, Stipagrostis pungens* and *Aristida sieberana*.

Somalia-Masai semi-desert grassland and shrub land

Where rainfall is between l00 and 200 mm per year, semi-desert grassland dominated by *Eragrostis hararensis, Panicum turgidum* or *Asthenatherum glaucum* occurs on deep sand.

Shrub land occurs on stony soils. The shrubby species are most abundant in overgrazed and eroded areas and it is possible that grasses including *Chrysopogon plumulosus* and *Dactyloctenium robecchii* were formerly dominant. Gypseous soils support a considerable variety of endemic succulents including several *Euphorbia spp.*

The Red Sea coastal desert

The Red Sea coastal plain, which is 15-20 km wide, receives very little rainfall Apart from halophytic communities on the littoral itself, the plain is devoid of vegetation except in the wadis. Inland from the coastal plain a chain of rugged mountains, with peaks over 2000 m high, running the entire length of the Red Sea. In the wadis of the coastal plain, saline areas have a dense growth of *Juncus arabicus* and *Tamarix sp* elsewhere in the wadis, Acacia tortilis, *Zilla spinosa, Capparis* decidua, *Calligonum comosum, Lasiurus hirsutus, Panicum turgidum* and *Retama retam* are characteristic species.

Wadis and Bare Desert

This extent of the Danakil Depression over the border from Ethiopia into Eritrea. The vegetation descriptions given in White are very mixed and may not be particularly representative of the Danakil vegetation. In addition to Oasis wadis are the only desert habitats where trees and large bushes are found. There are four main vegetation types, *Tamarix* communities, Acacia communities, Hyphaene, and those representatives of bare desert (*psammophilous* and *hamada*) communities

Generally, the classification of White (1983) categorization, the natural vegetation of the country constitutes 0.8% highland forest, 11.3% close, medium and open woodland; 63.8% grassland/wooded grassland/ and bush land; 1.6% riverine and mangrove forests.

Land cover

The land cover of the country is dominated by shrub land that constitute 42.5 %. The detail of the proportional coverage of the land cover of the country is summarized in Table.1.3

The loss of biodiversity, along with climate change and desertification, were identified as the greatest challenges to sustainable development in Eritrea (NEMP-E, 1995; NAP, 2002; and 5th NBSAP Report (DoE, 2015).

Table 1.3. Land cover in Eritrea

Land Cover Category	Area (km^2)	Land Area (% of Total)
Closed Woodland	4,600	3.7
Open Woodland	11,200	8.9
Grassland	25,700	20.4
Bush/shrub land	53,400	42.5
Riverine Forest	1,900	1.5
Mangroves	100	0.1
Agriculture	7,700	6.1
Barren	18,700	14.9
Others	100	0.1
Not Classified	2,300	1.8
Total	**125,700**	**100.0**

Source: DoE, 1999

Cutting of trees for firewood, cultivation, for construction etc. are a significant concern because of increased human encroachment upon forest areas and increased resource extraction. In Eritrea, forest resources and vegetation cover are under serious threat i.e. the forest cover and forest quality are declining.

Nonetheless, the *defacto* protected area of Semenawi and Debubawi Bahri (Green Belt); Buri-Irrori-Hawakil, Gash-setiti Elephant sanctuary and the Gash-Barka Riverine Forests etc., which harbors diversified flora and fauna and are playing significant role in their revival.

Marine biodiversity

Eritrea possesses a mainland coastline of more than 1,350 km along the southwestern coast of the Red Sea, from its northern border with Sudan to its southern border with Djibouti. In addition, the Red Sea of Eritrea contains more than 350 islands that form a shoreline of more than 1,950 km (MoMR, 2007). The coastal plains are hot, dry and sparsely inhabited. This has contributed to the survival of a relatively pristine coastal and marine environment, of which the coral reefs and their associated fish assemblages represent the most diverse ecosystems in Eritrea

There are areas that were identified as potential habitat for the world's most important coastal and marine environments, with unique coastal (aquatic/terrestrial) ecosystems and their associated species as important repositories of marine biodiversity on a global scale. This includes the zones of the Buri-Peninsula, Hawakil Archipelago and the bay of Bara'sole.

The Southern part of the Eritrean Red Sea coast is rich in marine plants especially; Sea grasses form dense meadows that perform a wide spectrum of biological and physiological functions,

serving as nursery, shelter or feeding area for fish, invertebrates, dugong and sea turtles. The sea grass beds also produce sediments from the associated fauna and interact with coral reefs and mangroves in reducing wave energy and regulating water movement. Mangrove forests are present along 380 km of coastline and cover 6,571 hectares (MoMR, 2007). Four mangrove species known in the Arabian region, *Avicennia marina* is by far the most common, being tolerant to harsh conditions including high salinity (DoE, 1999), their distribution is patchy all along the coastal and islands. Diversified coral reef communities, extensive mangrove mud flats, sea grass or seaweeds beds and standing kelps harbor diversified commercially important fisheries resources (DoE, 2015).

The coastal areas from Ghel'alo to Sahil and the Dahlak Archipelago are consider as an Important Bird Area (IBA) for marine birds especially for the Palearctic migrants (MoMR 2007). Nearly 90 marine and shore birds, 500 fishes and 44 genera of hard corals have been recorded (DoE, 2015). The flat intertidal areas of the Eritrean Red Sea especially coastal areas are ideal for roosting and foraging for seabirds Up to five marine turtles, 16 or more cetaceans and the dugong - almost all of which are species of global conservation concern, inhabit in the Eritrean coast. The offshore islands are important areas of turtle foraging and nesting areas. However, feeding and nesting monitoring sites for sea turtle can be near coastal areas were poaching from fishers is common phenomenon.

Although Eritrea has one of the least ecologically disturbed parts of the Red Sea relative to other enclosed water bodies, it is in increasing jeopardy. There is a potential risk of marine pollution, and environmental degradation from rapidly expanding maritime activities (MoMR, 2007).

Description of the Study area

The study area is located in three sizeable, geographically separated areas. These are the western lowlands (Gash Barka), the Red Sea coastal areas (Southern and Northern Red Sea and in the Danakil desert) and the Dahlak Kebir island of the Red Sea. Elevation ranges from -130 to +1000 meters below and above sea level respectively. The area was selected because of its fair abundance of gazelles. The climate is arid to semi-arid with high temperatures year-round. Mean annual daily temperature is approximately 30^0 to 35º C, but during the hottest months, the maximum temperature can exceed 50^0 C (DoE, 2008).

The seasons of rainfall of the respective study area have distinctive differences: in the coastal area rainy season is extends between Octobers and March, whereas the mainland has short and

long rain seasons, which extend between March-April and September–August, respectively (DoE, 2001). The description of the respective sites follows here under.

Description of the coastal study area

The coastal area covers south of the Gulf of Zula, about 100 km southeast of the port of Massawa and stretches south towards the town of Tio. The topography is composed of flat plains dissected by ridges of basaltic hills and plateaus. Geologically the area is composed of quaternary sediments but in some areas, particularly in the south, these sediments are overlain with basaltic lava flows from recent volcanic activity at the northern extreme of the Rift Valley. The saline solonchaks have no agricultural potential. However, where rivers carve through the mountains to the foothills and coastal plains, fertile alluvial fans are formed, such as at Wengebo, Simoti and Buya. These places are frequently make use by local communities for seasonal cultivation and serve as grazing ground for livestock.

The area lies within semi desert and arid lowland agro-ecological zone and is characterized by arid to semi-arid climate with extreme hot summer. The temperature range is between 24-50^{o} centigrade the area receives a very low and unreliable rainfall of less than 200mm falling mainly between November- March.

The rocky plateau and volcanic ridges are covered with scattered vegetation and a thin soil layer. The ravines that dissect the plateau and the plains below have more vegetation biomass and more soil.

The area could be divided into five landform types (physiographic regions): The Volcanic small hills and plateau, Irrori plains, Wengebo-valley, Buya-Simoti depression/trough, and coastal plain. All geographic designations are an ‘unofficial’ but take after the local naming of important land features. The landforms are key to understanding of several issues relating to biodiversity conservation and identifying possible climate change mitigation options.

Vegetation

The vegetation of the coastal and island study area is scattered with a combination of low growing trees and widely spaced annual and perennial grasses. Most of the coastal adjacent areas were characterized by basaltic lava fields with vegetation dominated by *Acacia mellifera* and sandy plains with scattered *Acacia tortilis*, *Acacia nubica*, *Acacia laeta*, *Salvadora perisica*, and *Ziziphusspina-christi*. *Tamarix aphylla* occurred in a low depression in the plain. In some areas of the lava flows and hills, *Commiphora africana* was the dominant woody

species. In many areas close to the sea halophytic shrubs such as *Suaeda monoica*, and where water is closer to the surface, such as along watercourses, there were small areas of doum palm (*Hyphaene thebaica dankaliansis*) dominating the vegetation. The plain area was characterized by grassland dominated by *Panicum turgidum*. The gorges and depression areas endowed with drought tolerant plant species. The shore of the Red Sea is covered by *Avicennia marina* (Mangrove) forest (Hagos, 2016).

Climate

Currently there is no operational meteorological station in the area. The nearest station with long-term climate data is at Port of Massawa and Foro. Data were additional collected from a recently installed weather station of Colluli Potash Mining Company in Danakil depression.

The area is arid and semi desert characterized by extreme hot summer and very small summer rains. Its proximity to the southern end of eastern escarpments makes the area distinct from the southern eastern lowlands south of Erafile (Gulf of Zula) through its greater exposure to weather systems originated from the north, which can produce some rainfall. Mean annual rainfall is usually less than 200 mm, erratic, unevenly distributed and unreliable. There are two wet seasons and a long dry season. The short rain occur during March – April, while December to February forms the main wet season.

Temperature

The mean annual daily temperature is approximately 30^0C, however, during the hot months of the year (July and August), maximum temperature can reach up to 50^0C. November to April are the coldest months with some rainfall showers. The dry hot season lasts May to October.

Hydrology

Most of the area is drained by small wadis radiating from volcanic hills in the upper watershed, with the exception of Wengebo and Buya-Simoti valleys basins, which receive considerable runoff from the eastern slopes of the southern escarpments. The seasonal discharge from these wadis flows either into the Red Sea or into the northern part of the Danakil Depression.

The ecosystem has high biodiversity and conservation significance particularly for African Wild Ass, Soemmerring's gazelles, Dorcas gazelles and Ostrich (Fig.1.12).

Figure 1.12. Nature of the habitat and common species of wildlife found in the coastal area. (Photo of Wild Ass from Messir Plateau and for Ostrich and Soemmering's gazelle in Buri Peninsula).

Description of Dahlak Kebir Island

The Dahlak Kebir Island is part of the Dahlak Archipelago located at about 60 km east of the port of Massawa. The Archipelago comprised more than 360 scattered small islands and the Dahlak Kebir is the largest of the islands that covers an area of approximately 637 km^2 and inhabited by less than 2,000 people. Dahlak Kebir is flat coral land and the name Dahlak is derived from Arabic word that means this is awkward.

There are six small villages within Dahlak Kebir Island, namely Jemhile, Desko-Melil, Selit, Debulo, Derbushet and Dahlak Kebir. The Islands vary in size from Dahlak Kebir that is over 48 km long, to islets covering only a few meters. The majority of the islands are uninhabited by humans, perhaps because ground water is absent or they are too small to offer any viable living facilities. They are largely composed of coral from the Pleistocene epoch with a limestone and sandstone foundation. Temperatures range from 35-45^o C but can reach 50^0 C during July and August. The climate varies little during the year but almost all the 175-250 mm annual rainfall falls between November and February. There have always been rains during these months although intensity often varies from year to year Tidal range is about one meter, with low tides exposing large mudflats on some islands.

Dahlak Kebir is dominated by flat pains with practically no vegetation except for a few pockets of thick, widely scattered acacia stands. During the rainy season, seasonal grasses and other herbs turn the area into a green landscape for a relatively short period; up to end of March (Fig.1.13). The sole mammal wildlife species that exists in the island is Soemmerring's gazelle.

Figure 1.13. Typical habitats in Dahlak Kebir Island

Description of the mainland (Western lowland) study area

The area is situated in southwestern part of the country at about 200 km northwest of Asmara. It is situated entirely in the arid lowland agro-ecological zone with mean daily temperatures that range between 21^{o}C and 29^{o}C and mean annual precipitation of 200 -500 mm (DoE, 2001).

Topography: The gazelles' habitat consists mainly of flat plains and mountains and small hills. Elevation ranges between approximately 500 to 900 meters above sea level. Most of the flat plains with some rolling hills are dissected by seasonal, ephemeral rivers that have substantial flows during the rainy season but are dry during the rest of the year. All the rivers drain to the Barka River.

The climate is semi-arid with high temperatures year-round. The average temperature during the April/May hot season is 42°C, although temperatures may rise to 50°C for short periods. The main rainy season is between June and September, and periodic flooding of the various tributary and Barka rivers can result in flash floods. Rainfall occasionally occurs in April or May.

Vegetation

The mainland study area is characterized by diverse ecosystems, dominated by flat plains with dispersed mountains and hills bisected by numerous tributary rivers that drain into the River Barka. The eco-region has mainly evergreen and semi-evergreen bush land and thicket with undifferentiated woodland of the Ethiopian type (Fig.1.11). In area with low water table, the vegetation changes to a community dominated by Acacia and Ziziphus. On the flat plains,

Cadaba rotondiflia becomes dominant and when the slope increases, the vegetation becomes more dominated by Acacia tortilis. Vegetation growing on hill slopes show that the abundance of *Acacia mellifera* was appeared dominant than other shrubs. Riverine vegetation is mainly characterized by Hyhaenae thebaica along the riverbanks, becoming more or less a monoculture in some places. *Tamarix aphylla* also occurs along the banks of rivers. On the steep slopes, trees are no longer present and shrub numbers becomes highly reduced more or less limited to the gullies (Fig.1.14).

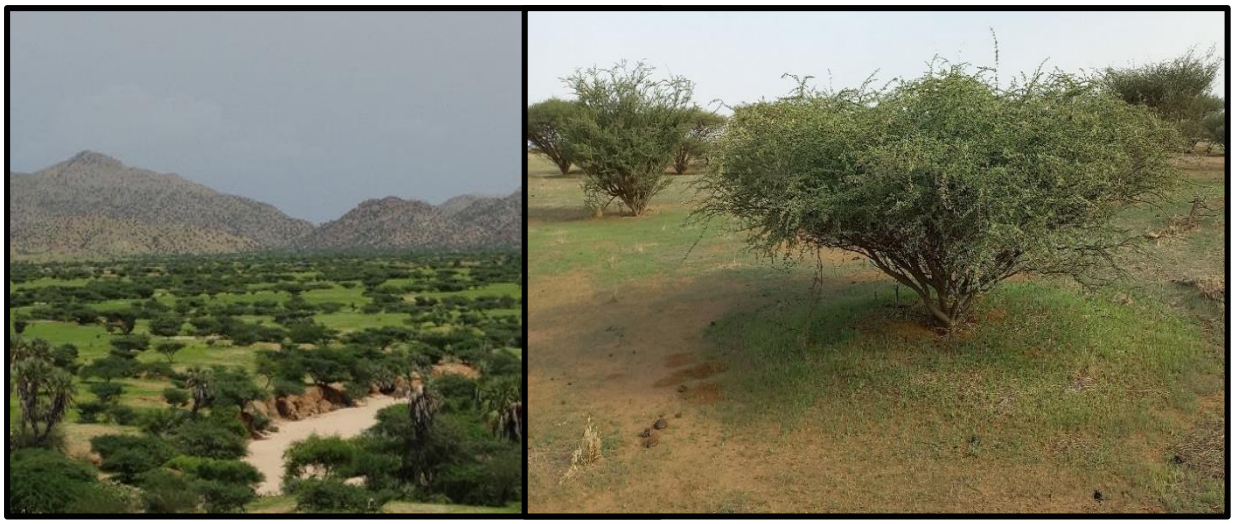

Figure 1.14. Landscape and the common vegetation found in the mainland study area

Fauna species in the area are dominated by Soemmerring's gazelle, Dorcas gazelle, Eritrean (Hegulin) gazelle, Jackals, Hyenas, Warthogs, Ostriches, Abyssinian hare, Salt's Dik-dik and Aardvarks. Other nocturnal mammals may also be present.

Outline of the thesis

The principal objective of the study was to assess and evaluate the overall distribution, abundance and conservation status of the three indigenous species of gazelles (*Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura*) in Eritrea. The empirical information obtained from the study could help to develop evidence based conservation strategy that ensure the continuous existence of the three species in particular and wildlife in general in the country. As an outcome, expected to provide pertinent scientific information and contribute to the holistic management of wildlife and habitat in the context of Eritrea and the region as whole.

Motivation (Justification) of the study

This study was motivated by the fact that the status and distribution of the three threatened gazelle species (*Gazella dorcas, Eudorcas tilonura* and *Nanger soemmerringii*) in Eritrea is

not well known or poorly studied. This applies predominantly for the gazelle populations that exist in the mainland, as so far no research has been carried out being to assess their distribution and conservation statues. Besides, these gazelles are living in unprotected areas, subsequently exposed to multiple threats that could subject them to the extinction. In view of that, this study will shed light on the conservation of the species through identifing the most pressing threats affecting the three gazelle populations, and come with possible ways of conservation. In addition, it would provide information on the existing situation and distribution of these three species in the country that could contribute on the establishment of protected areas. Furthermoe, the study will also provide updated data for inclusion in the forthcoming IUCN antelope database.

The study was carried in three sizable areas (Coastal, Island and Inland) using both direct and indirect methods. It was designed in order to collect data on a seasonal basis i.e. dry and rainy seasons. Field data was collected on the seasonal movements and the change in habitat use, along the established transects through road strip method. Furthermore, to assess the occurrence of the three gazelles in the entire country and obtain quantitative data, questionnaires (Appendix I) were also circulated in to the range of respected species.

The thesis is prepared as chapters, starting with Chapter I: Introduction with the background of the research, the general aims of the research and the main objectives, justification, and explaining the connections among articles and a general conclusion summarizing the outcomes of the entire article together.

Chapter II deals with the combined effects of climate, vegetation, human-related land use and livestock on the distribution of the three indigenous species of gazelle in Eritrea. The probability of observing a species was modelled through a Generalized Linear Model (GLM) with binomial error distribution, where climate, land use and livestock respectively entered in the model as predictors to examine which environmental variables or land use affect the occurrence of each of the three target species, and which species-specific habitat preferences are shown. In addition, a comparison of historical and current distribution of the three species of gazelles in the country was addressed and the paper was published on 27 April 2023 in scientific journal known as *Animal*.

Chapter III: Discourses the abundance and habitat use of the three indigenous species of gazelles. The survey attempts to estimate population abundance of the three target species in respective sites. In analyzing the data N-mixture models was applied, these models take

advantage of replicas of surveys to simultaneously model two different processes influencing each other in determining the observed counts i.e. abundance and detectability. To control the effect of site size, and for the non-independence of the observations from sites belonging to the same spatial unit. The observations were assigned along each transect on each occasion to the nearest site and obtained six-replicated counts of each gazelle species in each site. In the site-covariates matrix we included three variables: climate, land cover, and livestock.

Data of the habitat classification and use were analyzed using descriptive statistics such as percentages, means and standard deviations, which were calculated using the Statistical Package for Social Sciences (SPSS, version 26). Geospatial data were processed using Arc GIS 10.51 software.

Chapter IV. Deals with the assessment of the prevalence of threat and conservation status of the three indigenous species of gazelles in the country. Data that was obtained from the direct observation and questionnaire were analyzed and calculated using the Statistical Package for Social Sciences (SPSS, version 26). While the Geospatial data were processed using Arc GIS 10.51 software and soil mineralogical analyses were carried out via X-ray powder diffraction.

Chapter V. provide the General Discussion, Conclusion and Recommendation summarizing all the results from all the articles presented. It is presented in a way that to demonstrate the connection of the flow of ideas among papers

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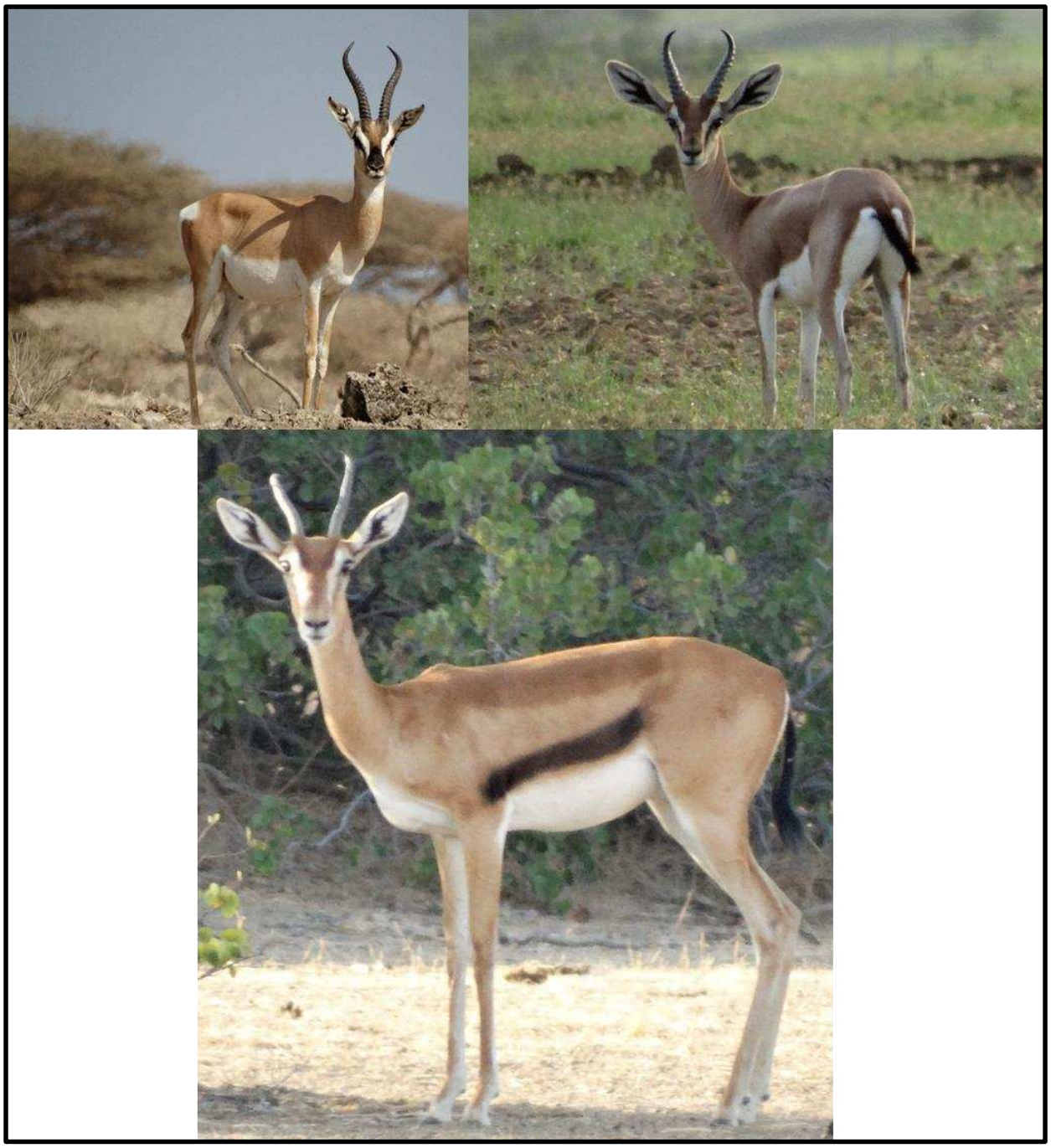

Eritrea's Three Indigenous Gazelle "Graceful, Charismatic and Resilient"

They need us to protect them and we need them for our wellbeings

Combined Effects of Clime, Vegetation, Human-Related Land Use and Livestock on the Distribution of the Three Indigenous Species of Gazelle in Eritrea

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Simple Summary: *Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura* are the three gazelles indigenous to Eritrea. Their status, distribution and habitat selection is poorly studied or unknown. This study fills this knowledge gap by providing the first data on environmental preferences and threats arising from human activities (agriculture and livestock) for the Eritrean populations of the three species. The distribution of the three species is mainly driven by climate and human related disturbance, rather than habitat features. Species tend to avoid agricultural areas and, particularly, areas with high density of livestock. To ensure the persistence of the three gazelles in the country, it is urgent and decisive the establishment of targeted protected areas, as well as actions to reduce the impact of competition with livestock.

Abstract

The status and habitat selection of the three species of gazelles indigenous to Eritrea, i.e., *Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura*, is not well known. In this study, we analyzed the present distribution of the three species in the country, in order to identify preferable habitats and assess the effect of human disturbance (land use for agricultural purposes and livestock) on species occurrence. These data represent a basal information for evidence-based strategies for conservation of the three species in Eritrea. Presence/absence data of the three species in each of the 67 administrative sub regions (Sub Zoba) composing the country were collected using direct (field surveys) and indirect methods (questionnaires). For each sampling unit, we collected 15 environmental variables, of which three associate with climatic features, eight with vegetation structure, and four with human disturbance (human related land use and livestock). The occurrence probability of each species was modeled

through Generalized Linear Models (GLM). The analyses showed that Dorcas gazelle occurred more frequently in warmer conditions and in a wide range of natural vegetation. Heuglin's gazelle occurred in warmer regions with higher seasonality in both temperatures and precipitations with a preference for closed woody and open grassland areas. In the case of Soemmerring's Gazelle, the GLM with climatic variables predicted a preference for warmer conditions, but with lower seasonality of temperature and precipitations. The species seemed to prefer arid and semi-arid open vegetation. Human disturbance resulted to be the variable with the strongest, negative, effect on the species occurrence. Indeed, the occurrence probability of each species decreased with increasing livestock density and agricultural land use. Most of these gazelles occurred in unprotected area thus the human related activities is undoubtedly the most relevant threat for the three species of gazelles in Eritrea. Therefore, the establishment of protected areas that preserve the potential optimal habitats for gazelles, and reduce the impact of livestock ranching are essential to ensure a future to these gazelle in Eritrea.

Keywords: Dorcas gazelle; Soemmerring's gazelle; Heuglin's gazelle; Eritrea; conservation and management; habitat selection; human disturbance; protected areas

Introduction

Ungulate species inhabiting arid regions of northern Africa are seriously threatened and several species risk extinction (IUCN, 2017). Among Antelopes, 31% of extant species are formally regarded as threatened, and 9% as nearly threatened. Furthermore, population trend is decreasing for 64% of assessed species and stable for 33% (Bro-Jorgensen et al., 2016). The primary reasons for species decline are certainly intensified hunting, habitat loss or deterioration as well as competition with domestic livestock (Beudels-Jamar *et al*., 2006, Bro-Jørgensen *et al*., 2016, Kingswood *et al*., 2001)

Eritrea hosts three species of autochthonous gazelles, i.e., the Soemmerring's gazelle, *Nanger soemmerringii* (Cretzschmar, 1828), the Dorcas gazelle, *Gazella dorcas* (Linnaeus, 1758), and the Heuglin's gazelle, *Eudorcas tilonura*, (Heuglin, 1863).

Soemmerring's gazelle is endemic to the Horn of Africa (Eritrea, Ethiopia, Djibouti, Somalia and southeastern Sudan, Fig.2.1). Its population in the region is declining and the total population in its range is estimated at less than 10,000 (IUCN, 2017). In Awash National Park,

Ethiopia, where it is legally protected, and populations of Soemmerring's gazelle have declined more than other antelopes (Gebremedhin and Yirga, 2006). The Sudanese populations have been probably extirpated (Kingdon *et al*., 2013). In Eritrea, the species occurs in the Coastal area, Dahlak Kebir Island, and in restricted inland areas. Notably, Soemmerring's gazelle is particularly abundant on Dahlak Kebir, probably due to the lack of terrestrial predators and the benign attitude of the local inhabitants, whose culture and ethical norms respect the wildlife (Yohannes 2001, Hagos, 2016). However, the knowledge about the general status of the species in the country is scanty, even though Eritrea is currently a stronghold for the conservation of the Soemmerring's gazelle (Mallon, 2014).

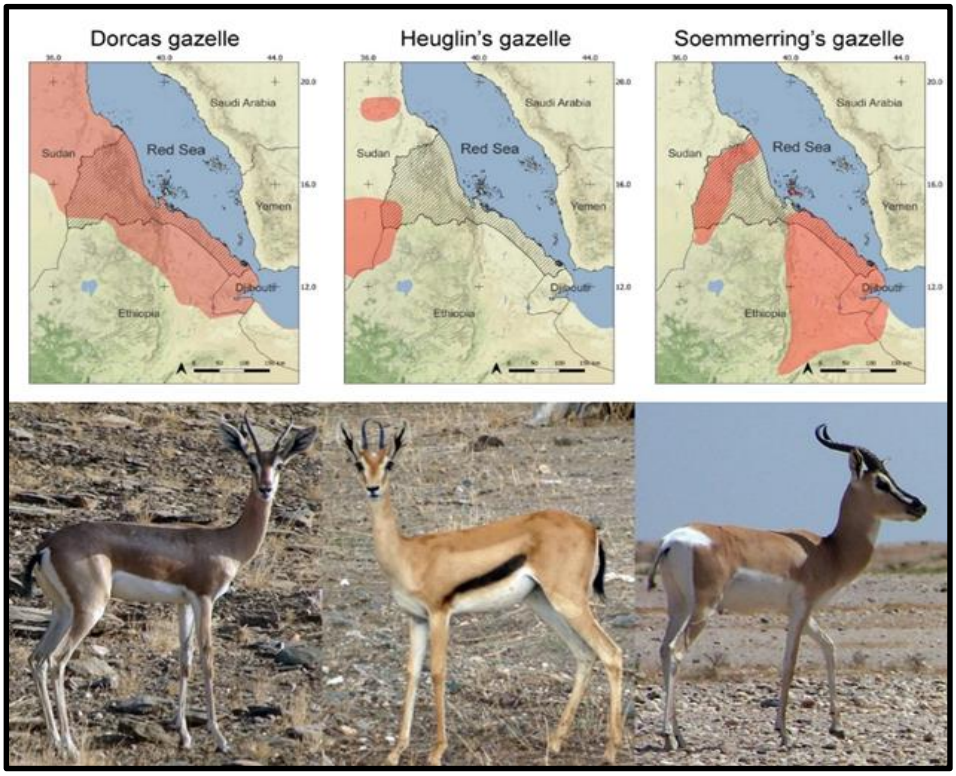

Figure 2.1. Historical distribution of the three gazelle's species (light red layers) occurring in Eritrea.
(Dashed area) according to IUCN data (IUCN, 2016 & IUCN, 2017). From left to right: Dorcas gazelle (*Gazella dorcas*), Heuglin's gazelle (*Eudorcas tilonura*), and Soemmerring's gazelle (*Nanger soemmerringii*).

Dorcas gazelle had previously the most extensive distribution of any African gazelle, but recent study revealed that the species no longer exists in several of its former areas (Frost, 2013, lerp *et al*., 2011). It was considered extinct from the mid-1970s in Senegal (Abaigar *et al*., 2013), where it was reintroduced in 2007. According to IUCN (2017), the decline of the species is estimated to be more than 30% over a period of about 15 years (up to April 2016) and that

fewer than 25% of those remaining at that time lived in protected areas. Furthermore, in the Sahara region the Dorcas gazelle no longer inhabited 86% of its former range (Durant et al, 2014). Consequently, Dorcas gazelle is categorized as a globally vulnerable species (IUCN, 2017). In Eritrea (Fig.2.1), the species has been reported from the coastal area, in the Southwestern and Northern part of the country (Afewerki &Yalden, 2013). However, accurate information on the distribution and status of the species does not actually exist.

The Heuglin's gazelle, also known as the Eritrean gazelle, is endemic to the Horn of Africa, specifically to Western Eritrea, NE Ethiopia and SE Sudan (Fig. 2.1). In the past, it was considered a subspecies of the red-fronted gazelle (*E. rufifrons*) or conspecific with Thomson's gazelle (*E. thomsonii*) and Mongolia gazelle (*E. albonotata*) (Yalden *et al,* 1984). Other authors consider Heuglin's gazelle an independent species (Groves 2013 and Hashim 2013) and this taxonomic status has been provisionally followed on the IUCN Red List (IUCN/SSG, 2017). According to the IUCN Red List, the species is classified as Endangered. Across its range, the main threats are hunting, competition with domestic livestock, and habitat degradation (Hashim, 2013). As stated by IUCN SSC antelope specialist group, the populations of the species might have fallen by 20% in roughly nine years since 2008 (IUCN, 2017) and, currently, the estimated global population of the species ranges between 2,500 - 3,500 gazelles (GoE, 1995).

The status and distribution of the species in Eritrea are not well known. For more than 80 years, no Heuglin's gazelles had been reported in the country; researchers lost sight of the species in the 1930s and it has not been recognized in Eritrea since then. There have been no confirmed sightings of the species by professionals until 2019, when a small group of animals was observed and photographed in the region of Gash Barka (Zoba), between sub regions of Dige and Gonge (Hagos, 2019).

These three gazelle species used to be widely distributed in Eritrea until the first half of the 20th century (1995), particularly Dorcas and Soemmerring's gazelles (Fig. 2.1). However, habitat degradation, chronic armed conflicts, drought, and limited conservation actions have led to a serious decline in their abundance as well as shrinkage of their ranges. During the 30 years of war for independence (1961-1991), soldiers took wild animals as food and many species declined, dispersed, or became locally extinct (DoE, 1999). After the independence of the country (1993), the Eritrean government has adopted a series of policies and practices, including the banning of hunting (1995), the establishment of protected areas, and a national

environmental management plan that emphasized community engagement, which have eventually allowed wildlife recovery (1995). As a result, wildlife of the country is climbing up (MoLWE, 2015), and the revival of the three species of gazelles is now evident (Hagos, 2019).

However, gazelle species are still under threat of human related burden, which may compromise their future existence. In order to prevent this scenario, and help planning conservation strategies, it is decisive to update the knowledge about their distribution, the potential ecological drivers, and the impact of human activities, including livestock. This can help determine protection areas of high priority and highlight essential habitat management (Canadas *et al*., 2005).

Ecological preferences by the three gazelle species in Eritrea are either not known or poorly studied. Similarly, the impact of human related activities on species occurrence has never been studied for the Eritrean populations. With this in mind, this study attempted to: i) fill the gap of knowledge on the distribution of the three gazelles throughout the country, ii) identify the main environmental drivers of their current distribution, and iii) assess the possible effects of livestock and land use by human activities (namely, urbanization and agriculture) on gazelles. The findings of this study are eventually pivotal to inform any evidence-based strategy for conservation of the three species in Eritrea.

Materials and Methods

Geographical setting of the Country

Eritrea is situated in the Horn of Africa and lies north of the equator between 12°22'N and 18°02'N latitude, and 36°26'E and 43°13'E longitude. It has an area of 124,300 square kilometers with a mainland and island coastline of more than 3,300km (DoE, 1999). The country is bordered by Sudan to the North and West, by Djibouti to the Southeast, and by Ethiopia to the South (Fig 1). The country is roughly divided into three physiographic regions, namely, the central highlands, the midlands and the lowlands (GoE, 1995). Three quarters of the country (more than 74%) falls in the arid or semi-deserts zones (Nagassi et al., 2002). The climate is arid to semi-arid with high temperatures year-round. Mean annual daily temperature is approximately 30 to 35 ºC, but during the hottest months, the maximum temperature can exceed 50 ºC (DoE, 1999). Rainfall is erratic, and both its amount and season varies depending on the region: in coastal area rain season occurs between October and March, whereas in the mainland extends between march-April and September –August respectively (DoE, 2001). The mean annual rainfall is usually less than 200 mm and 600 mm in coastal and mainland,

respectively. The three species of gazelles occur, even in sympatry, in three sizeable, geographically separated areas: the western lowlands (Gash Barka Region), the Red Sea coastal areas (Southern and Northern Red Sea Regions), and the Danakil desert (Southern Red Sea Region). Only one species i.e *Nanger soemmerringii* also inhabits in the Dahlak Kebir Island of the Red Sea.

Eritrea is divided into 6 main administrative regions (Zoba) and 67 sub regions (Sub-Zoba). We used these sub regions as sampling units, to report the presence/absence of each species, the environmental variables used to define species' ecological preferences, and the anthropogenic impact. For the purpose of this study the 13 sub regions of the central Zoba (Asmara) were excluded from the analyses due to its irrelevance in term of extension (less than 0.2%), thus analyses were referred to a sample of 54 sub regions of the country.

Species occurrence

To examine the occurrence of the three gazelles species within the selected sub region, different methods were applied, including direct and indirect observations (Denscombe, 2008). Field data was gathered along targeted surveys in the three geographical separated area (mainland, coastal area, and Island), during dry and wet seasons in 2020 and 2021. For each gazelle group or individual sighted, data on location, group size and habitat type was recorded. As much as possible, the observed species were photographed using standard HD digital and Video camera. To appraise the occurrence of the three gazelles in the entire country, data questionnaires were also circulated within the historical species range (Appendix I.). As (Newing, 2011) pointed out, questionnaires can be precise and powerful tools for collecting an enormous amount of carefully focused information from a large number of people. This task was accomplished through collaborators found in respective Zobas (regions) selected among scouts and/or experts of plant protection from the Ministry of Agriculture, who frequently travel to the field for assessing crop and rangeland condition. Besides, environmental experts from Bisha Mining Share Company and Colluli Potash Mining were also involved. Data coming from surveys and questionnaires was combined and used to classify each of the 54 sub regions included in the sample as suitable or not suitable depending on whether the species has been recorded at least once or not, respectively.

Environmental and human disturbance variables

To relate gazelle occurrence to environmental conditions and anthropogenic pressures, for each sub region we collected variables describing climate, vegetation, and human disturbance.

To characterize climate, we used the 19 bioclimatic variables from WorldClim data series (www.worldclim.org/version 1.4) (Hijmans *et al*., 2005) cut out on the study area. Map resolution was ~1 km, and the unsigned Pearson correlation among variables was on average 0.47 (range: 0.01- 0.99). The climatic principal component analysis (CPCA) produced three climatic principal components (CPCs) that explained 89.0% of the full variance and were used for modelling. Basing on the CPCs' loads, we were able to interpret each of those three CPCs, as summarized in Table.2. 1. For each sub region, we picked the mean value of the CPCs scores.

Table 2.1. List of variables used in the analyses of ecological preferences and human impact of the three-target specie of gazelle analyzed in the study.

Variable	Description	Pattern of variation/LCCS codes
Climatic variables		
CPC1 (50.6%)	Solar radiation (bio01, bio05, bio06,bio08-bio11)	From low to high
CPC2 (27.7%)	Rainfall seasonality (bio02, bio07, bio15, bio16)	From low to high
CPC3 (10.7%)	Temperature seasonality (bio04, bio18)	From low to high
Natural and semi-natural vegetation (VEG)		
FOC	Closed woody vegetation	2WC
FOM	Mixed forest with shrubs	2TC128, 2TC328
OSG	Open shrub grassland	2TP28, 2TP68, 2TR6, 2SOJ67, 2SP6, 2SPJ6, 2SPM58, 2SV6, 2SVJ67, 2SR6, 2SR6//6ST1, 2SR6//6ST2
SHC	Closed shrubs	2SCJ
OGR	Open grassland	2HR(CP), 2HR(CP)8, 2HR, 2HR//6L, 2HR//6S, 2HR//6ST1
SCR	Open scrubland on rocky and stony ground	6L, 6S, 6R, 6G
WRB	River banks	8WFN1
GFW	Close to very open grassland in swampy areas (fresh water)	4H(CP)F8, 4HCF
Human disturbance		
LPC1 (59.0%)	Livestock density	From low to high
LPC2 (22.1%)	Livestock composition (Prevalence of cattle, goats, and camels vs sheep and donkey)	From low to high
URB	Urban areas	5A, 5P, 5U
CLT	Crops	HD4, HD57, HL57, HR4, HR57, ND57, NR57, TBED47PL, TBEL57V, SBE57V

The vegetation data was sourced from the Africover Project, available at the United Nations website (www.un-spider.org). According to the FAO Land Cover Classification System (LCCS), the shape file of the Eritrea maps of the 69 different land cover categories grouped into seven main classes. This include natural and semi-natural terrestrial vegetation (LCCS class: A12 with 26 categories), the natural and semi-natural aquatic vegetation (LCCS class: A24 with 4 categories), bare areas (LCCS class: B16 with 10 categories), and inland natural water bodies (LCCS class: B28 with 5 categories). The vegetation categories from these four classes were grouped in 8 natural and semi-natural vegetation (VEG, Tab.2. 1), which were used to assess habitat preferences by the three target species. For each sub region, the coverage of each VEG class was computed and related to the sub regions. The unsigned Pearson correlation among VEGs was on average 0.18 (range 0.01 – 0.72), so we did not perform any data reduction, and we used all VEGs as independent variables in statistical analyses.

Human disturbance was assessed by two set of variables associated with livestock and land use. Number of livestock (cattle, sheep, goats, donkeys, and camels) for each sub region were obtained from Ministry of Agriculture of the state of Eritrea 2021 report (unpublished). Values were converted in density (n/ha) to make it comparable among sub regions. The unsigned Pearson correlation among the five groups of livestock was on average 0.46 (range: 0.02 – 0.69), so we summarized them using a PCA. The analyses produced two components that explained 81.1% of the full variance and were used for modelling. Similar to the climatic principal components, basing on the PCs' loads we were able to interpret each of these two PCs (hereafter "livestock PCs", LPC), as summarized in Table 2.1. Furthermore, we still used LCCS to assess the impact of human activities on natural environments, and specifically we used the build-up areas of any nature (LCCS class: B15, Artificial surfaces and associated areas, hereafter URB), and crops (LCCS class A11, Cultivated terrestrial areas and managed lands, hereafter CLT). The Pearson correlation was 0.30 and variables were standardized before being added to the model as independent predictors.

Statistical analyses

To analyze the effect of climate on species occurrence, we modelled the probability to observe a species through a Generalized Linear Model (GLM) with binomial error distribution, where CPC1, CPC2 and CPC3 entered the model as predictors. One different and independent model was performed for each species. Then we used the same approach to analyze the effect of natural vegetation on the probability of observing a given species. In this case, all the 8 VEGs

entered the model as linear predictors. Finally, a third GLM was used to assess the effect of human disturbance with LPC1, LPC2, and standardized URB and CLT as predictors.

In order to assess if the effects of livestock on the species occurrence basically due to the competition and common occurrence in the same habitats or to a direct interference not mediated by the environment, the last GLM was run a second time after controlling for the effect of VEG on disturbance variables. This was done by running four linear models, one for each human disturbance variable, where the eight VEG variables entered as predictors. The residuals of these four models were included as predictors in the GLMs accounting for the effects of human disturbance on species occurrence instead of the four original variables.

Models were fit in a Bayesian analytical framework available through the R (v. 4.2.1) package 'brms' (Burkner and Brms (2017), which uses the samplers implemented in STAN. Uninformative normal priors ($\mu = 0$ and $\sigma = 100$) were used for model's coefficients, and Cauchy distribution ($x0 = 0$, $\gamma = 2$) was used the error term (σ). Three chains were run using randomly selected initial values for each parameter within a reasonable interval, and conventional convergence criteria were checked. The number of iterations was selected for each run to obtain at least 10,000 valid values for each chain after convergence and thinning. Results from the posterior distribution are reported as the half sample mode (HSM) Bickel & Frühwirth (2006) with 95% and 50% highest density intervals (HDI95 (Meredith & Kruschke, 2018).

Table 2.2. Occurrence of the three species of gazelles indigenous to the Eritrea in the 55 sub regions monitored in this study.
Rare, not frequent, and frequent correspond to species: hard to see, occasional and persistent observation respectively**.**

Species	Absent	Present		
G. dorcas	37 (67%)	18 (33%)		
		Rare	*Not frequent*	*Frequent*
		7 (11%)	9 (50%)	2 (39%)
E. tilonura	42 (76%)	13 (23%)		
		Rare	*Not frequent*	*Frequent*
		6 (46%)	3 (23%)	4 (31%)
N. soemmerringii	44 (80%)	11 (20%)		
		Rare	*Not frequent*	*Frequent*
		3 (27%)	3 (27%)	5 (46%)

Results

The most frequent and widely sighted species was the Dorcas gazelle, which was observed at least ones in 18 sampling units (33%). This includes the following sub regions: Monsura, Akurdet, Dige, Gogne, Mogolo, Kerkebet, Adobha, Afabet, Korora, Foro, and all sub regions found along the Red Sea coastline (Fig.2.2). The Eritrean gazelle was observed in 23% of sampling units corresponding to the sub region of Monsura, Mogolo, Dige, Gogne, Forto-Sawa, Kerkebet, Golig, and Adobh (Fig.2.2). Finally, Soemmerring's gazelle shows the more restricted distribution in terms of sub regions, highly concentrated on coastal and Island areas, mainly in sub regions Ghelaelo Araeta and Dahlak Kebir Island (Fig.2.2) and to some extent in mainland mainly in sub regions Monsura, Akurdet and kerkebet. Each of the three species recurrent observations concentrated in more restricted areas (Table 2.2), corresponding to the two sub regions of Ghelaelo and Araeta for the Dorcas gazelle (Fig.2. 2), the five sub regions of Kerkebet, Dige, Monsura, Gogne, and Adobha for the Eritrean gazelle (Fig. 2.2), and the coastline between Foro and Maekel Denkalia for the Soemmerring gazelle (Fig.2.2). In addition, Dahlak Kebir Island guests an abundant population of Soemmerring's gazelles. Notably, Dorcas gazelle was repeatedly observed to occur in association with Soemmerring's gazelle, and occasionally with Eritrean gazelle in respective areas of their range (Fig.2. 2, lower panels).

Climatic and Natural vegetation preference – ecological niche of Dorcas gazelle

The GLM for the climatic variables (Table.2.3) showed that the Dorcas Gazelle occurred more frequently in warmer condition (higher solar radiation, CPC1, $P\beta>0 > 0.99$), with reduced thermal seasonality (CPC3, $P\beta<0 = 0.79$, Fig. 3), whereas no effect was observed for rainfall seasonality (CPC2, $P\beta>0 = 0.50$, Fig.2. 3). According to the model for VEG variables (Table 2.3), the species occurred in a wide range of natural vegetation, including herbaceous, shrubs and woody areas, but with different trends depending on the vegetation structure. Indeed, the occurrence probability increased in closed woods (FOC, $P\beta>0 = 0.96$) but decreased in mixed woody areas (FOM, $P\beta>0 < 0.001$, Fig. 4). The opposite trend appeared for shrubs. In this case, the model indicated a preference for open and sparse shrub grassland (OSG, $P\beta>0 > 0.79$) compared to closed ones (SHC, $P\beta>0 = 0.10$, Fig. 2.4). Accordingly, open grassland vegetation promoted the species occurrence (OGR, $P\beta>0 = 0.99$, Fig.2. 4), as well as open scrublands on rocky and compact grounds (SCR, $P\beta>0 = 0.83$, Fig.2.4). Finally, riverbanks (WRB) had a slightly negative effect ($P\beta<0 = 0.94$), whereas grassland in swampy areas (GFW) did not show any relevant effect on species presence ($P\beta>0 = 0.42$, Fig. 2.4).

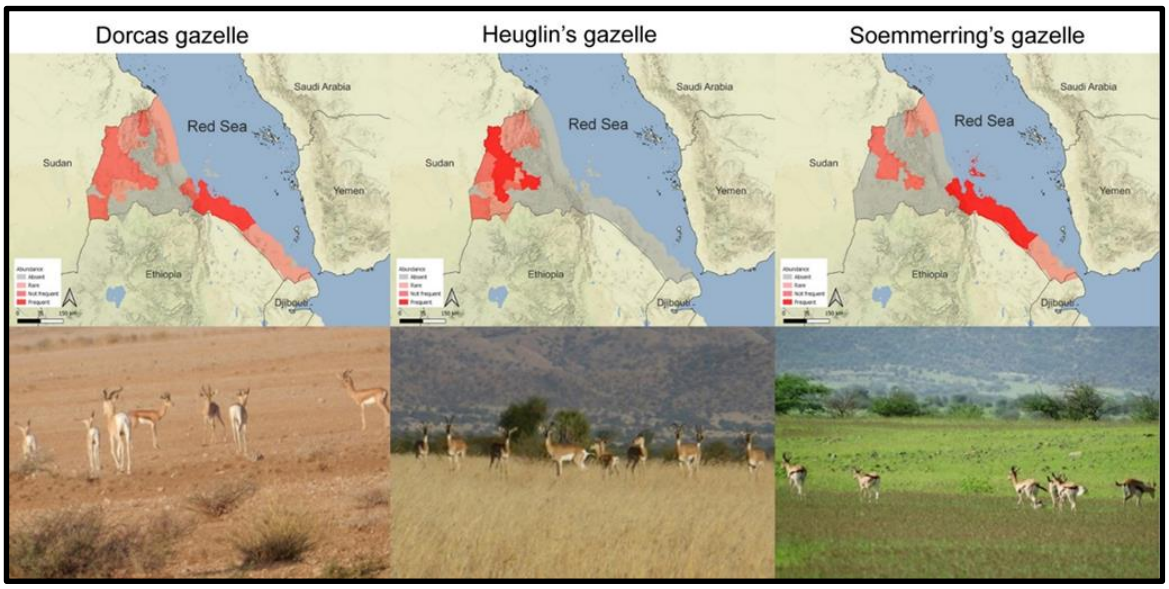

Figure 2.2. Current distribution of Dorcas, Heuglin's and Soemmerring's gazelles in Eritrea.

Lower panels from left to right: Soemmerring's and Dorcas gazelles occasionally seen feeding together (Buri peninsula); Dorcas and Heuglin's gazelles observed to overlap using the same area alternatively in different seasons with Soemmerring's gazelle; same habitat utilized alternatively by Heuglin's and Soemmerring's gazelles (Duluk, Gash Barka).

Table 2.3. Posterior distributions of the species occurrence as estimated by Bayesian GLM. HSM and HDI95 estimates are shown. Human disturbance values refer to the model without control for ecological effects on species occurrence (see methods for details).

Variables	*Gazella dorcas*		*Eudorcas tilonura*		*Nanger soemmerringii*	
	β (HDI_{95})	$P_{\beta<0}$	β (HDI_{95})	$P_{\beta<0}$	β (HDI_{95})	$P_{\beta<0}$
Climatic variables						
CPC1	0.85 (0.47; 1.40)	<0.001	0.55 (0.22; 0.98)	<0.001	0.58 (0.24; 1.09)	<0.001
CPC2	0.01(-0.32; 0.33)	0.50	0.95 (0.43; 1.72)	<0.001	-0.47(-0.90;-0.12)	>0.99
CPC3	0.23(-0.89; 0.32)	0.79	0.50 (-0.20; 1.3)	0.08	-0.22 (-0.98; 0.42)	0.74
Natural and semi-natural vegetation (VEG)						
FOC	35.3(-4.24; 79.2)	0.04	18.4(-26.9; 62.3)	0.21	18.0 (-30.1; 63.7)	0.22
FOM	-147.4 (-294.2; -38.8)	>0.99	-124.7 (-271.5; -19.4)	0.99	-112.7 (-262.5; -10.0)	0.99
OSG	1.94(-2.74; 7.19)	0.21	-3.23 (-7.9; 1.26)	0.92	5.37 (-0.6; 13.0)	0.04

SHC	-70.4(-227.1; 30.4)	0.90	-32.8 (-146.2; 43.0)	0.79	-25.9 (-166.4; 62.0)	0.69
OGR	5.53 (0.59; 11.1)	0.01	0.99 (-4.05; 6.1)	0.35	5.69 (-0.29; 12.7)	0.03
SCR	2.36 (-2.5; 7.53)	0.17	-2.06 (-7.95; 2.73)	0.80	4.1 (-2.44; 11.1)	0.11
WRB	-90.5 (-217.3; 24.3)	0.94	82.9 (-29.4; 196.1)	0.08	-71.0 (-202.1; 48.5)	0.87
GFW	-19.1 (-213.2; 176.1)	0.58	-8.31 (-199.2; 185.3)	0.53	-20.3 (-217.0; 172.3)	0.59
Human disturbance						
LPC1	-1.07 (-2.03; -0.41)	>0.99	-0.51 (-1.21; 0.02)	0.97	-3.59 (-6.98; -1.34)	>0.99
LPC2	-2.45 (-4.57; -1.11)	>0.99	-1.36 (-2.58; -0.46)	>0.99	-3.08 (-6.16; -1.02)	>0.99
URB	-0.60 (-2.15; 0.33)	0.88	-0.61 (-2.02; 0.31)	0.89	0.04 (-1.09; 0.99)	0.46
CLT	-0.37 (-1.27; 0.37)	0.83	0.14 (-0.64; 0.87)	0.36	-0.90 (-2.84; 0.30)	0.92

Climatic and Natural vegetation preference, ecological niche of Eritrean Gazelle

The model for climatic variables (Table 2.2) predicted the Heuglin's Gazelle in Eritrea occurring in warmer regions (CPC1, $P\beta>0 > 0.99$), with higher seasonality in both precipitation (CPC2, $P\beta>0 > 0.99$) and temperature (CPC3, $P\beta>0 = 0.92$, Fig.2.3). The model with VEG variables (Table 2.2) indicated a preference by the species for closed woody (FOC, $P\beta>0 = 0.79$, Fig.2. 4) and riverbanks (WRB, $P\beta>0 = 0.92$, Fig.2. 4) areas. On the other hand, mixed woods (FOM), open shrub-grassland (OSG) and open scrubland (SCR) are generally avoided ($P\beta<0 > 0.90$, Fig.2. 4).

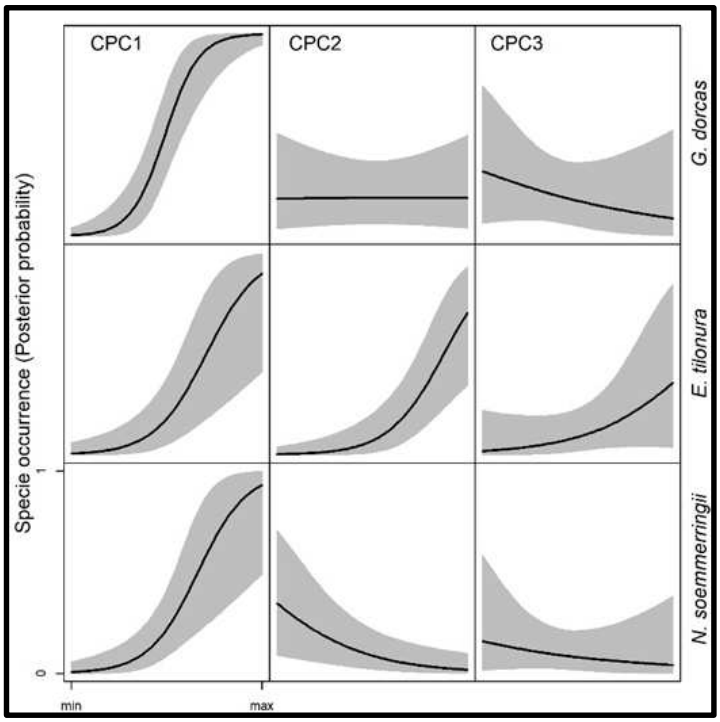

Figure 2.3. Bayesian model prediction for the probability of species occurrence in response to the climatic variables. The scales x-axis ranges from the minimum to the maximum of the variable; solid lines indicate HSM, and the grey areas represent HDI95.

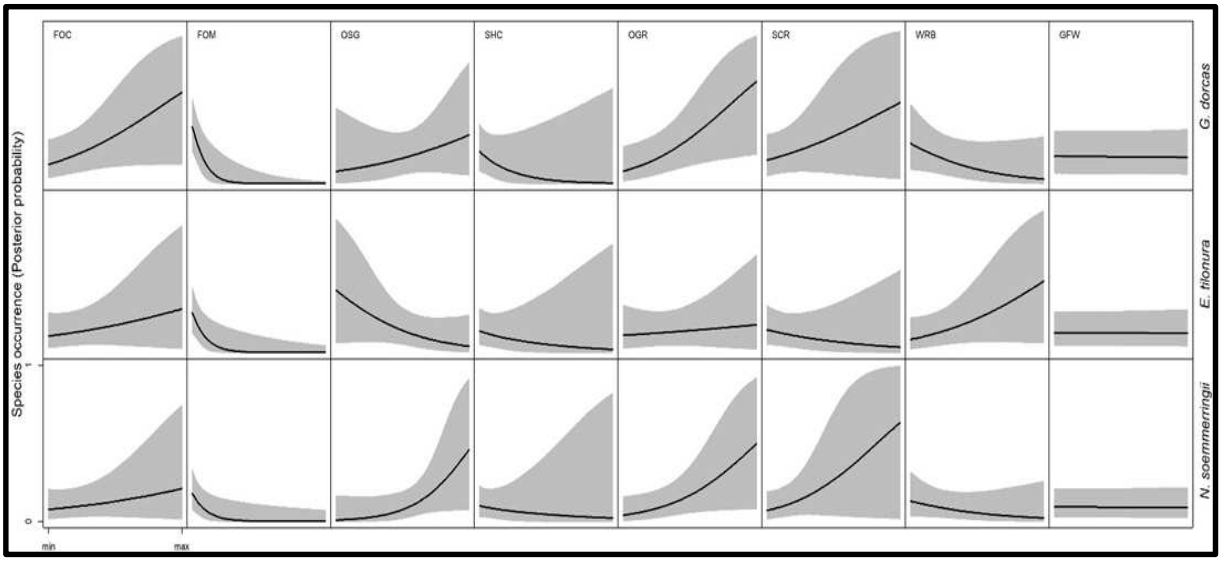

Figure 2.4. Bayesian model prediction for the probability of species occurrence in response to the climatic variables.
Solid lines indicate HSM, and the grey areas represent HDI95.

Climatic and Natural vegetation preference – ecological niche of Soemmerring's Gazelle

The GLM with climatic variables (Table 2.2) predicted for the Soemmerring's Gazelle, as for the other two species, a preference for warmer condition (CPC1, $P\beta>0 > 0.99$), but associated with reduced seasonality in both precipitation (CPC2, $P\beta<0 > 0.99$) and temperatures (CPC3, $P\beta<0 = 0.74$, Fig. 2.3). According to the model for VEG variables (Table 2.2), the species

occurs more frequently in arid and semi-arid open vegetation. Indeed, the model detected a clear preference for open shrub-grassland (OSG), open grassland (OGR) and open scrubland on rocky ground (SCR, Pβ>0 > 0.89, Fig. 2.4). Riverbanks (WRB) and mixed woods (FOM) were generally avoided by the species (Pβ<0 > 0.87, Fig. 2.4).

Human disturbance

The GLMs with human disturbance variables (Table 2.2) were consistent among the three species of Gazelles in predicting a negative effect on species occurrence of both livestock and human made environments (Fig. 5). The probability of gazelles' occurrence decreased with increasing livestock density (LPC1, Pβ<0 > 0.97), and also with increasing prevalence of cattle, goats and camels with respect to sheep and donkey (LPC2, Pβ<0 > 0.99). The effect of human related land use was less intense compared to that of livestock, but it was still negative (Fig.2.5).

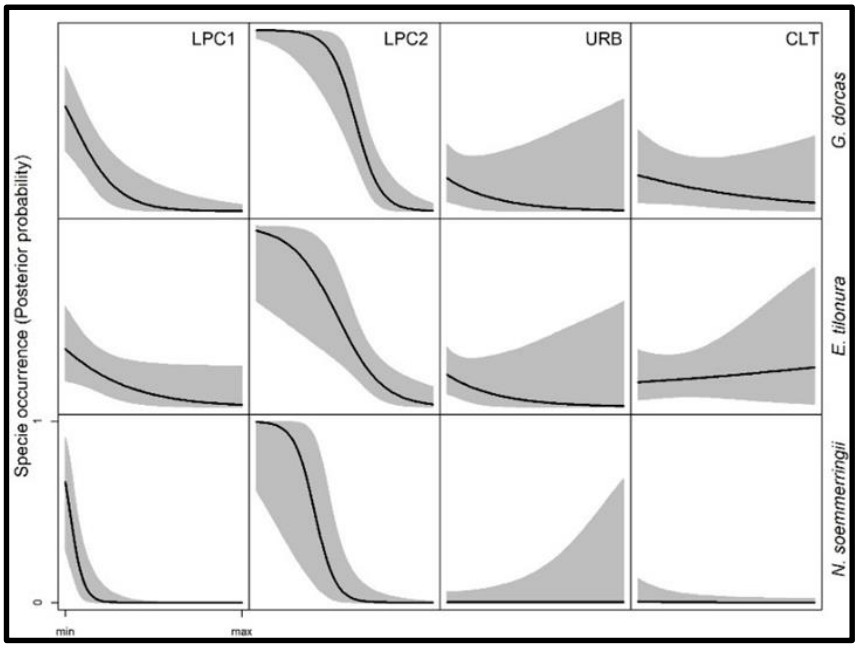

Figure 2.5. Bayesian model prediction for the probability of species occurrence in response to the human disturbance
Estimated through livestock (LPC1 and LPC2) and human related land cover (URB and CLT). Solid lines indicate HSM, and the grey areas represent HDI95.

Models predicted a clear negative effect of the urban areas (URB, Fig. 2.5) for Dorcas Gazelle (Pβ<0 = 0.88) and Heuglin's Gazelle (Pβ<0 = 0.89), but not for Soemmerring's Gazelle (Pβ<0 = 0.46). The negative effects of cultivated areas (CLT, Fig. 2.5) on species occurrence were detected for Dorcas Gazelle (Pβ<0 = 0.83) and Soemmerring's Gazelle (Pβ<0 = 0.92), but not for Heuglin's Gazelle (Pβ<0 = 0.36).

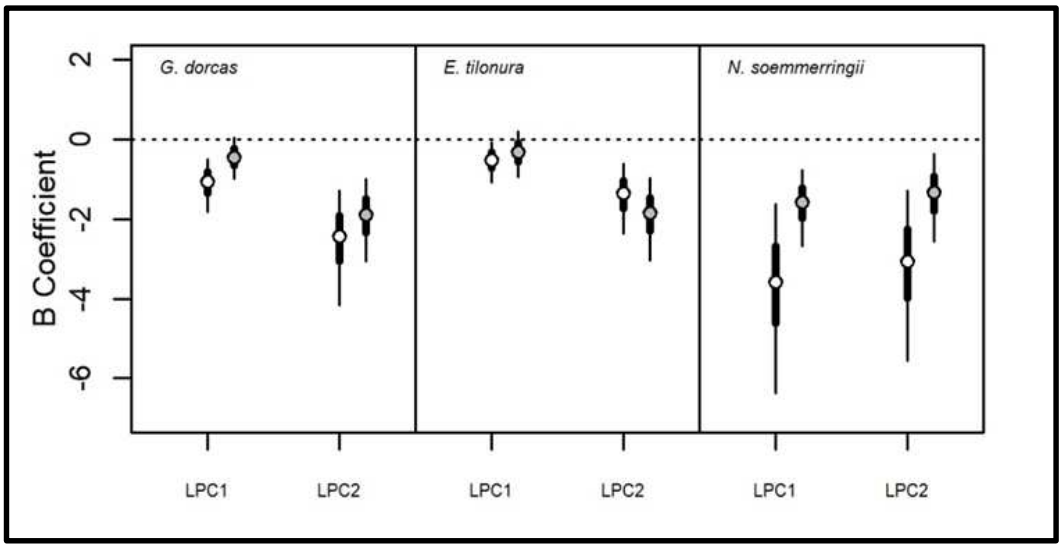

Figure 2.6. Comparison between the effects (posterior distribution of model β coefficients) of human disturbance on species occurrence

Estimated by Bayesian GLM with (grey dots) or without (white dots) the control for the effect of species ecological preferences. (See Methods for details).Solid lines indicate HSM, and the grey areas represent HDI95.

When controlling for the effect of climatic and VEG variables, the negative effects of livestock density and composition on species occurrence were fully confirmed ($P\beta<0 > 0.84$ in all cases; Fig. 2.6). The negative effect of livestock abundance on species occurrence were less intense in Dorcas and Soemmerring's gazelles ($P\beta diff<0 > 0.90$, Fig. 2.6), but no difference occurred for the Heuglin's gazelle ($P\beta diff<0 = 0.66$, Fig. 2.6). As regards the effect of livestock composition, the difference between models followed the same pattern as for livestock abundance (Fig. 2.6). The negative effect of livestock composition was less intense after controlling of the effects of VEG variables for Dorcas ($P\beta diff<0 = 0.71$) and Soemmerring's ($P\beta diff<0 = 0.90$) gazelles, but slightly increased in Heuglin's gazelle ($P\beta diff<0 = 0.27$).

Discussion

This study confirmed that the three indigenous gazelle species of Eritrea persist in the country although not in all the sub-regions that were surveyed. *N. soemmerringii* gazelles are widely distributed in the Red Sea Coastal area, Dahlak Kebir Island, and further inland in the southwestern part of the country. The coastal area appears to have the highest abundance of both *N. soemmerringii* and *G. dorcas* compared to the mainland. Interestingly, all three species are sympatric on the mainland, whereas in the coastal area only *N. soemmerringii* and *G. dorcas* were observed to co-exist. In Dahlak Island, only *N. soemmerringii* occurs with a viable population.

Climatic and VEG models of habitat choice point to ecological niche preference as a likely explanation of the observed geographic distribution of the three gazelle species. With regard to climatic variables, while they all prefer hotter regions, *E. tilonura* seems to associate with climate regimes with more seasonality than the other two species. On the other hand, N. soemmerringii is more common in areas with less seasonality, especially in temperature. Considering VEG variables, the distribution of *E. tilonura* is associated with wooded grassland, and frequently observed in riverine vegetation. The latter finding confirms previously reported observations in Ethiopia among *E. tilonura* populations from the Kafta Shiraro National park (Tatek, 2021) along the border with Eritrea; here too, Heuglin's gazelle showed preference for wooded grassland. However, contrary to the current study, avoidance of both open and closed shrubs (SHC, SHO) was not detected in the Ethiopian population and in other previous reports (Hashim, 2013 and Tatek, 2021). Encroachment by agriculturists could explain this discrepancy. In the areas we surveyed, it is common to see cultivation and pastoralism scattered in the open shrub land and grassland habitats. Thus, human disturbance rather than habitat unsuitability may be the reason for gazelle to move to other areas, leading the models to predict an apparent open areas avoidance. The preference by Heuglin's gazelles for riverine vegetation agrees with what is known about the species (Hashim, 2013), which is reported to be more water dependent than other species of gazelles in the same region.

The environmental niches of *N. soemmerringii* and *G. dorcas* are much more similar to one another than they are compared to the niche of *E. tilonura*. The models revealed that their habitats preferences were open woods or shrub grasslands followed by open grasslands (herbaceous), suggesting that these species are more adapted to arid and semi desert habitats. The two species of gazelles are the only ungulates occurring in the harsh, arid environment of Danakil depression. The vegetation structure of open wood/shrubs and grasslands of the coastal regions and inland are different; in the former, a savannah structure dominated by *Aristida mutabilis* and *A. adcensionis* prevails. In the latter, a semiarid vegetation, dominated by grass such *Pancium turgidum* and *Cynodon doctylon* is common. Therefore, it can be concluded that in Eritrea the Heuglin's gazelle is exclusively a Savana dweller, whereas Dorcas and Soemmerring's gazelles inhabit both Savanah and open desert grassland.

Our finding revealed that Dorcas gazelles tend to inhabit a wider range of habitats including open shrub grasslands, grasslands, scrublands, in arid-to semi-desert areas, including the Danakil depression. These findings align with previous reports from Tunisia (Chammem *et al*, 2008), which emphasized Dorcas gazelles avoid areas with agricultural development and did

not show preference for any specific habitat feature, occurring in grassland, shrub land, and semi-desert. Our findings are also consistent with data from the Sahara's Grand Erg region in southern Tunisia (Meliane *et al.,* 2023), where Dorcas gazelles were reported to be more affected by human disturbance than land use. Human activities have led the species to avoid more humid and greener areas, which although suitable are likely to be perceived by gazelles as too dangerous and are avoided in favor of less suitable but safer habitats. On the other hand, our findings contrast with research carried out in the Egypt's Eastern Desert (Attim, 2014) regarding the effects of precipitation patterns. The study on Egyptian's Dorcas gazelle concluded that the species may not be able to withstand long periods of drought, particularly due to spatially unpredictable precipitations. In contrast, our study showed that one of the most frequented areas by the species is in the harshest area of Eritrea, with very low precipitations. Nevertheless, this does not necessarily mean that gazelles prefer those habitats; we cannot exclude that the common occurrence of the animals in the Danakil depression may be due to human avoidance. Nonetheless, our findings suggests that the Eritrean populations of Dorcas gazelles are well adapted to drought and desert environments and are capable of responding to long periods of drought through behavioral adaptation.

Among the three species, Soemmerring's gazelle has more limited range of habitat but is most common in the Danakil depression. Our climatic and environmental GLMs revealed that the species shows a strong preference for open shrub grassland and open grassland habitats. These results are consistent with a similar study conducted in the Alledeghi Wildlife Reserve in Eastern Ethiopia (Mamo, 2019) where Soemmerring's gazelles were observed to prefer grassland habitat during the wet season and bush land habitat during the dry season. However, in Eritrea the species has demonstrated a remarkable tolerance to high temperatures from behavioral and physiological adaptations. During the hottest season (July-August), when temperatures soar above 45 °C, we repeatedly observed the gazelles seeking refuge in mangroves to escape heat stress until temperatures dropped. Additionally, the gazelles are capable of maximizing water conservation efficiency through mechanisms such as urine concentration, body temperature adjustments, and evaporative cooling (Ford *et al*., 2016)

The recurrent and severe droughts in the restricted range of Soemmerring's gazelles could influence the species conservation given the fact that the species is much more sedentary than the other gazelles. Indeed, sedentary animals like Soemmerring's gazelles are vulnerable to the impacts of drought due to their limited mobility, which can hinder their ability to escape the effects of extreme weather conditions (Estes, 2012 and Duncan *et al*., 2012). They face a higher

risk of death from thermal shock during periods of particularly elevated temperatures. This risk is further exacerbated by sedentary behavior exposing individuals to food scarcity during the dry season. For instance, in the coastal area where temperatures can rise to 50 °C, the death of gazelles due to heat stress may be a common occurrence, as reported by Scout Mohamed Ahmed (pers. comm.).

Another significant finding of this study is the detrimental impact of human activities, particularly livestock farming, on the occurrence of gazelle species. Our models consistently predict a decrease in the probability of gazelle occurrence with increasing livestock density, with the effect being more pronounced for cattle, goats, and camels, compared to sheep and donkeys. Additionally, human-related land use, such as cultivation, also had a negative impact on species occurrence, albeit to a lesser extent compared to livestock farming, with Dorcas gazelle being particularly affected.

Economic development is altering land use patterns in savanna ecosystems, leading to the conversion of uncultivated land into economically profitable uses, which in turn is reducing suitable habitats for gazelles outside protected areas (Ford *et al*., 2016). For instance, the transition from a nomadic to a sedentary lifestyle in Southern Tunisia has resulted in the privatization of lands and the creation of farmlands for cereal and olive crops, leading to a severe decline in the occurrence of Dorcas gazelles (Chammem *et al*., 2008). It is widely recognized that livestock farming is one of the main threats to gazelles and antelope conservation in general (IUCN, 2017, Bickel, 2006 and Mamo *et al*., 2019). The negative effects of livestock can be both direct, such as preventing access to optimal foraging areas due to high stocking density, and indirect, such as altering habitat quality through forage reserve depletion or shrub encroachment in open habitats (Ford *et al*., 2016, Georgiadis *et al*., 2007 and Roques *et al*., 2001). However, it is important to note that the effects of livestock are not always negative, and in some cases, cattle may coexist with, or even facilitate, wild grazers (Georgiadis *et al*., 2007).

The study findings indicate that despite conservation efforts (Yohannes, 2001 and Hagos, 2019), gazelles in Eritrea are facing threats from both natural and human-induced factors. The interaction between livestock and gazelles in grazing areas, particularly in mainland regions like Gash-Barka where livestock density is high, is identified as a major threat to the survival of gazelles. Goats, in particular, have similar feeding behavior to gazelles, resulting in competition for resources and habitat degradation. The absence of protected areas for wildlife

allows unrestricted grazing and browsing by livestock, further exacerbating the degradation of gazelle habitats. In the absence of proper land use planning, the long-term conservation status of gazelles in Eritrea is not expected to improve, and the fate of these species is uncertain.

Conclusions

Ecosystem in African savannahs can be better conserved if management is based on a clear understanding of threat on wildlife dynamics and the interaction with livestock. We showed that the distribution of the three species of gazelles indigenous to Eritrea is mainly driven by climatic and human related disturbance, rather than habitat features. Species tend to avoid agricultural areas and, particularly, areas with high livestock density. Our results suggest some recommendations for future planning of conservation actions in favour of the three species of gazelles. First, the preferable gazelles' habitats need active protection; thus, there is a dire need for the establishment and operationalization of protected areas in the country. Second, specific protected areas should be established in those areas that are facing serious human-wildlife conflicts. Such type of protected area need to be preferably IUCN category VI (multiple use) type. The creation of a network of unfenced conservation areas in which livestock densities are persistently low, which are sufficiently large to act as 'sources' of individuals that are prone to disperse. Some forms of subsidy could be used to support the income of ranching during dry years in order to promote coexistence of gazelles with livestock (Georgiadis *et al*., 2007). Geographically, priority needs to be given to such areas that are facing serious threat from the expansion of agriculture and pastoralists. Further studies are also needed in order to evaluate population dynamics of the three gazelle species in the country.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Questionnaire.

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The future of these charismatic and resilient species remain at our hands thus; let us take our share to ensure their continuous existence

Pattern of Abundance and Habitat use of the Three Gazelle Species in Eritrea.

Abstract

Understanding species abundance and knowledge of wildlife ecology including their feeding habits and habitat associations is a key pre-requisite to successful wildlife conservation and management. The three indigenous gazelle species **(***Nanger soemmerringii, Gazella dorcas and Eudorcas tilonura*) found in the Horn of Africa are all distributed in different parts of Eritrea. However, little study has been done to assess their abundance and habitat preferences. Consequently, knowledge of abundance and the ecological niche of these threatened species are lacking. This study addresses these shortfalls and obtain data of the existing situation that can support the development of a conservation strategy for the gazelles in particular and for wildlife in general. Sample sites were selected in the coastal and mainland areas that are endowed with high gazelle abundance. Data were collected seasonally along the established transects through a conventional road strip count method. For each gazelle group or individual sighted, data on location, type of vegetation and population structure (group size, sex and age composition) were recorded with GPS. To support direct observation, and for methodological triangulation, interviews and focus group discussions with local peoples were undertaken.

Abundance estimates for each site and species according to N-mixture models analyses revealed that N. *soemmerringii* and *G. dorcas* are more abundant in coastal areas than in the mainland*,* while greater abundance of *E. tilonura* was observed in the sample area Monsura-Duluk than in Kerkebet. Their abundance was significantly affected by climate thus; climate principal components positively correlated with *G. dorcas* and *N. soemmerringii* counts. Contrary to the other species, *E. tilanura* abundance negatively responded to increasing scores. This may reflect an overall higher adaptation of *G. dorcas* and *N. soemmerringii* to extreme dry conditions and high temperature whereas *E. tilanura* appeared to suffer from conditions that were too extreme. Furthermore, a substantial effect on the abundance of the gazelles was also noted from land cover and livestock. The correlation of the three variables revealed that the presence of herbaceous and livestock has a strong correlation on species abundance. Open shrub grassland followed by open grassland were identified as the most preferred habitats and there was no significant difference in seasonal abundance of the gazelles. The population of the three species appeared to have viable composition of age and sex group. However, their future existence appears unsecure due to being living in unprotected areas.

Key words: Abundance, Gazelle, habitat selection, Horn of Africa, conservation strategy, Eritrea.

Introduction

Estimating abundance is one of the most important prerequisites for the conservation and management of wildlife because it defines the need and scope of human action (Ransom *et al.,* 2012). This principle is highly relevant for gazelle conservation because the design of management programs for gazelle populations requires exact estimates of their abundance, as emphasized by Marques *et al.,* (2001). Thus, understanding species' abundance patterns and demography rates across space and time is critical. Similarly, as stated by (Jones, 2001), effective conservation, especially of endangered species, needs a deep understanding of habitat and frequency of use and as well as population relationships. In this respect, estimating species abundance and knowledge of wildlife ecology including their feeding habits and habitat associations is fundamental for Eritrea's endeavors in wildlife conservation and management.

Since Eritrean independence (1991), positive interventions have been ongoing to reverse deteriorating wildlife numbers. This has proved promising in the revival of wildlife including the three gazelle species indigenous to the Horn of Africa: Soemmerring's gazelle (*Nanger soemmerringii)*, Dorcas gazelle (*Gazella dorcas),* and Eritrean gazelle also known as Heuglin's gazelle (*Eudorcas tilonura)*.

A recent study revealed that these species are distributed in three different parts of the country (Hagos et al., 2023). This information starts to address the gap in our knowledge regarding the distribution of the species in Eritrea. However, prior to this study there is no study conducted to investigate their abundance and ecological niche, particularly in the mainland population where almost no information exists (Mallon, 2014). Therefore, published information on abundance and species habitat interaction is not in place. Climate change and anthropogenic activities have already resulted in the loss of large tracts of wildlife habitat in the region, including the home range of the gazelles. It is of paramount importance to conduct research in order to understand the species habitat relationship and develop ecological practice that can mitigate the trend of the adverse impacts that can be exerted on gazelle habitat before irreversible conditions occur, which may eventually lead to species extinction.

This study therefore aims to bridge the existing gap of knowledge on pattern of abundance and habitat interaction of the three species by providing empirical data on abundance and species habitat interaction for future conservation and management of these three threatened gazelle species and wildlife in general.

As described in chapter one, Soemmerring's gazelle (*Nanger soemmerringii),* currently categorized as a vulnerable species (IUCN, 2016) is endemic to Horn of Africa. The total population size of the species is estimated at less than 10,000 and declining (IUCN, 2016; Gebremedhin and Yirga (2005). In Eritrea, the species is present along the Red Sea coast, on the Dahlak Kebir Island, and in the southwest part of the country (Yohannes, 2001; Hagos, 2016, Hagos, *et al.,* 2023). However, their status of abundance is not only unknown but also so far no study has been carried out to examine the situation of population of the species in the mainland accordingly their status is not known (Mallon, 2014).

Dorcas gazelle used to be widely distributed in Saharan and sub-Saharan region but recent studies have reported that the species no longer exists in several of these former ranges (Frost, 2014; Abaigar *et al*., 2013). The IUCN red list estimated that a total population decline of more than 30% over a period of about 15 years up to 2016. The species currently is categorized as globally vulnerable (IUCN, 2016). In Eritrea, the species has previously been reported from the coastal, southwestern, and northern parts of the country (Yalden et al., 1984; Bekele andYalden, 2013) and the recent study also confirms that the species still exists in most of the former range of the species except in the highland part of the country (Hagos *et al*., 2023). However, their abundance and ecological niche is still unknown.

The Eritrean (Heuglin's) gazelle is endemic to western Eritrea, northeastern Ethiopia, and southeast Sudan (IUCN, 2016). Throughout its range, the population is declining and IUCN Red List (2017) classifies the species as endangered. As with the other two species, the existing population and ecology of the species in the country is unknown.

Study Objectives

The ultimate objective of this study was to examine the pattern of abundance and species habitat relationship of the three gazelle species in their foremost areas of the country and provide empirical data on abundance and habitat use of the species to inform conservation and management strategies.

Material and Methods

Study area

The study area is located in three sizeable, geographically separated parts of Eritrea, where there are abundant of the species. These are the mainland (western lowland), the Red Sea coastal areas (Southern and Northern Red Sea and in the Danakil desert) and in the Dahlak Kebir island of the Red Sea (Fig 1). Elevation of the study area ranges from -150m to +1000

m below and above sea level respectively. The climate is arid to semi-arid with high temperatures year-round. Mean annual daily temperature is approximately 30^0 to 35^o C, but in the coastal and island during the hottest months, the maximum temperature can exceed 50 ºC (DoE, 2008).

Rainfall is erratic and unreliable, its amount and season varies with the location of the study area, and the mean annual rainfall of the study areas is usually less than 200 mm and 600 mm in coastal and mainland respectively (DoE, 2001). In the coastal areas November to April are the coldest months with some rain showers and the dry hot season lasts May to October (Hagos, 2016). The mainland eco-region has a tropical climate with a hot and dry season and a short and long rainy season with summer rainfall. The coastal study areas is situated in the semi-desert, whereas the mainland is located within the moist and arid lowland agro-ecological zone characterized by an arid to semi-arid climate with extreme hot summer (See agro ecological map of the country).

The vegetation of the coastal area is scattered with a combination of low growing trees and widely spaced annual and perennial grasses. Most of the coastal and adjacent areas are characterized by basaltic lava fields with vegetation dominated by *Acacia mellifera* and sandy plains with scattered *Acacia tortilis, Acacia nubica*, *Acacia laeta, Salvadora perisica,* and *Ziziphusspina-christi.* The plain area is characterized by grassland dominated by *Panicum turgidum*. The gorges and depression areas are endowed with drought tolerant plant species. The Red Sea shore is covered by *Avicennia marina* (Mangrove) forest (DoE, 2001).

The mainland study area is characterized by diversified ecosystems, dominated by flat plains with dispersed mountains and hills bisected by numerous tributary rivers that drain into the Barka River. The physical features of the terrain and availability of water influence the distribution of the vegetation and it is characterized by Acacia shrub land community associated with grassland mainly dominated by *Aristida* species.

Methodology

Designing appropriate survey methodology has vital role in obtaining reliable results; and it is with this in mind that different approaches are applied in this study. Applying different data collection methods is likely to help researchers come up with sound information because as Denscombe (2008) pointed out, using more than one data collection method has the advantage of providing a fuller or more complete picture about the issue that is being studied. In this

respect, the study had to involve both direct and indirect methods of field investigation. The data collection methods applied during the study are presented below.

Literature review and reconnaissance surveys

Prior to selecting sample areas, available literature and reports related to gazelles in Eritrea was reviewed. Following that, reconnaissance surveys took place in potential gazelle habitats. The author's prior field experiences were used as a foundation to select sample sites and carry out focused surveys.

Selection of sample sites

In each of the habitats identified, fixed transects were established that suited road survey accessibility. Eight transects were established of which five were in coastal areas, two in mainland and one in the Island (Fig.3.1). Transect lengths varied as dictated by the landscape and the distribution of gazelle habitats. Hence, transects Monsura-Duluk covers 38.5 km, Kerkebet 46 km (mainland area), Buri peninsula 87.61 km, Morah 29 km, Bededa 18 km, Garsa-Marsafatuma 20 km, Marsafatuma-Adayto 22 km (coastal area) and Dahlak Kebir Island 24 km.

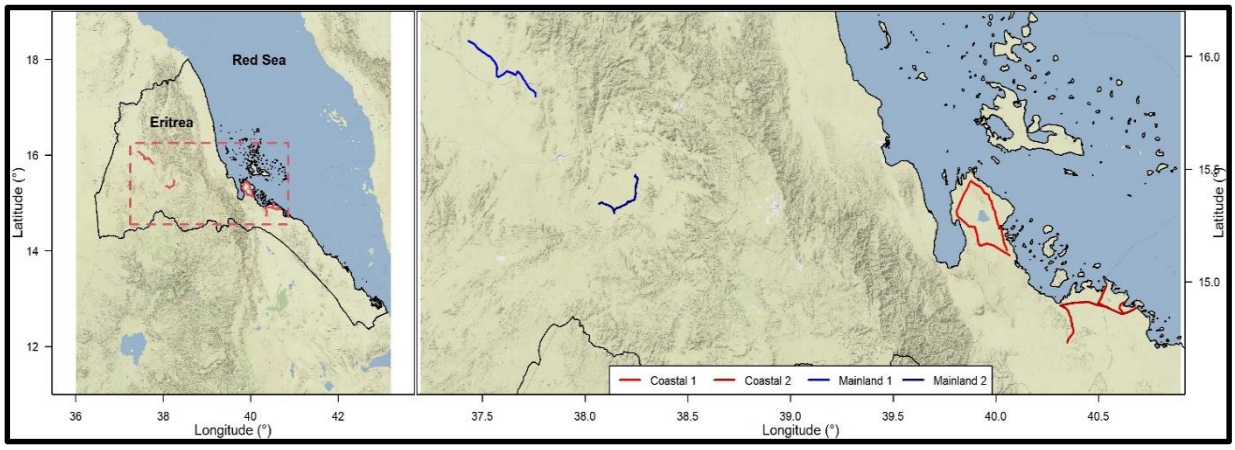

Figure 3.1. Location of the sample transects used to estimate the abundance ofthethreegazellespeciesin Eritrea.
Left panel: distribution of transects across Eritrea; dashed-red-box highlighted the area zoomed in the right panel. *Right panel*: zoomed map showing the location of the transects according to their grouping on the mainland (blue tones) and coastal (red tones) areas (see Appendix IV for details).

Seasonality of the survey

Six complete surveys were carried out from November 2020 to September 2021 along the established transects by two persons i.e. a driver-observer and observer-recorder, using a 4x4 vehicle and applying a conventional road strip count methodology. The method is considered the most practical for rangers and conservation managers to determine changes in the

population size of gazelles (Wronski, 2013). The transect was followed by a vehicle moving at slow speed (20-30 km / hour) and the survey was conducted during early morning and late afternoon (from 6-11AM and 3-6:30 PM)in order to avoid harsh mid-day temperatures when gazelles rest in the shade. The itinerary was recorded on GPS, observations were made with the naked eye and binoculars to spot all medium to large-sized mammals (herbivores and carnivores, feral and domestic) on both sides of the transect. For each gazelle group or individual sighted, location (habitat) and population structure (group size, sex and age composition) were recorded using the field data sheet (Appendix III)

Data collection were done in two seasons i.e. Dry and wet seasons. For this purpose, the survey periods were divided into six periods (two-month intervals) with 5 days spent in each study area. Due to COVID 19 travel restrictions, additional data could not be collected from Dahlak Kebir Island after the first survey that was conducted in 2020. For this reason, data on the study of estimation abundance in Dahlak Island was excluded.

Indirect observation

To appraise the direct observation of the abundance of gazelles and habitat interaction, interviews and focal group discussion were also exercised with local people who have an attachment with the area encountered during survey period in the respective sample sites.

Parameters collected

The following parameters were collected using mixed method approach.

Habitat type and structure

During the survey seasons, visual assessment was made for the landscape, topography, land cover, and presence of water. Land Sat images at 30 m resolution at the scale of 1:50,000 were used for land cover mapping. Likewise, SPOT-5 satellite images with a resolution of 2.5 m were used for, drainage, and vegetation map verification. The digital elevation model (DEM) was taken from the Advanced Spaceborne Thermal Emission and Reflection (ASTER) Version 3, which was released on August 5, 2019 (Aster *GDEM*, 2019).

In each site, gazelle potential habitat was identified and its preference was rated according to the level of concentration of gazelles. Information on the vegetation structure were also collected as ground validation of the habitat classification. In each study area the diversity of plant species were identified (Fig.3.2), in the event when identification was not possible,

specimens were collected, pressed and taken to a herbarium (Asmara) for identification. Data on foraging ecology were also collected in area where the species were spotted feeding.

Figure 3.2. Vegetation identification in study area Author (right) with Jabir Ahmed.
(Photo, Kerkebet area)

Abundance and habitat interaction

Field data on the seasonal abundance and habitat use of the species along the established transects were collected both in wet and dry seasons. On the mainland the dry seasons survey was conducted during November, January, and May and wet season are March, July and Sept where as in coastal areas have a different seasonality, thus dry season survey was carried out in the month of May, July and September and for the wet season in November, January and March. Interestingly the mainland receives short rainfall by March, thus both sites receive rain showers during March.

All sighted species and their habitat interaction were recorded, and whenever possible species were photographed using standard HD digital and video camera. Attempts were also exerted to assess Species range distribution through the consultation with local people

Population structure

Throughout the survey period the population structure which includes group size, group composition, estimated age, sex and age ratio, distance from the observed species, habitat type, and geo-referenced location were recorded for each sighting of the three species of gazelles using the field data sheet (Appendix III)

Material of the study

The material used for the study include video and still camera, GPS. Range finder, counter, topographic maps, Computer, vehicle, boat, camping equipment and binoculars.

Data analysis

Estimating Abundance

Estimating abundance of the three gazelles along the surveyed sites was carried out through assessing the implication of climate, habitat, and livestock. For this purpose, N-mixture models were applied to a repeated sampling design. The models allow estimating abundance accounting for imperfect detection (Royle, 2004; Madsen & Royle, 2023). These models take advantage of replicas of surveys to simultaneously model two different processes influencing each other in determining the observed counts: abundance (λ), i.e., the actual number of individuals in a site; detectability (p), i.e., the probability of observing an individual in a specific occasion given it is present at that site. Abundance is usually modelled using Poisson distribution, while detectability is modelled using a binomial distribution. In both cases, site-level or observation-level covariates can be used to model λ and p, respectively (Royle, 2004). The dataset needed to run N-mixture models for repeated counts consist three components: (1) a matrix of detection histories, reporting for each site the observed species count for each survey, (2) a site-covariates matrix, summarizing the environmental variables associated with each site and supposed to influence abundance (e.g., climate, land cover, topography) and (3) a set of observation-covariates matrixes, each reporting the values of the variables supposed to influence detectability (e.g., season, disturbance, effort, weather conditions) for each site of survey.

To run N-mixture models, we focused on transects with six complete surveys made during the study period. Overall, they were geographically distributed into four areas, two along the coast (coastal 1 and 2), and two in the mainland (mainland 1 and 2; Appendix IV and Fig. 3. 1). Each transect was divided into a variable number of sub-transects, i.e., subsequent segments of the original track, in order to increase sample size and account for environmental variability along each transects (Sacchi *et al.*, 2022). The number and length of the sub-transects depended on the original characteristics of the main transects they belonged to, but we tried to satisfy two criteria: 1) keeping a comparable length among sub-transects; 2) having more than one sub-transect for each original track, considering that they could change in their overall length due to field work conditions. Through the process 31 sub transects were obtained (Appendix IV**)**. Sites length and grouping factor (i.e., geographic region where they originated) were used in

modelling to control for the effect of site size, and for the non-independence of the observations from sites belonging to the same spatial unit (see below). Observations were assigned along each transect on each occasion to the nearest site, thus obtained six-replicated counts of each gazelle species for each site (detection histories).

In the site- covariates, matrix three kinds of variables were included: climate, land cover, and livestock. As climatic variables, we used the nineteen bioclimatic layers available from worldclime.org, at 30 arc-second (1 km) spatial resolution (Fick & Hijmans, 2017). We extracted the mean value of the variables in a 1-km-wide buffer around each site. Then, we performed a principal component analysis (PCA) on the obtained climatic matrix, and used the scores of the first three components (CPC1-3), globally accounting for 97.55% of variation, as proxy for the climate variability among sites (Table**. 3.2**). Similarly, we used the map of African land cover, from the Africover project, available at the United Nations website (www.un-spider.org). We computed the proportion of each land cover class within a 1-km-wide buffer around each site. We again used a PCA to reduce the dimensionality of the obtained matrix, keeping the scores of the first three components (HPC1-3), which accounted for 78.51% variation (Table.3. 2). Finally, to quantify the impact of livestock at site-level, we used the total counts of camel, cattle, goat, sheep, and donkey for each site across the six surveys. After a PCA, we picked the scores of the first two components (LPC1-2; 74.20%; Table. 3.2). The site-covariates matrix eventually consisted of eight variables.

To model detectability, three variables were measured at the observation-level: the date of the survey (dtrl), to account for p variation across seasons; the starting hour of the survey (hh), to control for a potential daily activity effect on detectability, the size of the site (length) used as proxy for sampling effort. All the above variables were standardized before analysis. Data processing, variables extraction, and dataset assembling were done in R v4.1.2 (R Core Team, 2021) using the package `terra` v1.5-34 (Hijmans, 2022) and *ad hoc* scripts.

N-mixture models were built for each gazelle species separately, using the same model formulation. Notably, we included all the observation-level variables (dtrl + hh + length) in the detectability model; to model abundance, we used CPC1-3, HPC3 and LPC2. We excluded HPC1-2 and LPC1 because they resulted redundant (i.e., highly correlated) with climatic component CPC1 and CPC3 (Table. 3.3). A random intercept was added to the abundance sub-model to account for the spatial non-independence of the sites coming from the same areas. N-mixture models were run using unmarked R package (Fiske & Chandler, 2011; Kellner *et al.*, 2023), setting mixture to "Poisson" for *Nanger soemmerringii*, and *Gazella dorcas*, and "zero-inflated-Poisson" (ZIP) for *Eudorcas tilanura* (since most sites had zero observations).

Population structure

The data of the population structure (age and sex) were analyzed using descriptive statistics specifically the average of the six survey data including its standard deviations were calculated using the Statistical Package for Social Sciences (SPSS, version 26).

Habitat type and structure

To date, no systematic comparison of the different classifications of habitats is undertaken in the country (DoE, 1999), and thus there is no standard habitat classification in the country. For this reason, the habitat structures have been categorized according to physiognomic features of the vegetation. It was determined on the ground by professional judgment and by bringing together some of the different classification systems that were reflected in various national reports in a way that can fit the common wildlife habitat in the country, then applied across an extent as determined by satellite imagery. The Geospatial data were processed using Arc GIS 10.51 software. Further analyses also made using descriptive statistics such as percentages, means and standard deviations, which were calculated using the Statistical Package for Social Sciences (SPSS, version 26). It was regarded that the differences between two variables as statistically significant when the two-sided p-values was <0.05 and averages were presented as mean ± SD.

Results

Estimating Abundance

For the sake of satisfying the model of analyses, the sample size had to increase thus transects were grouped, into four main regions representing each coastal and mainland with two sample sites indicated as one and two without changing their original track. The partition of transects in to segments was based on their relative geographical positions and thus 31 sub transects were obtained (Appendix IV).

The correlation of the three variables: climate, land cover and livestock on the abundance of the respective species is summarized in Table 3.1. For each component, the percentage of variance explained, the most positively (+), and negatively (-) correlated original variables and an overall interpretation of the component according to its relationship with the original variables.

Table 3.1. Description of the principal components for the three variables groups (Climate, land cover, livestock) used in modelling gazelles' abundance.

Variable		Most correlated original variables	PC score interpretation (from low to high score)
Climate	CPC1 (62.86%)	*bio1,2,5,7,8,10,11,15 (+)* *bio19,17 (-)*	Increasing air temperature and peaking of dry conditions
	CPC2 (23.64%)	*bio4,6,9 (+)* *bio3,12,14,17(-)*	Decreasing rainfall combined with increasing temperature seasonality
	CPC3 (11.05%)	*bio6,9 (+)* *bio15 (-)*	Decreasing precipitation seasonality, with high temperature during the dry season.
Land cover	HPC1 (42.23%)	*2H(CP)8 (+)* *2SR6, 2SV6, 6ST1 (-)*	Herbaceous coverage with sparse shrubs
	HPC2 (20.76%)	*2HR, 2SV6 (+)* *2SR6, 6ST1 (-)*	Shrubs coverage with sparse herbaceous vegetation
	HPC3 (15.52%)	*2HR/6S, 6L (+)* *2SR6, 2SV6 (-)*	sparse herbaceous vegetation on sand soil, without shrubs
Livestock	LPC1 (42.81%)	Camel, cattle, donkey, goat, sheep (+)	Livestock density
	LPC2 (31.38%)	Camel, donkey, goat (+) cattle, sheep (-)	Livestock composition (Prevalence of camels, donkey and goat vs. cattle and sheep)

The correlation of the three variables revealed that the presence of herbaceous (HPC1) and livestock (LPC1) has strong correlation on the abundance of the species (Table 3.2)

Table 3.2. Pearson bivariate correlation matrix for the eight principal components representing climate, land cover and livestock:
Absolute values above 0.6 (indicating strong correlation) are bolded.

	CPC1	CPC2	CPC3	HPC1	HPC2	HPC3	LPC1
CPC2	0.000						
CPC3	0.000	0.000					
HPC1	**0.817**	0.084	-0.325				
HPC2	-0.332	-0.164	-0.068	0.000			
HPC3	-0.021	0.232	0.389	0.000	0.000		
LPC1	**0.674**	-0.349	0.006	0.054	-0.187	-0.112	
LPC2	-0.537	27	175	-0.527	0.005	-0.064	0.000

The detection histories of the three gazelle species in the 31 sites, considering raw counts, *Nanger soemmerringii* and *Gazella Dorcas* seemed common and well distributed across the

study areas. On the contrary, *Eudorcas tilanura* was rarer and restricted to the mainland sites only (Appendix V).

The abundance estimation shows that *G. dorcas* and *N. Soemmerringii* are abundant in both coastal area and mainland areas with highly pronounced in coastal area, whereas *E. tilanura* is restricted to the mainland and appeared more abundant in Monsura-Duluk area than in kerkebet sample sites (Table 3.3).

Table 3.3. Abundance estimates for each site and species according to N-mixture models**.** Nest = mode and 95% confidence interval (lower – upper) of the estimated abundance; Nmax = observed maximum count**.**

	G. dorcas		*N. soemmerringii*		*E. tilanura*	
Site	N_{est}	N_{max}	N_{est}	N_{max}	N_{est}	N_{max}
bp_1	10 (7-16)	4	45 (40-51)	33	0 (0-0)	0
bp_2	26 (20-32)	10	75 (72-75)	50	0 (0-1)	0
bp_3	10 (6-14)	3	1 (0-3)	0	0 (0-1)	0
bp_4	14 (11-19)	7	36 (31-41)	21	0 (0-1)	0
bp_5	4 (2-7)	2	6 (5-9)	5	0 (0-1)	0
bp_6	7 (5-11)	3	26 (23-31)	17	0 (0-1)	0
bp_7	12 (8-17)	5	55 (49-61)	36	0 (0-1)	0
bp_8	13 (9-17)	6	39 (34-45)	27	0 (0-0)	0
bp_9	9 (6-14)	3	40 (35-47)	22	0 (0-1)	0
bp_10	13 (9-18)	5	45 (40-52)	27	0 (0-1)	0
gb_1	42 (35-47)	22	75 (71-75)	42	0 (0-1)	0
gb_2	26 (20-34)	13	26 (21-32)	16	0 (0-0)	0
gm_1	35 (29-43)	11	61 (56-68)	44	0 (0-0)	0
gm_2	28 (22-35)	11	50 (44-56)	28	0 (0-0)	0
k_1	24 (18-31)	8	26 (21-31)	16	13 (8-19)	4
k_2	22 (16-29)	7	28 (23-35)	17	18 (13-24)	5
k_3	17 (12-24)	4	8 (3-14)	0	10 (6-16)	4
k_4	19 (14-26)	7	26 (21-33)	12	12 (8-18)	4
k_5	36 (29-43)	11	73 (66-75)	44	41 (33-51)	9
k_6	31 (24-39)	6	71 (62-75)	27	32 (25-41)	11
m_1	35 (27-44)	5	45 (38-55)	16	0 (0-2)	0
m_2	32 (24-41)	5	38 (31-46)	23	0 (0-1)	0
m_3	21 (14-29)	5	37 (31-45)	17	0 (0-0)	0
m_4	44 (35-47)	9	66 (57-74)	30	0 (0-2)	0
ma_1	34 (26-43)	6	60 (51-70)	17	0 (0-0)	0
ma_2	36 (28-44)	13	74 (65-75)	30	0 (0-0)	0
ma_3	39 (30-46)	7	70 (60-75)	20	0 (0-0)	0
md_1	45 (37-47)	17	56 (49-63)	30	31 (25-38)	10
md_2	24 (18-32)	8	50 (44-56)	25	28 (22-35)	11
md_3	37 (30-45)	9	58 (53-64)	41	61 (51-69)	20
md_4	29 (22-37)	8	75 (70-75)	40	65 (55-70)	16

The estimated abundances for each site and species (Table. 3.3) reflected such pattern.

Both abundance and detectability responded differently to the variables included in the models, according to a species-specific scheme (Table. 3.4; Fig. 3.3).

Table 3.4. Coefficient estimates from N-mixture models

		G. dorcas			*N. soemmerringii*			*E. tilanura*		
Sub-model	**variable**	**β**	**βSE**	**P**	**β**	**βSE**	**P**	**β**	**βSE**	**P**
λ	CPC1	**0.300**	**0.080**	**<0.001**	**0.187**	**0.039**	**<0.001**	**2.738**	**0.423**	**<0.001**
	CPC2	0.013	0.049	0.788	**-0.118**	**0.036**	**0.001**	**-0.841**	**0.23**	**<0.001**
	CPC3	**0.359**	**0.070**	**<0.001**	**0.105**	**0.038**	**0.006**	**-1.346**	**0.52**	**0.010**
	HPC3	**0.099**	**0.049**	**0.043**	**0.112**	**0.036**	**0.002**	1.107	0.572	0.053
	LPC2	**0.155**	**0.062**	**0.013**	**0.304**	**0.036**	**<0.001**	-0.038	0.122	0.755
p	dtrl	0.056	0.082	0.492	0.093	0.06	0.124	-0.163	0.286	0.570
	hh	-0.013	0.060	0.829	**-0.184**	**0.039**	**<0.001**	0.128	0.132	0.333
	length	**0.311**	**0.080**	**<0.001**	**0.387**	**0.061**	**<0.001**	0.818	0.783	0.296

β = mean, βSE = standard error, P = probability. Significant values are bolded.

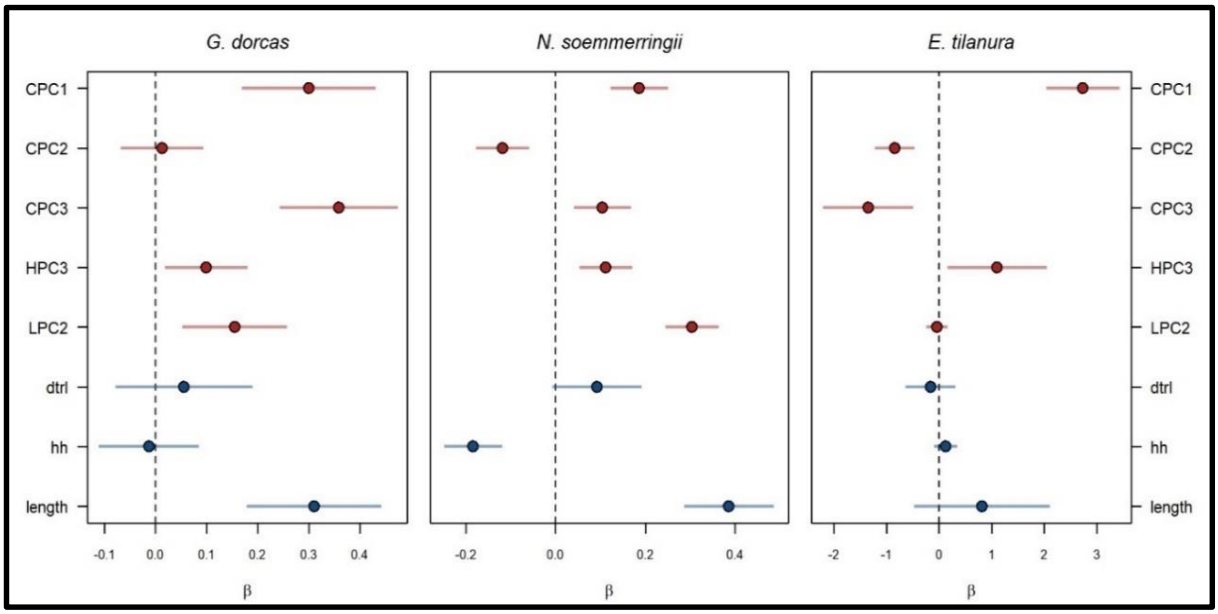

Figure 3.3. Weights of the environmental predictors in the N-mixture models for the three Gazelles.

Points and segments represent the mean and 95% confidence interval of the estimated values for the coefficients (β) associated to each variable (in the y-axis). Red tones mark the coefficients of the abundance sub-model; betas for the detectability sub-model are in blue. Segments crossing the (dashed) zero-value vertical line indicate non-significant effects.

Concerning detectability, it was significantly and positively affected by sampling effort (transect length) in *G. dorcas* and *N. soemmerringii*, while it was not in *E. tilanura* (Fig. 3.4).

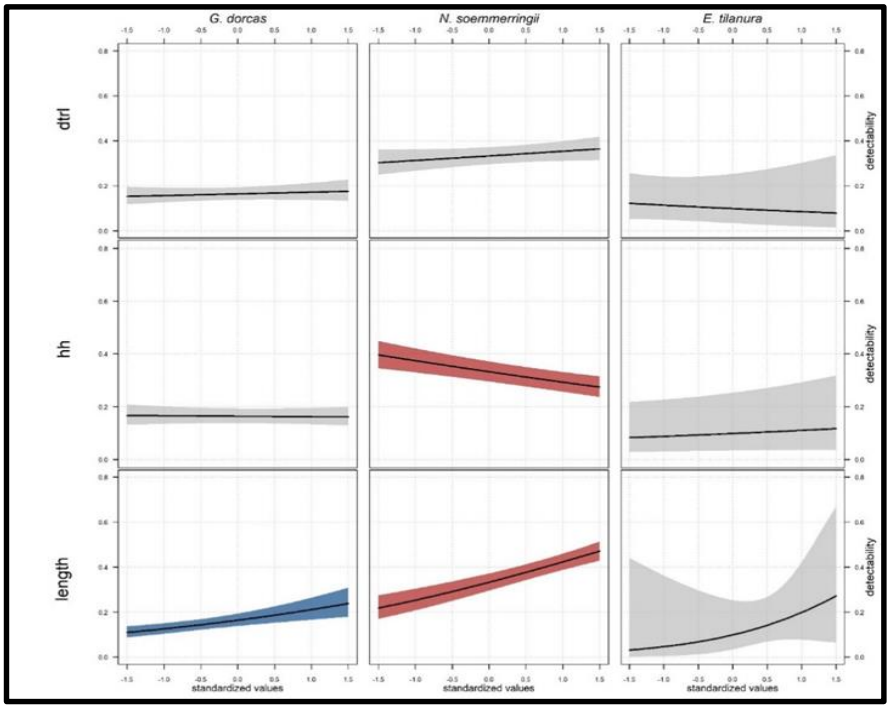

Figure 3.4. Marginal response curve of detectability to increasing values of one predictor at a time: Variables are organized by row, species by column. Solid lines represent mean predicted values; shadowed areas indicate 95% confidence interval of the prediction. Colored shadows highlight statistically significant trends, while grey color is used for non-significant relationships

The abundance of the three species was significantly affected by climate (Fig. 3.5). Concerning livestock, LPC2 score, which was a proxy for livestock composition, significantly correlated with the abundance of *G. dorcas* and *N. soemmerringii*, while it did not with *E. tilanura* (Fig.3. 4).

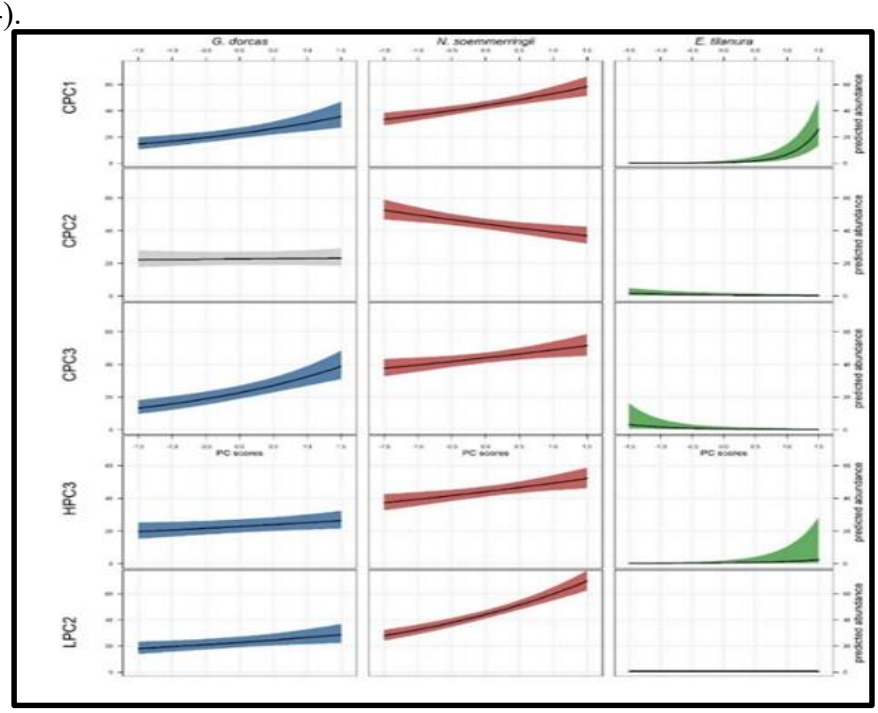

Figure 3.5. Marginal response curve of abundance to increasing values of one predictor at a time.

In figure 3.5, Variables are organized by row, species by column. Solid lines represent mean predicted values; shadowed areas indicate 95% confidence interval of the prediction. Colored shadows highlight statistically significant trends, while grey color represent for non-significant relationships

Seasonal abundance of gazelles.

The statistical test for both within and between the groups of gazelles showed that the P-value is greater than 5% thus there was no significant difference seasonal abundance of the gazelles in either sites (Table 3.5 & 3. 6). The only variation observed was on seasonal fluctuation of group size in habitat difference (Table 3.9)

Table 3.5. Average number of individuals (mean and Standard Deviation) observed in the six survey in each season of the coastal area

Species	Season	Mean number	Std. Deviation
Dorcas gazelle	Wet	189	.845
	Dry	62	1.403
Soemmerring's gazelle	Wet	296	9.009
	Dry	77	4.013

N.B Eritrean gazelle is exclusively inland dweller.

Table 3.6. Average number of individuals (mean and Standard Deviation) observed in the six survey in each season in the mainland study area

Species	Season	Mean number	Std. Deviation
Dorcas gazelle	Wet	78	1.044
	Dry	72	1.037
Eritrean gazelle	Wet	54	1.581
	Dry	49	1.688
Soemmerring's gazelle	Wet	81	3.234
	Dry	79	3.260

Habitat classification

So far, no systematic comparison of the different classifications of habitat is taken place in the country (DoE, 1999). For this reason, the habitat structure has been classified according to physiognomic features, of the vegetation characteristics, which was evaluated by expertise judgment and complemented by satellite imagery. Attempts have been made to bring together some of the different classification systems that were reflected in various reports in a way that suit to the common wildlife habitat in the country. In this respect, five types of habitats were identified in both sample sites of the mainland study areas (Fig 3.6). These includes open Shrub grassland, open Grassland, riverine vegetation, scrubland and Agricultural land.

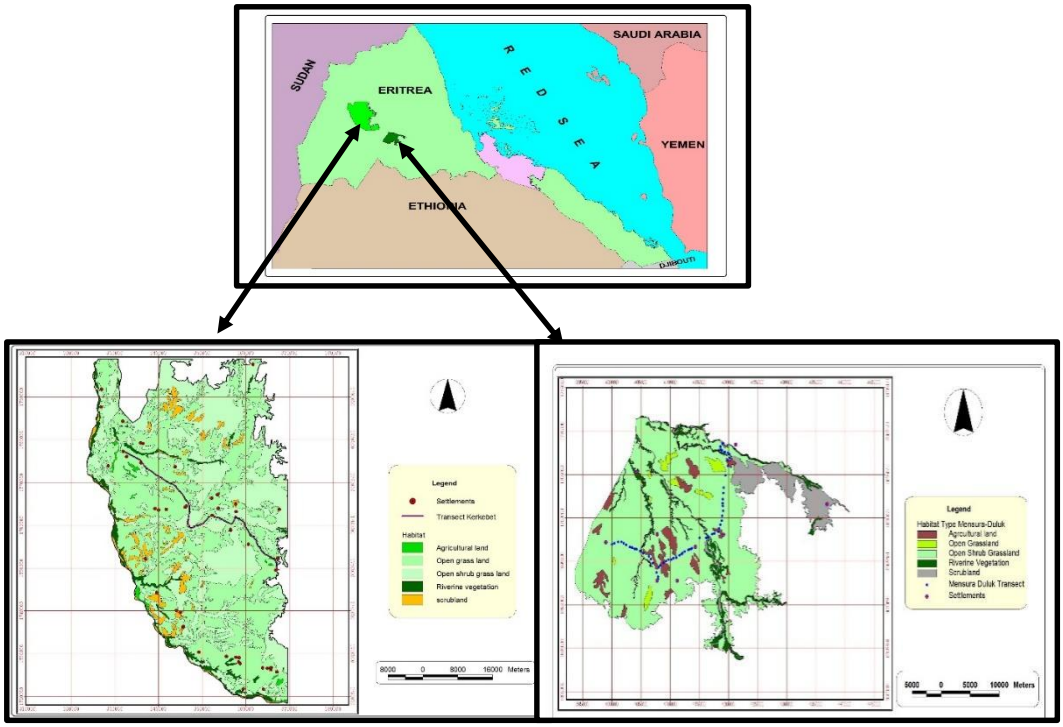

Figure 3.6. Common habitats identified in the mainland study areas,
Kerkebet (left) and Monsura-Duluk (right).

The vegetation coverage, on the flat plains was dominated by *Cadaba rotondiflia* and *Acacia tortilis*. On the steep slopes, trees become non-existent and the number of shrubs becomes scattered and *Acacia mellifera* appeared to be dominant than other shrubs.

In sample site of Kerkebet, open grassland was found be the dominate habitat followed by open grassland and agricultural land founded to be the least coverage area. Proportional area coverage of habitat in Kerkebet study area is described in the Table 3. 7

Table 3.7. Proportional of area coverage of the kerkebet study area

Habitat	Area in km^2	Percentage (%)
Agricultural land	15.29	0.58
Open Grassland	1341.40	50.73
Open Shrub Grassland	1084.29	41
Riverine	62.31	2.36
Scrubland	140.57	5.32
TOTAL	2643.86	100

Whereas In Mensura-Duluk sample site more than 75% of habitat was observed to be open shrub grassland (Table 3. 8).

Table 3.8. Proportion of habitat coverage in Monsura-Duluk study area

Habitat type	Area in Square Kilometres	Percentage (%)
Agricultural land	33.74	4.89
Open Grassland	14.72	2.13
Open Shrub Grassland	532.05	77.15
Riverine Vegetation	40.36	5.85
Scrubland	68.80	9.98
Total	689.67	100.00

In most cases, gazelles in mainland were observed to inhabit in the plain area with an elevation ranges between 650 to 770meter above sea level (Fig 3.7)

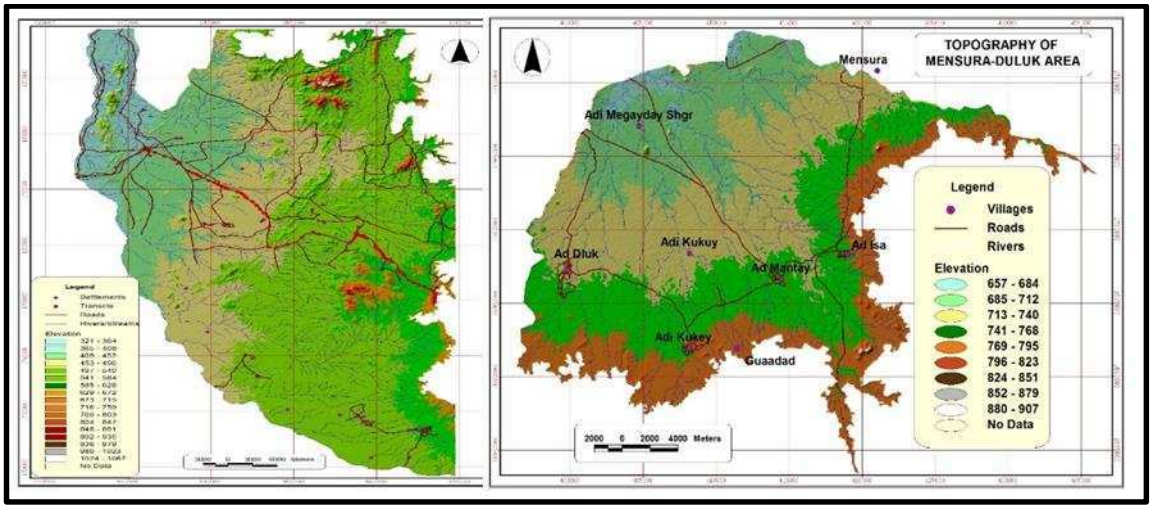

Figure 3.7. Digital elevation model kerkebet (Left) and Monsura-Duluk (right) study areas

The highest number of gazelle was observed in open grassland followed by open shrub grassland (Table 3.9).

Table 3.9. Mean of observed gazelle per habitat in six-survey period of the mainland

Species	Habitat	Mean Number	Std. Deviation
Dorcas gazelle	Agricultural land	28	1.086
	Open Shrub Grassland	52	.975
	Open Grassland	58	1.128
	Scrubland	12	.754
	Total	150	
Eritrean gazelle	Agricultural land	8	1.753
	Open Shrub Grassland	56	1.678
	Open Grassland	38	1.567
	Total	102	
Soemmerring's gazelle	Open Shrub Grassland	73	2.949
	Open Grassland	85	3.454
	Total	158	

Table 3.10. Statistical test for habitat preference by gazelles in mainland study area

ANOVA						
Species		Sum of Squares	df	Mean Square	F	Sig.
Dorcas gazelle	Between Groups	1.638	3	.546	.501	.682
	Within Groups	159.195	146	1.090		
	Total	160.833	149			
Eritrean gazelle	Between Groups	.871	2	.435	.161	.851
	Within Groups	267.208	99	2.699		
	Total	268.078	101			
Soemmerring's gazelle	Between Groups	19.080	1	19.080	1.828	.178
	Within Groups	1628.572	156	10.440		

The result revealed that there was no significant difference in habitat preference by the three species of gazelles (P >5).

In both wet and dry season of the survey period, significant number of the three species of gazelles were observed to concentrate on open shrub grassland (Fig.3.8)

Figure 3.8. Viable population of the three gazelle species in open shrub grassland.
From left to right photos of *N. Somemernigii*, *E. tilonura* and *G. dorcas* (Photo in Duluk)

The open grassland habitat was observed to attract numerous number of livestock irrespective the seasons (Fig 3. 9)

The vegetation characteristics of the open shrub grassland was dominated by shrubs and bushes with few scattered trees associated with grasses (Fig 3.10).

Figure 3.9. Irrespective of the season, enormous number of livestock were observed to make use gazelles habitat
(Wet and dry season's photo of the main land)

The dominant shrub species observed were, *Acacia tortilis*, *Acacia nilotica* and *Cadaba rotundifolia,*. The list of vegetation observed in gazelles in gazelle's habitat were recorded (Appendix VI)

Figure 3.10. The landscape of open shrub grassland in mainland (western lowland).

The open grassland habitat dominated by the *Aristida mutabilis* community are dominated by the *Aristida mutabilis* and *A. adcensionis* species. In moist places where water tends to accumulate for some time, other species like *Chloris vorigata* were observed to grow in a more or less pure stand. In addition to the dominant Aristida species, other grasses commonly observed were *Pancium turgidum, Eragristis tenella, Tragus berteronianus, Schoenefeldia gracilis* and *Tetrapogon tenellus* were observed. Interestingly during the dry season survey, the area was completely barren contrary to the wet season whereby the area was fully covered by grass (Fig 3.11).

Figure 3.11. The two sides of the open grassland habitat in the mainland. (Dry and wet season)

The other attractive gazelle habitat recognized was Riverine (ravine) vegetation mainly dominated by *Hyhaenae thebaica associated* with *Acacia species* and *Zizphis sphinacrsit*. It is densely growing and in some spots more or less as monoculture stand along the banks of seasonal rivers that commonly found along depression areas of the open shrub grassland (Fig

3.12). In this habitat, even though during the survey period none of gazelle species were detected but information from the local people and scouts revealed that the riverine vegetation was identified as critical gazelle habitat due its crucial role in providing thermal cover and year-round feed more particularly in dry season

Figure 3.12. Riverine vegetation found intercepted within open shrub grassland

.

Similarly in coastal study area five habitats were identified (Fig 3.13), namely open shrub grassland, open grassland, scrubland, water body and the coastal area characterized by semi desert and there was no that much vegetation cover. The digital elevation model of the coastal area revealed that both Soemmerring's and Dorcas in habit at an elevation of less than 40 meter above sea level (Fig 3.13).

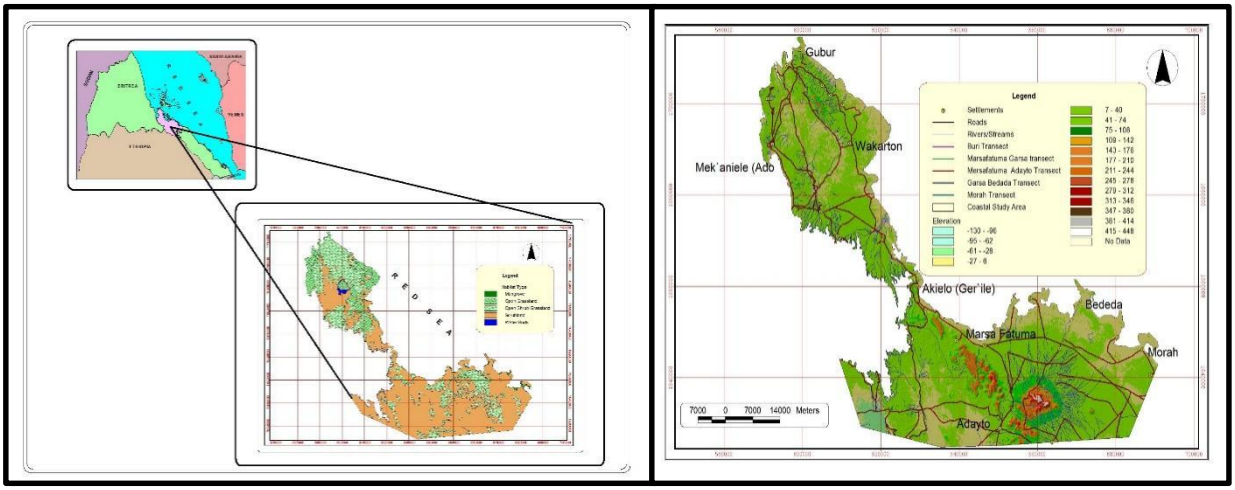

Figure 3.13. Main habitats identified (Left) and digital elevation model of the coastal study area.

In most cases the habitat identified in the coastal area dominated by scrubland (Table 3.13) that hold rock outcrop, bare land tidal area, and area with scattered vegetation. The proportion habitat coverage of coastal area is summarized in table 3.11.

Table 3.11. Proportion habitat coverage of the coastal study area

Habitat	Area (km^2)	Proportion (%)
Mangrove	18.79	0.65
Open grass land	203.91	7.00
Open shrub grass land	1272.55	43.69
Water bodies	9.87	0.339
scrubland	1407.68	48.32
Total	**2912.80**	

During extreme temperature that is in dry season gazelles were observed to avoid the common habitat and migrate to adjustment, are and interestingly they were observed to return and make use in wet season (Fig 3.14)

Figure 3.14. Gazelles were observed to avoid their common habitat in coastal area
During harsh season (Left) and move towards the hilly side and return in wet, season (Right**).**

The highest abundance of gazelles was observed in open shrub grassland followed by open grassland (Table 3.14). This is due to the fact that availability of pasture and thermal cover. The proportion of gazelle observed per habitat in the six survey is described in Table 3.12.

Table 3.12. Mean of observed gazelles per habitat in the six-survey period of the coastal area

Species	Habitat	Observed Mean Number	Std. Deviation
Dorcas gazelle	Open Shrub Grassland	106	0.839
	Open Grassland	113	1.227
	Scrubland	30	0.626
	Total	249	
Soemmerring's gazelle	Open Shrub Grassland	187	11.001
	Open Grassland	135	3.695
	Scrubland	43	4.112
	Total	365	

Table 3.13. Statistical test for the abundance of gazelles in relation to habitat.

ANOVA						
Species		Sum of Squares	df	Mean Square	F	Sig.
Dorcas gazelle	Between Groups	3.379	2	1.690	1.636	0.197
	Within Groups	254.026	246	1.033		
	Total	257.406	248			
Soemmerring's gazelle	Between Groups	79.113	2	39.557	.572	0.565
	Within Groups	25047.999	362	69.193		
	Total	25127.112	364			

In both species P > 5% thus there was no significant difference in Gazelle's abundance among the habitats.

The open shrub grassland area of the coastal area was characterized by vegetation community of *Acacia tortilis*, *Acacia nubica, Acacia laeta* and *Acacia melifera* and desert grasses dominate the open grassland mainly *Pancium turgidum and cynodon doctylon* that provide excellent fodder for gazelles particularly during the dry season with sporadically distributed acacia trees that provide worthy thermal cover (Fig.3.15). *Tamarix aphylla* also occurred in a low depression in the plain. In many areas, close to the sea halophytic shrubs such as *Suaeda monoica*, and where water is closer to the surface, such as along watercourses, there were small areas of doum palm (*Hyphaene thebaica dankaliansis*) dominating the vegetation specifically around Akelo coast, which is located between Ghelalo, and sub port of Marsa-Fatuma.

Figure 3.15. The landscape of open grassland and open shrub-grassland in coastal area

The mangrove habitat, which is highly patchy mainly found around Buri penisnul, Akelo, Bededa and Morah, was observed to have a great role in providing thermal cover for the gazelles. During the survey period, significant number of gazelles were observed to harbor inside mangrove to avoid the harsh weather (Fig 3.16).

Figure 3.16. *N. soemmerringii* during harsh season of the year observed to spend daytime inside mangrove to avoid heat stress.

Throughout survey period concentration of significant number of gazelles were observed in scrubland, which was endowed with sparse vegetation (Fig 3.17)

Figure 3.17. During dry season, Gazelles and livestock tend to concentrate in patchy vegetation (Photo, Buri peninsula).

Population structure.

The result revealed that the group size of the mixed herd Soemmerring's gazelle ranges between 5 and 60, whereas the group size for Dorcas gazelle observed were ranging 3 to 7 and Eritrean gazelle group size was observed to be 3 to 15 individuals. In the three species of gazelle, the sex ratio skewed towards female (Fig 3.18 and 3.19). It was noted that there was

also significant change in structure of the population as a response to change in land cover. Between wet and dry season, slight variation was observed in group sizes in certain habitat (Tables 3.7 and 3.8) and those differences persisted when group sizes were broken down into the most important categories; female, male and mixed groups.

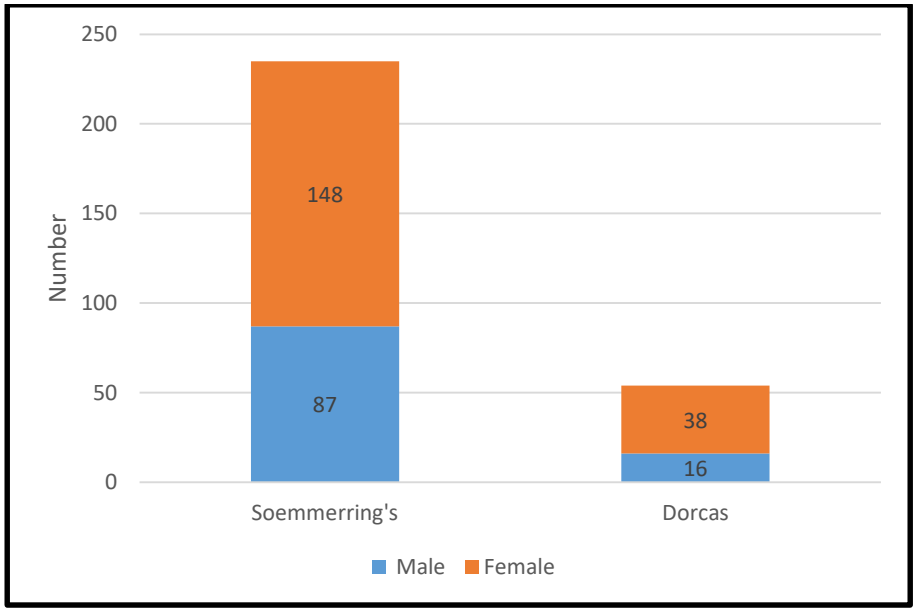

Figure 3.18. The average sex ratio of the six survey for Soemmerring's and Dorcas gazelles in the coastal areas. The standard devation is 2.31 and 0.58 for Soemmering's and Dorcas respectively

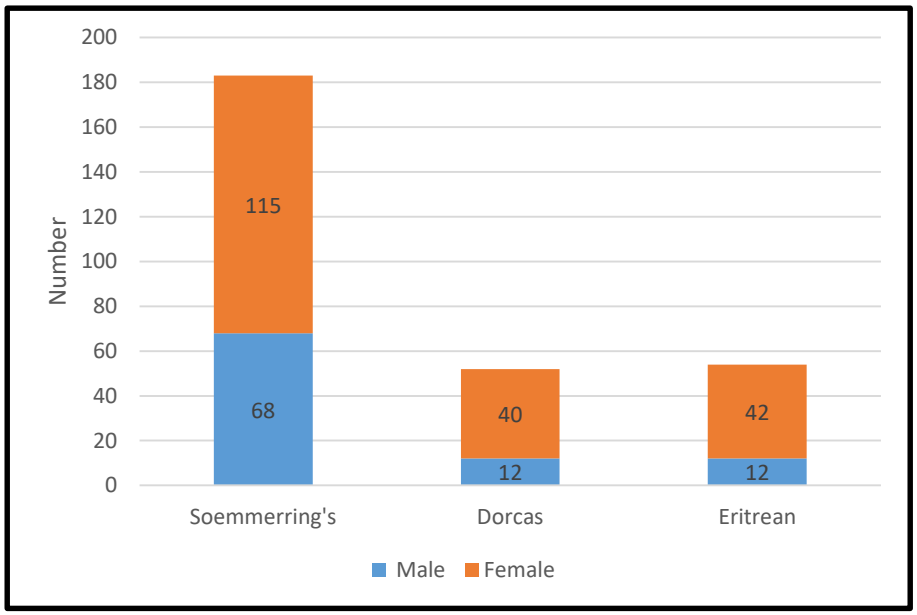

Figure 3.19.The average sex ratio of the six survey for the three gazelles in the mainland. Their standard devations are 2.9, 0.84 and 1.6 for Soemmerring's, Dorcas and Eritrean gazelles respectively.

The herd composition of the three species encompass all age groups with the ration skewed towards adults (Fig 3.20 &3.21), followed by sub adults. The reason for lower proportion of

younger once could be that most gazelles tend to hide their young in dense bushes until they are strong enough to run fast and escape from predators.

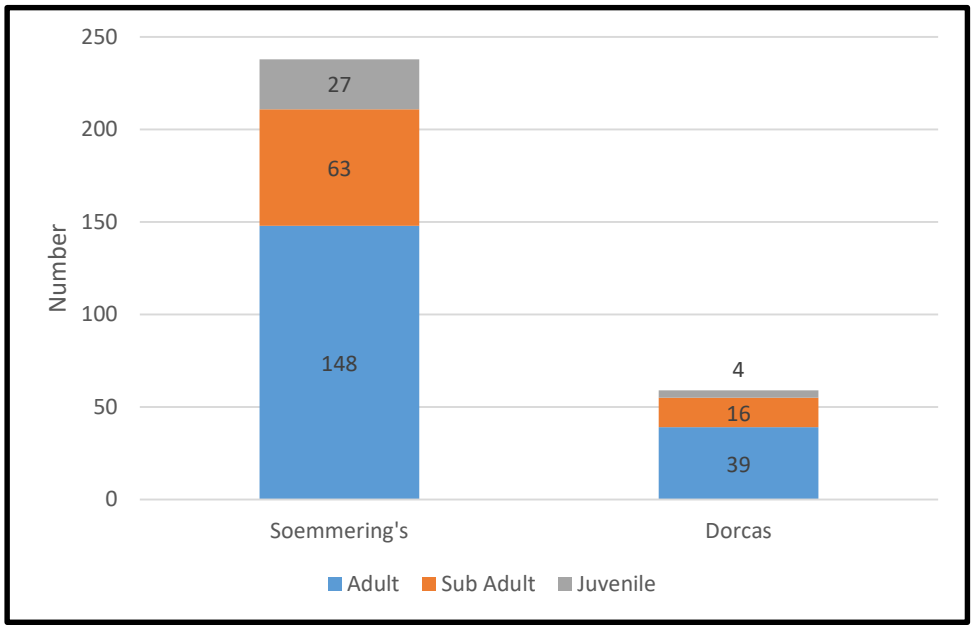

Figure 3.20. The average age-ratio of the six survey for Soemmerring's and Dorcas gazelle the coastal area. Their sandrad devations are 1.6 and 0.5 for Soemmering's and Dorcas respectively

Similarly, in the mainland adult dominated the age group of all species (Fig 3.21)

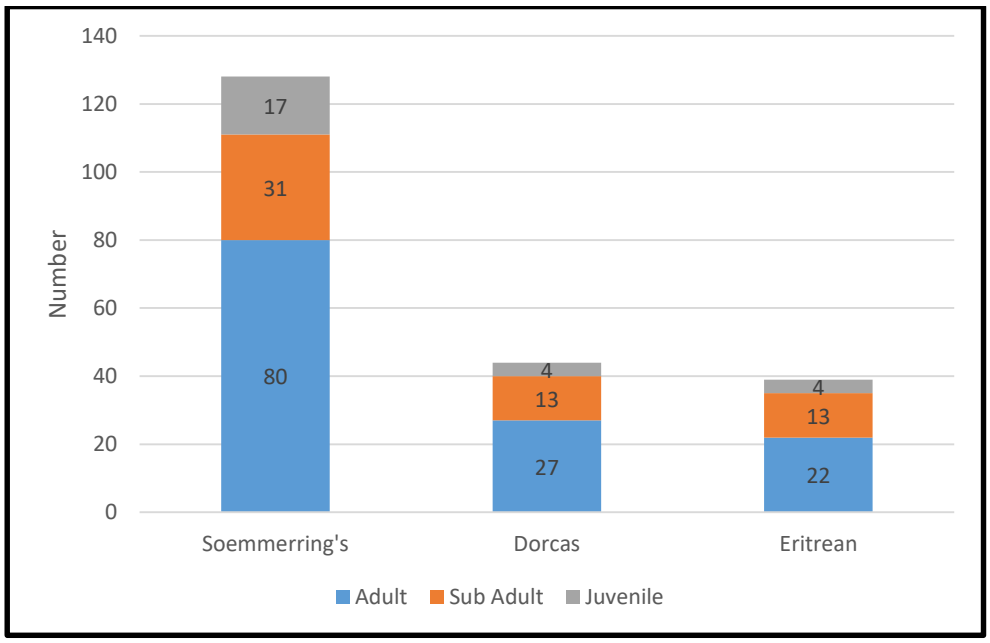

Figure 3.21.The average age-ratio of the six survey for the three species of Gazelles in the mainland. Their standard deviations are 1.16, 0.41and 0.65 for Soemmerring's, Dorcas and Eritrean gazelles respectively

Discussion

The findings of this study on the pattern of abundance and habitat use of the three gazelle species indigenous to Eritrea align with Hagos *et al.* (2023) report confirming the presence of these species in both coastal and mainland regions of the country. Specifically, *G. dorcas* and *N. soemmerringii* occur in both coastal areas and inland, while *E. tilonura* seems to be confined to specific parts of the western lowland. The study's abundance estimates for each species and site highlight the consistent presence of the G. *dorcas* and *N. soemmerringii* in both coastal and mainland regions with a prominent population concentration along the southern coast of the Gulf of Zula (Buri peninsula) up to Tio area (Sub region of Ara'eta). Notably *N. soemmerringii* dominates this population. The result also indicates highest abundance of *E. tilonura*, in Monsura-Duluk area compared to the Kerkebet area.

The mode-based analysis identified Climate, land cover and anthropogenic activities as the primary influencing factors on the abundance of the three species of gazelles. Several previous studies (Andrewartha and Birch (1974), Dalrymple et al. (1991), Secor (1994), Arthur et al. 1996, Greene 1997, Osborne et al. 2001, and Zug et al., 2001) have all understood the direct impact of seasonal climate variations on species abundance and local distribution despite some variations among species is evident. Multivariate statistical analyses in the form Principal component analyses (PCA) identified rising air temperature and intensifying dry conditions, and reduced precipitation seasonality, particularly with elevated dry season temperature has been positively correlated with counts of *G. dorcas* and *N. soemmerringii*. However, these two species exhibited opposing relative ranking.

Conversely, both *N. soemmerringii* and *E. tilanura* were adversely affected by decreasing rainfall combined with heightened temperature seasonality represented by the second principal component (CPC2). This factor did not had an impact on *G. dorcas*. Contrary to the other species *E. tilanura* appeared vulnerable to extreme conditions, with its abundance negatively respondent to increasing CPC3 scores i.e. decreasing precipitation seasonality, with high temperature during the dry season. These findings underscore the overall resilience of *G. dorcas* and *N. soemmerringii* in adapting to extremely dry conditions and high temperatures, particularly (CPC1). The region where both species (*G. dorcas* and *N. soemmerringii*) exhibit high abundance represents one of the world's harshest environments due to its aridity, scorching temperature, and recurrent droughts. Throughout the survey season, *G. dorcas* was consistently observed in the most challenging parts of the study area where other mammals were hard to observe. Furthermore, *G. dorcas* inhabits a broader range of habitats including

open shrub grasslands, grasslands, scrublands, in arid to semi-desert areas, including the Danakil depression. This complement with the findings of Hagos et al., (2023), which indicated that *G. dorcas* is exceptionally resilient, and can thrive in more diverse habitats compared to the other two species. It is also aligns with the argument made by Kingswood and Mallon (2001) emphasizing that *G. dorcas* is an extreme habitat generalist and adaptable species among gazelle species. Meliane et al., (2023) reported similar findings based on data from the Sahara's Grand Erg Oriental region in southern Tunisia.

The diverse vegetation cover in the study area had a noticeable impact on gazelle abundance although the influence varied among species. This relationship between land cover and species abundance is significant because it reflects how animals tend to gather or disperse depending on seasonal changes in forage availability, which is primarily associated with rainfall. Mamo et al. (2019), who studied Soemmerring's gazelle in the Alledeghi Wildlife Reserve in Eastern Ethiopia, observed a similar trend: variations in gazelle abundance between wet and dry seasons can be attributed to changes in the quality and quantity of foraging resources.

The results of the seasonal surveys indicated that there was no significant seasonal variation on the population abundance of the species in respective study areas. This suggests that the gazelles tend to stay within their local area and migrate locally to an area with better food and shelter, such as ravine vegetation in the mainland and mangrove in the case of coasts. Notably, we observed *N. soemmerringii* seek refuge inside mangroves during the daytime until the temperature drops. Further, during periods of very high temperatures these animals move from coastal areas to less harsh areas, mainly the plateau adjacent to the coast. These findings support the report of Estes et al., (2006), who emphasized that when other sympatric herbivores migrate to different areas in search of water and fodder during dry season, gazelles remain within their original ranges or move locally within short distances as long as sufficient forage is available.

One significant land cover component, sparse herbaceous vegetation on sand soil, without shrubs (HPC3), consistently and significantly affected the abundance of the three species. Another factor that had an influence on species abundance was presence of livestock. The livestock composition, (LPC2) scores indicated the prevalence of camel, goat and donkey, negatively affected the abundance of the gazelles. This is likely camels and goats share feeding behavior with gazelles, as they are all browsers and grazers. As a result, gazelles are likely to move away from their preferred habitat to avoid livestock and human disturbance, a pattern consistent with the findings of Chammem et al., (2008). It is worth noting that this study's results differ from that report, because the presence of camels did not affect the distribution of

Dorcas gazelles, and numbers were even positively associated with gazelle occurrences. Additionally, they indicate that there was no significant relationship between number of goats and gazelles' occurrence, which contrast with the finding of this study.

The model-based analysis revealed that the detectability of the three gazelle species was influenced by several factors including sampling hours, sampling effort (transect length) and seasonal variation. *N. soemmerringii* detectability was influenced by the sampling hour (hh), with a significant negative effect (i.e., probability of detection higher in the morning; (Fig. 3), suggesting a daily activity pattern where gazelles are more detectable in the morning likely to avoid heat stress during the day by seeking shade or densely vegetated areas. This behavior may also affect the detectability of *G.dorca* and *E.tilonura*. Particularly because they occur in smaller populations compared to *N. Soemmerringii*, which frequently observed in large groups (15-65 individuals). Furthermore, sampling effort, represented by transect length, significantly and positively affects detectability in *G. dorcas* and *N. soemmerringii* but not in *E. tilonura*. This difference may be attributed to the broader distribution of the former two species across the study area, in contrast *E. tilonura*, which is found in smaller concentrated populations. Additionally, seasonal variation marginally affect detectability providing circumstantial evidence for a seasonal activity pattern associated with the availability of resource availability. During the dry season when food becomes scarce *N. soemmerringii* was observed to move from the wet season habitat seeking better forage to meet the needs of large groups. This behavior was less evident in the other two species, likely because of their smaller population's sizes and limited resources options.

Habitat type and structure

Habitats have substantial influence on herbivore distribution and abundance (Boyce et al., 2016). The preference for particular habitat layers by various species depends on their specific requirements and cognitive abilities in selecting foraging areas. For instance, spatial memory can influence grazing patterns (Bailey et al., 1996), consequently, each species actively searches suitable habitat to fulfil its requirements. This survey focuses on examining habitat structure and species habitat relationship between different gazelle's species and their habitats. This assessment combines ground-based observations and remote sensing data while considering the nature of the landscape and the vegetation physiognomic features. Five district habitat types were identified in each sites of study area, i.e., open Shrub grassland, open Grassland, Riverine vegetation, rock outcrop (scrubland) and mangrove in coastal areas.

Similarly, in the mainland, the study identified open shrub grassland, open grassland, Riverine vegetation, Rock outcrop (scrubland) and agricultural land. The habitat association of animals reflects strategies that enhance their survivorship and successful reproduction (Grignolio et al., 2003). Group size within a species can also be indicative of habitat quality (Mattiello et al., 2004). In this respect, the highest abundance of gazelle was observed in open shrub grassland followed by open grassland. Shrubs and bushes with a few scattered trees amidst grasses characterize the open shrub grassland habitat. Notably, high concentrations of gazelles were detected in open grassland during wet season and in open shrub land during dry season. The availability of forage and thermal cover is likely to attribute to its preference (Hagos et al., 2023).

The landscape of the mainland study area is predominantly plain with elevation range of 550 to 750 meters above sea level. Tributary streams that drain to the River Barka traverse this area and the soils primarily consist of alluvial deposits from the central highlands, favoring vegetation growth, specifically during the rainy season. Feature of physical terrain and the water availability influence the distribution of the vegetation. In areas with low water table the vegetation transform to a community dominated by Acacia species and Ziziphus. *Ziziphus spina-christi* is evergreen plant and produces reliable source of green browse throughout the year (Ogbazghi and Bein, 2005). However, this vegetation is likely to create competition between gazelles and livestock. During both dry and wet survey seasons, high livestock numbers were observed grazing in the area. Local community information indicates, that Ziziphus and other ravine vegetation offer good livestock feed particularly during the dry season when many of the shrubs shed their leaves, while these species remain important evergreen forage. This competition is likely to disrupt gazelle's use of their preferred habitat and may eventually affect their survival. Gebremedhin & Yirga (2005) drew a similar conclusion regarding Soemmerring's gazelle in Awash National Park and Alledeghi Wildlife Reserve in Ethiopia.

The shrub land habitat was dominated by *Cadaba rotundifolia, Acacia tortilis, Acacia oerfota* (*nobica*) and *Acacia mellifera*. This habitat encompasses flat plains to rolling hills and mountains. On flat plains, shrubby plants such as *A. oerfota, A. tortilis* and *C. rotundifolia* that are sparsely dispersed with open spaces where annual grasses grow during the rainy season. In the dry season, the grasses die out and the Acacia shed their leaves, giving the impression of dry, bare rocky area. The Acacia shrub land was further divided into an *Acacia mellifera*

community and *Acacia tortilis* community. The former is commonly located along the slopes and hilltops and the latter on the plains surrounding the hills. *A. mellifera* community exhibits relatively sparse shrubs, primarily concentrated along the gorges. *Aristida mutabilis* community dominated the open grassland. The predominant grass species in this habitat are annual type with *A. mutabilis* and *A. adcensionis* as the dominant species. In areas where water accumulates, other species like Chloris vorigata were observed to growing in pure stand. Additional grasses commonly found include *Eragrostis tenella, Tragus berteronianus, Schoenefeldia gracilis* and *Tetrapogon tenellus*. During the dry season survey, the area becomes barren, in contrast to the luch grass cover during the wet season.

The riverine habitat is primarily characterized by vegetation comprising *Hyphaenae thebaica*, *Acacia tortilis* and *Zizphis sphinacrsit*. Pocket of *Tamarix aphylla* was also observed along the banks of the rivers. While no gazelles were observed in this habitat during the survey season, local people reports suggest that gazelles tend to congregate in riverine areas during the dry seasons to access green forage and thermal cover making it a preferred habitat for them.

Coastal vegetation coverage in the study area consists of *Acacia tortilis*, *Acacia nubica, Acacia laeta and Acacia mellifera* and to some extent with *Cadaba rotundifolia* and *Salsola spinescens* bushes in erosion gullies with a ground cover feature of *Cenchrus ciliaris, Trianthema crystallina* and *Cyperus conglomeratus*. Limited tree growth along wadi banks, mainly *Tamarix aphylla* with occasional *Tamarindus indica,* and a few woody perennials and annuals on the sandy plains, contributes to the diversity of this habitat. The grass species are typical desert type and dominated by *Pancium turgidum* and *Cynodon doctylon* that provide excellent fodder particularly supplemented during the dry season. In patches with better soil, occasional *Aerva persica* and a patchy grass cover of *Dactyloctenium scindicum* are found, whilst in depressions, either thin *A. tortilis* or Euphorbia bushes with *Cenchrus ciliaris* grass cover or salt-tolerant *Sueada monoica* appears dominant intercepted with *fogonia species* and *limonium spp*. In some areas of the lava flows and hills particular around Gulf of Zula Commiphora africana was the dominant woody species. In many areas, close to the sea halophytic shrubs such as *Suaeda monoica*. Where water is closer to the surface, such as along watercourses, there were small areas of doum palm (*Hyphaene thebaica dankaliansis*) mainly around village of Akelo dominating the vegetation. The plain area was characterized by grassland dominated by *Panicum turgidum*. The gorges and depression areas are endowed with drought tolerant plant species. The shore of Red sea around Buri peninsula, Hawakil and Akelo is covered by

Avicennia marina (Mangrove) forest (Hagos, 2016) and around Morah; there is a different species of mangrove, known as *Rhyzophora mucronata.*

Similar to the mainland, open shrub grassland followed by open grassland emerged as most preferable habitat for both *G. dorcas* and *N. soemmerringii* on the coastal area. The main difference between the open shrubs grassland along the coast and inland is that the former is semi-desert while the latter is savannah. This observation suggests that *E. tilonura* are exclusively inhabit savannah environment whereas the other two species of gazelles inhabit both ecological settings.

Mangroves offer good thermal cover particularly during the hardest season (July-August), when temperatures exceed 45 degree Celsius. During this period, *N. soemmerringii* were observed to seek refuge within mangroves until the temperatures dropped. In addition, local people reports suggest that gazelles may also feed on newly emerged mangrove leaves as food sources, but the information needs to be treated with caution until scientific validation is in place.

Another noteworthy habitat is Scrubland, characterized by sporadic vegetation cover, which covers a significant portion of the coastal sample site. The concentration of both livestock and gazelles in this habitat increase during the dry seasons when forage is scarce in other areas. However, this habitat also attracts camels and goats, leading to resources competition. With time, the existing scenario could potentially drive gazelles out of the area, as emphasized by Attum (2007) and Attum et al.. (2009), in arid eco-systems, livestock and feral animals likely to compete with native ungulates for limiting resources like vegetation and water supply. Therefore, implementing a proper land use system is essential to mitigate the disturbance caused by livestock.

Population structure

The results of the study reveal interesting insights into the population structure of the three gazelle species in their respective habitats. The group size of the mixed herds of Soemmerring's gazelle ranges from 5 to 60 individuals, while Dorcas gazelle groups sizes typically comprised 3 to 7 individuals and Eritrean gazelles 3 to 15 individuals. Notably, across all species, the sex ratio was skewed towards females. This implies that the population of the three species are viable with a tendency for growth due to the high number of females. Furthermore, it was observed significant change in structure of the population as a response to change in cover density. While there was slight variation between wet and dry season, in certain areas, these

differences persisted when group sizes were broken down into the most important categories; female, male and mixed groups. However, it is important to note that statistically these differences were found to be not significant.

Regarding seasonal abundance, it was noticed that the animals tended to aggregate or disperse depending on the forage availability, which is closely linked, to seasonal variation particularly associated with rainfall. Rainfall plays a pivotal role in influencing the structure and productivity of vegetation, which in turn, affects the availability of and water (Groom et al., 2006). The finding of the dry and wet season surveys indicates that, there was no significant difference in the seasonal variation of the population size of the species in their respective study areas, but there were observed variation in-group size across different habitats. These variations could be attributed to the quantity and quality of forage available in different seasons. In the dry season, food and water become scarce in certain areas, leading the gazelles to concentrate in areas with patches of green vegetation. Consequently, the detectability of species is likely to be lower during this time, unless their preferred habitat is visited. Conversely, in the wet season when forage is abundant, gazelles tend to disperse more widely, with higher concentrations observed in open shrub grassland and open grassland.

Although the statistically tests failed to detect a difference within and between groups of gazelle in terms of habitat preference and seasonal abundance, some variability in population size and habitat use among the species were actually observed, especially associated with the availability of vegetation. These findings align with a study of Gebremedhin & Yirga's (2005) on abundance, group size and composition of soemmerring's gazelle in Awash National park and Alledeghi wildlife reserve in Ethiopia. Their study indicated that irregularly distributed rainfall in the areas, creates patches of green vegetation influencing the habitat use of soemmerring's gazelle.

In conclusion, this work has produced a set of new data on the consistency and ecology of the populations of the three species of gazelles that will be very useful in the planning of conservation actions and in the management of protected areas in Eritrea.

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Like us, animals feel love, joy, fear and pain, but they cannot grasp the spoken word. It is our obligation to speak on their behalf ensuring their well-being and lives are respected and protected."

Sylvia Dolson.

Prevalence of Threat and Conservation Status of the Three Species of Gazelles in Eritrea

Abstract
Gazelle populations worldwide are experiencing population declines because of overhunting, habitat destruction, and habitat degradation. The Eritrea case is no exception; habitat degradation, war, and drought have undoubtedly caused serious loss of wildlife in Eritrea. During the 30 years' war of independence (1961-1991), large numbers of wild animals were consumed as food by soldiers and others species were reduced, dispersed or became locally extinct. After independence, the government and people of Eritrea gave due attention to reversing the adverse situation of wildlife in general and results of this intervention have proved promising. The revival of the three gazelle species (Nanger soemmerringii, Gazella dorcas and Eudorcas tilonura) is now evident. However, their conservation status is not well known. To that end this study was carried out to assess the current situation of the three species of gazelles in the country. The objective of the study is to assess and evaluate the prevalence of threats and conservation status of the three gazelle species (Nanger soemmerringii, Gazella dorcas and Eudorcas tilonura) in Eritrea and eventually to develop a conservation strategy that can mitigate existing threats and ensure the continuous existence of the species. Visual assessment, focal group discussions and interviews were applied to collect data. The study revealed that the population of the three species of gazelles and their viability remains indeterminate due to the multiple existing threats. Climate change, resource competition, habitat loss, invasive species and lack of institutional capacity were among the main threats. Interestingly hunting was not recognized as a threat. However, the absence of legally protected areas appears to exacerbate the threats of resource competition and habitat loss. Nevertheless, to tackle the existing challenges and ensure the continuous existence of wildlife, relentless endeavors are ongoing and promising achievements are underway.

The study highlights to address the existing threats and eventually secure the wellbeing of the wildlife (gazelles), development of a conservation strategy and enforcement of protected areas are decisive. In view of these, the study proposes some strategies and actions that need to be undertaken in order to overcome the existing conservation challenges.

Key words: Gazelle, prevalent threats, conservation, strategy and protected area

Introduction

Worldwide gazelles are experiencing population decline as result of human induced pressures that include overexploitation, poaching, habitat destruction and degradation (IUCN, 2017). The trend of the deterioration is becoming a matter of concern. As Price and Gentleman (2007) have suggested it an estimated, 62% of antelope populations are decreasing worldwide, 30% of antelopes are threatened, and 12-15 % are highly threatened. Global data from the IUCN Antelope Specialist Group show that 27% of antelope species are threatened with extinction; however, this rises to 89% when only arid adapted antelope are considered (Mesochina and Cooke 2015).

Gazelles in Eritrea are no exception to this scenario. Habitat degradation, war and drought have undoubtedly caused a serious loss of wildlife in Eritrea (DoE, 2008). During the Italian colonial era, hunting licenses was issued and many species declined, dispersed or became locally extinct. Then, in the 30 years of war for independence (1961-1991), large numbers of wild animals were taken as food and other species declined, dispersed, or became locally extinct. The extinct species includes Black rhinoceros (*Diceros bicornis*), African Buffalo (*Syncerus caffer*), Beisa Oryx (*Oryx beisa*), Giraffe (*Giraffa camelopardalis*) (Yalden, 1984; Bekele and Yalden, 2013: Gippoliti, 2020). Successive colonial eras, recurrent droughts and habitat loss gave no chance for the continuous existence of the above-mentioned species and other species were reduced to the brink of extinction (GoE, 1995a).

After independence in 1991, with the establishment of peace and stability, the people and government of Eritrea gave due attention to reverse the adverse situation of wildlife through developing polices and campaigns. Among these, as of 1994 high school students were organized to spend their summer holidays in greening activities. Moreover, the National Environmental Management Plan for Eritrea (NEMP-E) that stipulates the rational conservation and management of natural resources was prepared in 1995. Furthermore, to create synergy and momentum for all national activities related to environmental rehabilitation, in 2006 a National Greening campaign was launched. The result of all these courageous interventions proved to be promising achievements in the revival of biodiversity in the country (DoE, 2008) and the recovery of the three gazelle (*Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura*) species is now evident (Hagos, 2019). However, since most of the gazelles occur in unprotected areas (Hagos et al., 2023), their continued existence is likely to remain uncertain.

In this context, the study was carried out to assess the prevalence of threat and conservation status of the three species of gazelle in Eritrea.

Soemmerring's Gazelle (Nanger soemmerringii) is one of the few still understudied species of the Order Cetartiodactyla. This species inhabits savannas, scrublands and grasslands in Eritrea, Ethiopia, Djibouti, Somalia, and Sudan (Yalden et al., 1984, IUCN 2017); the Sudanese population has probably been extirpated (Schloeder & Jacobs 2013). Throughout its range the trend of the species is declining and East (1999) estimated the total population at about 14,000 individuals but a decline has occurred recently in Ethiopia (Gebremedhin and Yirga 2005) and elsewhere, down to a recent estimate of a total population fewer than 4,500 adults (IUCN 2016), coupled with a fragmented range. Consequently, the species is classified as Vulnerable (IUCN 2017). In Eritrea, the species is still present in the Danakil region, in Dahlak Kebir Island, and in some areas of the western lowlands (Nile River catchment) (Bekele & Yalden 2013; Hagos et al., 2023). However, comprehensive information on the status of the species is lacking.

In the past, the Dorcas gazelle (*Gazella dorcas*) had the most extensive distribution of any African gazelle. However, recent study revealed that the species no longer exists in several of its former areas (Frost, 2014). In Senegal, it was considered extinct from the mid-1970s until it was reintroduced in 2007 (Abaigar et al., 2013). Similarly, as Frost (2014) indicated, in Mauritania, Burkina Faso and Nigeria, its status is unknown, and the species is probably extinct. According to IUCN (2017), the decline of the species is estimated to be more than 30% over a period of about 15 years up to April 2016 and that fewer than 25% of those remaining at that time lived in protected areas. Currently Dorcas Gazelle is categorized as globally vulnerable species (IUCN, 2017).

In Eritrea, the species has been reported from the coastal area, the southwestern and the northern part of the country (Hagos et al., 2023, Bekele & Yalden 2013). However, detailed information on the status of the species in the country does not exist

Heuglin's Gazelle (*Eudorcas tilonura*), also known as Eritrean Gazelle, is endemic to the Horn of Africa, specifically in W Eritrea, NW Ethiopia and SE Sudan.

According to the IUCN Red List, the species classified as Endangered, and across its range, it is under the threats of hunting, competition with domestic livestock and habitat degradation. It is hypothesized that its population might have fallen by 20% in roughly nine years since 2008.

Currently, it is estimated that 2,500 to 3,500 individuals remain in small fragmented groups, with fewer than 2,500 adults (IUCN, 2017).

The status and distribution of the species in Eritrea are not well known. There have been no confirmed sightings by professionals until 2019 when a small group was observed and photographed in the region of Gash Barka (Zoba) between the sub -regions of Dige and Gonge (Hagos, 2019). For this reason, the species was not included in the list of threatened species that require special attention in the Forestry and Wildlife Conservation and Development Proclamation No. 155/2006' (GoE, 2006).

Objective of the study

The objective of the study is to assess and evaluate the prevalence of threat and conservation status of the three gazelle species (*Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura*) in Eritrea and eventually develop a conservation strategy that can ensure the existence of the three species and wildlife in general

Study area and Methods

Study area

The study area is located in three sizeable, geographically separated areas (Fig 4.1). These are the south- west part of the country (mainland), the Red Sea coastal areas, the Danakil desert and the Dahlak Kebir Island of the Red Sea. The sites were selected becasue they are endowed with a fair abundance of gazelles. Elevations range from -150 to +1000 meters below and above sea level respectively. The climate is arid to semi-arid with high temperatures year-round. Mean annual daily temperature is approximately 30 to 35º C, but during the hottest months, the maximum temperature can exceed 50 ºC (DoE, 2008).

The rainfall seasons of the respective study areas have distinctive differences: in the coastal region, the rainy season extends between Octobers and March, whereas the mainland has short and long rainy seasons are between March-April and June - September–August, respectively (DoE, 2001).

Methods

A mixed approachmethod was applied in this study. Such an approach is useful because it allows a researcher to use different data collection methods to improve the validity of the data collected (Saunders et al., 2009). In view of this, the mixed approach of study had to involve several methodologies as detailed below.

Reconnaissance survey

Prior to selecting sample areas, reconnaissance surveys were carried out in potential gazelle habitats. The author's prior field experiences were used as a foundation to carry out intensive and focused surveys in the three selected areas

Selection of sample sites

In each of the identified habitats, fixed transects were established in such way that suited road survey accessibility. Each transect was followed by a 4x4 car at slow speed (20-30 km / hour) and the itinerary in which the observation was made recorded on GPS. Binoculars were used to spot all medium-large mammals of wild and domestic animals on both sides of the transect. A total of 8 different transects was established: five in the coastal area, two in the Western lowlands and one in Dahlak Kebir island (Fig 4.1). To measure the disturbance density of the livestock was calculated by dividing the number of livestock observed by the area of the survey, obtained by the length of the transect (in km) multiplied by 0.6 (width in km of the area visible from the transect line)"

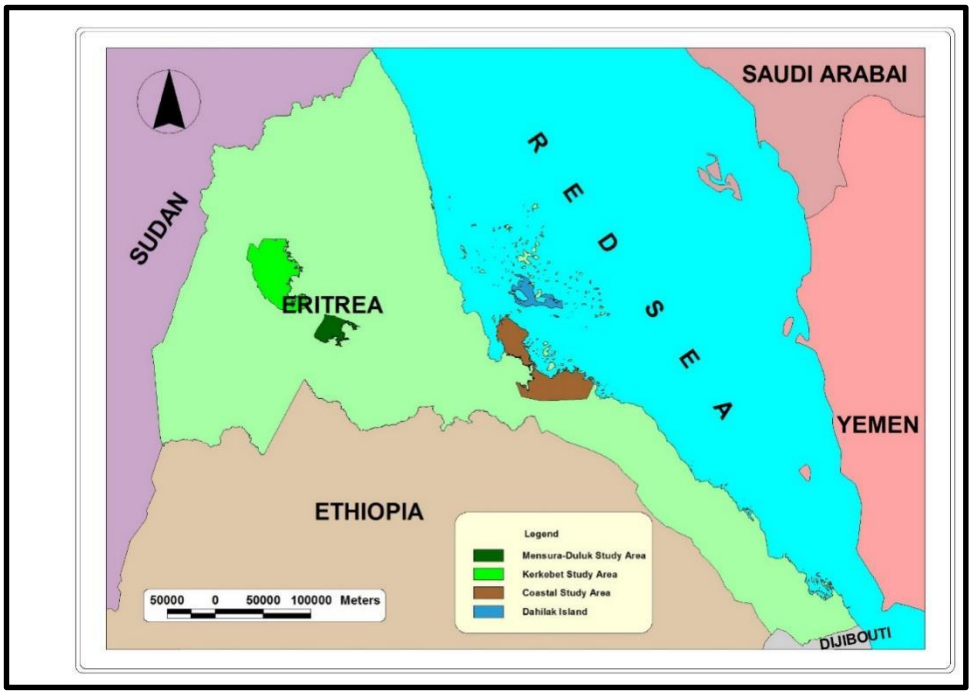

Figure 4.1. Location of the sample sites

Transect lengths varied as dictated by the landscape and the distribution of gazelle habitats. Thus, transects, Monsura-Duluk covers 38.5 km, Kerkebet 46 km (western lowland), Buri peninsula 87.6 km, Morah 29 km, Bededa 18 km, Garsa-Marsafatuma 20 km, Marsafatuma-Adayto 22 km (coastal area) and Dahlak Kebir Island 24 km.

Seasonality of the survey

The survey was designed to collect data on a seasonal basis i.e. dry and wet seasons. For that purpose, the survey period was divided into six with two-month intervals that covered the full year and 5 days were spent in each study area. Due to Covid 19 travel restrictions, after the first survey no further data collection was made in Dahlak Kebir Island. However, during the first survey significant information on the soil and gazelle situation was collected.

Data collection

Through the mixed approach method, data were collected on the following parameters.

Gazelle situation assessment

The existing gazelle situation was assessed and evaluated with the emphasis on the prevalence of threat was evaluated and all species observed to share the habitat with gazelles were recorded. In addition to measure the level of livestock related disturbance species density was calculated by multiplying the distance of the transect with 0.6km (width). As suggested by Anderson (2005), informants should also have traditional knowledge or ecological knowledge and thus, traditional data and information knowledge were incorporated through discussion with local inhabitants. As emphasized by Crandall et al., (2018), key informants who agree with specific conservation goals or programs can help to bring together differing opinions. In this respect, key informants were selected and interviewed. The informants were selected from the local inhabitants, administrators, scouts, mining workers and staff of the Ministry of Agriculture with different ages and sex groups all of whom have good knowledge and experience on the area. For this, 45 people from Dahlak Kebir Island, 135 people from the coastal area and 180 people from the western lowland (mainland) were consulted based on the data collection sheet (Appendix II). The respondent were requested to rate the severity of the threat by giving 5 to the highest and 1 to the lowest. The coastal and island respondents were pastoralists and angler whereas respondents of the mainland were farmers and pastoralists. As emphasized by Denzin (2010), data triangulation uses dissimilar sources of data or different data from the same source to examine the same issue. With this in mind, attempts were made to triangulate the data obtained through qualitative and/or quantitative methods by conducting informal discussion with local people encountered during the survey period.

Soil survey

To examine the mineralogical contents of soils in the target areas with that of the morphological variation of gazelles (mainland versus island populations), soil samples were collected in plastic bags in areas whenever concentration of gazelles was detected. From each study area, 10 samples were collected and it was sent to the University of Pavia (Italy) for analyses.

Figure 4.2. Prof. Mauro Fasola (left) supervising author in the coastal and Island study areas.

Climatic data collection

To assess the climatic condition of the study area with emphasis on the pattern of rainfall, data of the last 25 years were collected from the nearest metrological station of each respective study area. For the coastal area, data were collected from Massawa, Foro and Tio. Additional data were also obtained from Colluli Potash Mining Company, whose mining plant is located adjacent to the Buri-Irrori-Hawakil Protected area. Similar data were also collected from the western lowland specifically from Mensura, Akurdet and Kerkebet metrological stations. In addition reference was also made to the historical data for the mean of annual rainfall of the entire country including meteorological and hydrological information, collected during the Italian colonial period (1890-1941) obtained from the Department of Water Resources of the Ministry of Land Water and Environment.

Assessment of conservation opportunities

In view of supplementing the visual wildlife situation assessment, formal and informal discussions were held with key stakeholders at head quarter and regional levels. The consultation were conducted mainly with the staff of the Ministry of Local Government

(MoLG), Ministry of Agriculture (MoA), Ministry of Tourism (MoT), Ministry of Marine Resources (MoMR) and Ministry of Land, Water and Environment (MoLWE). In addition, all relevant documents specifically sectorial reports, research papers and project reports extensively reviewed and valuable data on the historical and current status of conservation and management of biodiversity in the country in general and wildlife in particular have been assessed.

Material used for the study

The materials used for the study include video and stealth camera, GPS. Range finder, counter binocular, topographic maps, vehicle, boat, camping equipment and Soil laboratory equipment.

Data analysis

The data were processed using descriptive statistics such as percentages, means, and standard deviations, which were then analysed using the Statistical Package for Social Sciences (SPSS, version 26). The geographical information system data was processed using Arc GIS 10.51 software and soil mineralogical analyses were carried out via X-ray powder diffraction.

Results and Discussion

The prevalence of threats facing the gazelles

Natural ecosystems are increasingly threatened by a wide range of human activities from habitat degradation and loss, habitat fragmentation, overexploitation, pollution and the spread of invasive species due to climate change (Groom et al., 2006). These factors combined cause most of the natural ecosystem to lose its meaning and purpose. The findings of this study are not exceptional because gazelles in their respective ranges are facing multiple threats. The conservation threats to species typically recognized are measured by reductions in range and/or population size (Lamoreux et al., 2003). Interestingly, hunting, which is perhaps the most devastating threat to wildlife, was not identified as a threat mainly due to the policies and directives imposed by the government. Hunting was banned soon after independence of the country; thus, this issue is not a matter of concern in Eritrea. This is probably an exceptional event throughout the geographical range of the three species. The only hunting incident reported was from the coastal area was in 2008. On that occasion visitors from Arab countries mainly from Saudi Arabia attempted to hunt using trained falcons and dogs; it was believed that they have killed enormous numbers of gazelles (Ahmed Refik pers. comm. 2021). However, the government took immediate action to control the illegal hunting and prosecuted

the offenders. Since then hunting has almost become a history in the country. Nonetheless, the scores of the respondent in respective study area were aggregated (averaged) according to the type of the threat then for the average score statistics was generated using SPSS 26 thus the prevailing threats and level of severity in the respective study areas are captured (Table 4.1).

Table 4.1. Respondent view on the level of threat facing to gazelles in respective study area

Study area	Threat Identified	No of respondent	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
Mainland	Climate change	180	3.87	0.720	0.054	3.76	3.97	3	5
	Habitat degradation	180	3.73	1.065	0.079	3.58	3.89	1	5
	Habitat Loss	180	3.17	1.393	0.104	2.86	3.27	2	5
	Competition with livestock	180	3.07	1.065	0.049	2.91	3.22	1	5
	Invasive species	180	1.07	1.127	0.084	0.90	1.23	0	5
Coastal	Climate change	135	3.73	1.001	0.086	3.56	3.90	2	5
	Competition with livestock	135	2.33	1.079	0.093	2.15	2.52	1	5
	Habitat degradation	135	4.13	0.621	0.053	4.03	4.24	3	5
	Habitat Loss	135	3.53	0.960	0.083	3.37	3.70	2	5
	Invasive species	90	1.40	1.207	0.127	1.15	1.65	1	5
Island	Climate change	45	4.29	0.944	0.141	4.01	4.57	2	5
	Competition with livestock	45	3.22	0.636	0.095	3.03	3.41	3	5
	Habitat degradation	45	4.27	0.654	0.097	4.07	4.46	3	5
	Habitat Loss	5	4.00	0.000	0.000	4.00	4.00	4	4

N.B: The level of threat was calculated based on the rank given as 5 for very High and 1 for Lowe threat.

As indicated in the figures 4.3 - 4.11, the direct observation of the survey corresponds with the view of the respondents and the threats mentioned by respondents are evident. As the study areas are located in two different ecological regions, the status of the threat varies with the location of the site as detailed below.

Climate change

The study shows that climate change to be one of the major threats. The decrease in rainfall and successive drought in the past decade has caused a devastating effect on the wildlife and habitat. This is in agreement with the suggestion made by Pachauri & Reisinge (2008); that climate change has already altered the rate and intensity of precipitation in many regions around the world, similarly as reported by many authors including (Gichochi et al., 1996) who reasoned that rainfall influences the structure and productivity of vegetation, and determines food supply and availability of water.

In Eritrea, there is no more limiting factor than water because the drought cycle repeats every 5 to 7 years (MoA, 2002). Rainfall is also erratic and often torrential, and quickly creating heavy floods with little chance of the water penetrating into the ground. Perennial streams hardly exist and there are no lakes. River Setit is the only perennial river in the country. The mean annual rainfall for more than 50 years revealed that the country receives a very low amount except for the moist zones, which receive more than 700mm (DoWR, 1999).

Eritrea is one of the countries most vulnerable to the adverse effects of climate change, mainly because of its least adaptive capacities (DoE, 2001). Eritrea lies in the Sahelian belt, which is characterized by frequent and prolonged droughts. The country has suffered from major prolonged droughts since 1965; It is generally considered that weather patterns in Eritrea started changing greatly since some time in the 60's (DoWR, 1999). Moreover, farmers observe that the duration of the rainy season has been narrowing for the last two or three decades. This has resulted in the changing spatial and temporal availability of water resources throughout the country. These observations need to be substantiated by detailed studies but they are in agreement with the general belief that climate change is affecting the global hydrologic cycle in general and precipitation, and runoff in particular.

Due to the effect of climate change, increases in temperature or a reduction in the amount of rainfall and /or irregular rainfall patterns and recurrent drought, which are common features in Eritrea, the wildlife population has been seriously affected (DoE, 2015). Due to the impacts of drought, the catastrophic death of animals is a common phenomenon particularly in the coastal and island areas (Fig 4.3).

Figure 4.3. Drought seriously threatening the existence of gazelles. (Photo, Dahlak Island)

Coupled with drought, heat stress was also noticed as the main causes of death of the gazelles. Particularly in the coastal areas, it was observed that when the temperature raises gazelles were submerged in wells to avoid heat stress and prone to death (Fig 4.4).

During the past decades, the frequency of droughts has increased, allowing for shorter recovery periods (Fig 4.5), and therefore having a more intense negative impact on the vegetation and on herbivores.

Figure 4.4. Gazelles were submerged in wells to avoid heat stress

This is likely to have a serious impact on vulnerable populations in the respective study areas. The impact is very critical in the coastal and island areas, and the only good rainfall received in the area was in 1998 during the *El Nino* (Mohamed Ahmed pers. Comm. May 2021). For this reason, vast areas are either encroached by sand dunes or have turned in to barren land

because of which rangelands are degraded and shade and foraging areas are becoming scarce. Consequently, the declining population of wildlife in general and gazelles in particular is evident.

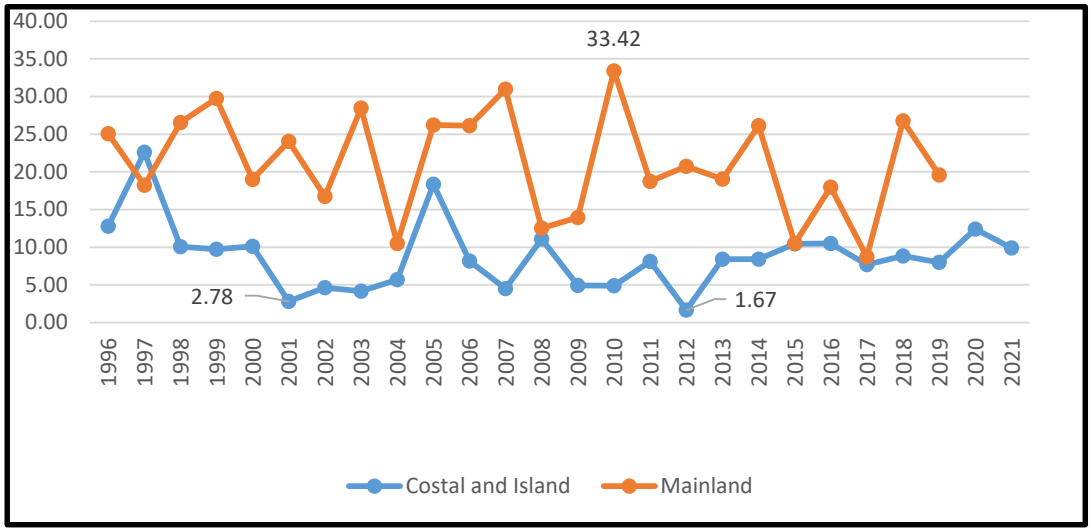

Figure 4.5. Rainfall pattern between 1996 and 2021 in the coastal and mainland study areas,

For the last 25 years, the means annual rainfall (Appendix VIII) of the respective metrological stations indicated that the rainfall pattern of the study area is highly variable. This variability is likely to have a negative impact on the availability of forage and thermal cover for the gazelles and will eventually result in habitat loss.

Competition with livestock

Competition with livestock was identified as a serious threat facing the gazelles in the respective study areas. As Krebs (2009) stated, competition occurs as both species strive to obtain resources that each needs. Throughout the study area, huge number of livestock were observed to make use of gazelle's habitats and their distribution overlapped with gazelles. Although our knowledge on the effects of pastoralism on the biological diversity of arid and semiarid systems have not been definitively determined. However, Kaufman et al., (1996) stated that it is possible that the diversity and abundance of the charismatic mega fauna is reduced by pastoralism and such a situation could be exacerbated due to the frequent incidence of drought in the region. The surveys revealed that the number of livestock that included cattle, camels, sheep and goats exceeds that of gazelles in the study area (Table.4.2). The problem was more pronounced in western land (mainland) due to the presence of high numbers of livestock particularly goats that have dietary overlap with gazelles due to having similar feeding behavior. In addition, the absence of protected areas allows the livestock to graze and browse

freely which may result in severe habitat degradation and exert a major influence on the existence of the gazelles.

Similarly, in the Coastal and Island areas, the inter-specific competition was also in place. However, the local community (Afar tribe) shows good respect for wildlife and have conservation ethics: according to their traditional beliefs, God will give them rainfall for the sake of animals and plants (Yohannes, 2001 and Hagos, 2016). Hence, it is not a revelation to see gazelles near the settlements of local people (Fig 4.6).

Table 4.2. Measure of the livestock related disturbance in respective study area

Species	Density/ km^2 in Costal and Island	Density/km^2 in Mainland
Goat	53.32	32.70
Cattle	6.56	41.90
Camel	3.02	1.59
Soemmerring's Gazelle	2.11	3.76
Dorcas Gazelle	1.77	1.19
Ostrich	1.66	0.65
Sheep	1.61	87.77
Donkey	1.22	0.52
Others	0.84	0.11
Eritrean Gazelles	0.00	1.18

Surprisingly during the survey seasons particularly in harsh times, it was observed that local people left the watering point of livestock with full of water in order to give watering access for wildlife around the Buri peninsula (Pers. Obs. May, 2021). Therefore, due to the presence of conservation ethics of the local community, in the Coastal and island areas, the existing tendency of threat is likely to restrain.

Figure 4.6. It is common to see gazelles staying near the settlement of Afar people.

The presence of the *defacto* (functional but not officially gazetted) Buri-Irrori-Hawakil protected area also plays a vital role on the existence of the gazelle. However, since it is not yet legally gazetted, livestock remains free to utilize the gazelle's habitat thus the threat of competition with livestock will continue to exist and is likely to have an impact on the wellbeing of the gazelles.

As herds of livestock keep growing, it is going to have a devastating effect on rangelands (GoE, 1995). The presence of high numbers of goats and camels in the coastal area (Fig 4.7) will also aggravate the competition with gazelles for of pastureland due to the dietary overlap, because all of them browsers and grazers.

Figure 4.7. Camels and Goats feeding in association with gazelles (Photo Buri-Hawakil-Irrori)

The interspecific competition in Dahlak Kebir Island was not high, due to fewer human inhabitants. However, some feral goats were observed in association with the gazelles (Fig 4.8) and sharing resources. In time, this could have a negative effect on gazelles foraging and health.

Figure 4.8. Feral goats foraging in association with Soemmerring's Gazelles (Dahlak Island).

Throughout the survey periods livestock were observed to share habitat with the gazelles and the data shows that they were consuming a significant amount of food in the respective study areas (Table 4.3 & 4.4). Reduction in total biomass and grain dry matter weight is presumed to be due to increase in temperature, which shortens the growing period of grass. Partly, it may be due to the predicted moisture and nutrient stress (DoE, 2001). Hence, taking into consideration the scarcity of rainfall in the region, the chance for rangeland recovery could take some time or else could keep deteriorating thus it is likely to have a serious impact on the food and habitat of the gazelles. As Madhusudan, (2004) argued, livestock and feral wildlife populations often have negative consequences on native wildlife.

Table 4.3. Observed number and biomass of livestock sharing habitat with gazelle in the mainland study area

Species	Body weight in kg	Observed number	Individual Food consumption per day in kg	Total food consumption per day in kg
Sheep	30	7285	0.9	6,556.5
Goat	30	2713	0.9	2441.7
Camels	400	131	12	4.800
Cattle	300	3477	9	31,293
Donkey	180	43	5.4	231.2
Total				45, 322.4

In the Coastal study area, goats dominated the livestock population (Table 4.5) and such a situation is likely to aggravate the trend of competition with the gazelles due to both species having similar feeding habits

Table 4.4. Observed number and biomass of livestock sharing habitat with gazelles in the Coastal study areas

Species	Body weight In kg	Observed number	Food consumption per day in kg	Total food consumption per day in kg
Sheep	30	203	0.9	182.7
Goat	30	6687	0.9	6018.3
Camels	400	392	12	4704
Cattle	300	810	9	7290
Donkey	180	153	5.4	826.2
Total				19,021.2

*The food intake (biomass) was calculated using 3% of the dry matter basis of the individual body weight. (Source MoAF, 2013)

Habitat loss

In Africa, loss of wildlife habitats is a widespread phenomenon; the current loss is estimated at 60% (Newmark & Hough, 2000). Human population pressure was cited as the main contributor to this loss, mainly through deforestation prompted by increased demand for arable land, settlements and fuel wood. The case in Eritrea is not different from this trend because the degradation including deforestation, loss of biodiversity and habitats remain the most serious environmental problems in the country. The scale of impact of land degradation on the social and economic wellbeing on the Eritrean population is incalculable (GoE, 1995). Since majority of the Eritrean, population depends on biomass fuel, as a source of energy, shortage of fuel wood, for example, is one of the most visible problems.

The study indicated that excessive clearing of vegetation for agriculture and cutting of live trees for firewood, both for local consumption and for urban centers of the country, as well as expansion of settlements has resulted in the loss of habitat. This agrees with the statement stipulated in the National Environmental Management Plan of Eritrea prepared in 1995 (GoE, 1995). Furthermore, the report revealed that people returning from Sudan are settling around the Gash Barka river basin and they construct their houses from Acacia trees and the leaves of doum palm (*Hyphaene thebaica*). The same report also indicated that 10% of the total firewood for Asmara is collected from the eastern lowland. Due to the absence of legally protected areas, overgrazing/over browsing by livestock and wildfires are common phenomena and result in a devastating impact on wildlife and their habitat. The threat is becoming chronic in the mainland (western low land) because expansion of agricultural land and overgrazing is happening at an alarming rate. During the survey, we observed attempts to clear land for agriculture (Fig 4.9).

Figure 4.9. Expansion of Agricultural land is threatening the future of gazelles (Photo- Duluk)

To some extent, unathorised agricultural practice were also observed in the coastal areas particularly around Wongobo (Gulf of Zula), Menhaso and Gerhara (Buri Peninsula).

Habitat degradation

Species are two to four times more likely to be threatened by habitat degradation than by any other type of threat (Krebs, 2009). Soil erosion is a major problem in Eritrea. Every year millions of tons of fertile soil are eroded due to torrential rainfall, deforestation, overgrazing etc (DoE, 2015). As a result, vast rangelands are losing their integrity and are being turned into barren land. Similarly, shade becomes an expensive commodity and consequently wildlife species are forced to abandon their preferred habitat and roam to other areas.

The worst habitat degradation observed in the coastal areas was the intrusion of sand dunes. Eventhough there is no study available that could support the trend of habitat degradation in the area but local information indicated that sand dune invasion is spreading at an alarming rate (Ahmed Refik pers.comm, 2021). During the survey period, it was prominent that sand dunes, invaded substantial areas of gazelle habitat altering the understory growth of grasses and herbs in to barren land (desert) (Fig 4.10). Taking the aridity of the ecosystem in to consideration, the prevalent habitat loss could have a devastating effect on the existence of gazelles unless urgent action is taken to halt it. As it is widely known, habitat conversion or loss corresponds to a complete change in community and ecosystem status and thus it is likely to cause losses at all levels of biodiversity.

Figure 4.10. Sand dune altering the grazing area in to a desert (Photo Buri peninsula)

Invasive alien species

Expansion of alien invasive species particularly that of Prosopis juliflora is evident in the grazing areas of gazelles. Invasive species have both direct and indirect effects. This alien species has a direct effect through competition or disease/parasitism. The indirect effect follows through habitat modification and Wootton (1994) has already reported such interaction. As he suggested invasion impacts can be evaluated across ecological and evolutionary realms. First, we can consider both direct and indirect effects of a single invader. The direct effects of an invader result from its immediate interaction with another species through predation, competition, parasitism or disease. Other studies, however, have documented that reducing resources limitation in a community increases their invisibility by favoring nonnative species, which in turn competitively suppress natives (Leishman & Thomson, 2005)

The alien invasive species identified as a serious threat was *Prosopis juliflora*, and it was invading the habitats of wildlife aggressively. The issue is more serious in the mainland (western lowland). Quite large areas of the preferred habitat of gazelles around kerkbet area has been invaded by the prosopis species and the situation is exacerbating for the last 10 years (Tekeste pers.comm, May 2021). Unless urgent management intervention is taken to control its expansion conceivably by using it for fuel wood or for other purpose such as for handcraft or construction material, otherwise with time, it is likely to make the wildlife habitat is in accessible or could block the migratory route (Fig 4.11) and such situation could intimidate the existence of wildlife.

Figure 4.11. Expansion of *Prosopis juliflora* is making the habitat of Gazelles inaccessible

Furthermore it could also have a serious impact on the continuous existence of the gazelles as reported by Ogbazghi (2016), Prosopis is a highly competitive species; and appears to suppress the growth and development of indigenous plant species that support the gazelle in terms of food and shelter. Moreover, the species also intoxicates livestock that consume too much of its seed (Zeray, 2016, cited in Ogbazghi, 2016). Thus, it is likely that it would also have similar effects on the gazelles.

Allied threats

In addition to the earlier mentioned threats, the survey revealed that there are also other allied threats facing the conservation of gazelles, namely lack of capacity and solid nutrient deficiency.

Lack of capacity

Human and material capacities are detrimental factors for conservation and management aspects. The Eritrean Forestry and Wildlife Authority (FWA), which entered into force in 2012, has limited capacity in conservation of wildlife. The institution is lacking necessary facilities to run effective conservation practices. The issue of these bottlenecks together with the impact of the border conflict of Ethio-Eritrea has had also an impact on the slow process of establishment of protected areas in the country.

Soil nutrient deficiency

The study also identified the deficiency of soil nutrients as a possible reason for morphological differences in gazelles on the island. The soil samples collected from the study areas showed that each study area presented a variable mineralogical composition (Table 4.5)

Table 4.5. Soil property of the respective study areas

Site	Soil Properties
Coastal area	variable quartz content, abundance of feldspar (K-feldspar and plagioclase), low carbonate, varying contents of smectite from absent to very rich and without kaolinite
Dahlak Kebir Island	generally high quartz content, low feldspar content (K-feldspar and plagioclase), generally high content of carbonates, varying contents of smectite from absent to very rich and presence of kaolinite
Gash Barka (Mainland)	variable quartz content, with an abundance of feldspar (K-feldspar and plagioclase), without carbonates, abundant smectite content and soils with absent to low kaolinite

Soemmerring's Gazelles in Dahlak Kebir Island appear smaller and have irregular horns (Fig 4.13). Different researchers have suggested reasons for the irregular nature of these gazelles (De Marchi et al., 2013; Masseti *et al*., 2015; Ibrahim, et al., 2020, and Chiozzi *et al*., 2021).

This study revealed that the variation of the soil in the respective sites also had a likely impact on the type and growth form of the vegetation and this is likely to affect the morphology of the gazelles; particularly interesting is the difference in smectite (Fig 4.12). It is an important mineral because it is responsible for ionic exchanges and above all for capturing organic molecules.

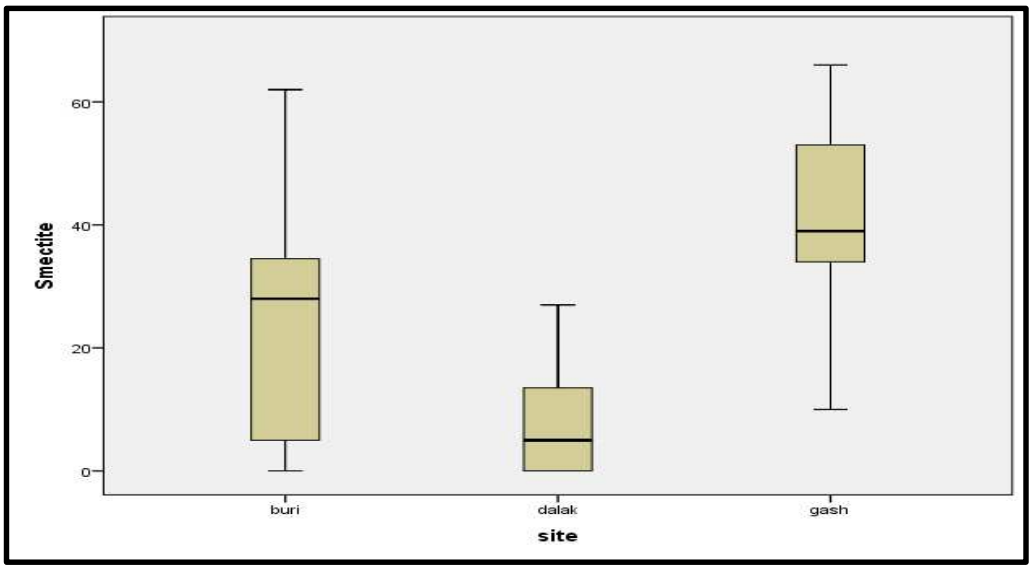

Figure 4.12. Plots of smectite content of the three study areas

Clay minerals in animal nutrition are used in particular due to their absorption/adsorption properties significantly contributing to the health of the animals (Slamova *et al*., 2011). Smectite is also known to facilitate absorption of nutrients during digestion (Setti et al., 2000), thus the dwarfism and the horn deformities of Soemmerring's Gazelles of the Dahlak Island, compared to the continental areas, might be related to lower level of smectite in the island soil in addition to that of food scarcity.

Figure 4.13. In Dahlak Island, it is common to see gazelles with irregular shapes of the horns

Conservation status of the three species

A century ago, Eritrea used to be endowed with all sorts of natural resources, which included fertile land, adequate water resources, dense forests and various species of wildlife (DoE, 2008). However, during the period of war for independence, natural and anthropogenic effects caused immense damage to the environment in general and biodiversity in particular. Consequently, many wildlife species became locally extinct, while others reached at the brink of local extinction (GoE, 1995). After independence (1991) together with the positive statutes of peace, security and stability in the country, the people and government of Eritrea have given due attention to reverse the adverse situation of wildlife species that had been resilient to the stresses of drought, hunting, and loss of habitat as the government accords environmental issues among its top priorities.

Soon after the independence, Eritrea acknowledged the need to establish ecosystem based management including the establishment of a protected areas system as a way to preserve its rich biodiversity and conserving valuable natural resources (DoE, 1999). Policy makers and planners recognized the importance of biodiversity integration into national policy frameworks, strategies and planning. In spite of the gains of high level commitment, this assessment has shown that there are inadequate overall environmental policies/legislation, which include protected area policy/legislation, land and sea-use policies/legislation and integrated strategies and planning regarding biodiversity conservation, management and financing.

To facilitate the protection of local and regional biodiversity resources, Eritrea has been committed to carry out all possible roles and responsibilities, and as concrete measures have ratified numerous International Conventions, Treaties, Agreements and Frameworks (Table 4.6)

The ratification of the conventions, biodiversity conservation and management in the country gained momentum and endeavors exerted to reverse the decline of biological diversity through the activities of the CBD (DoE, 2008). As part of its international obligation and more importantly meeting its development objectives, Eritrea has now put in place it's National Biodiversity Strategy and Action Plan (NBSAP) and in 2019 submitted the country's 6th NBSAP national report (DoE, 2019).

Table 4.6. International convention, protocol or treaties to which Eritrea is party (DoE, 2008)

International convention, protocol or treaty to which Eritrea is party	Ratification accession date
Convention on Biological Diversity (CBD)	May 21, 1996
Convention on Migratory Species (CMS)	February 01, 2005
The Basal Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal	March 1, 2005
The Rotterdam Convention on Prior Informed Consent (PIC) for Certain Hazardous Chemicals and Pesticides in International trade	March 1, 2005
Stockholm Convention on Persistent Organic Pollutants (POPs)	March 1, 2005
Vienna Convention for the Protection of the Ozone Layer	March 2, 2005
Cartagena Protocol on Bio-safety to the Convention on Biological Diversity	March 1, 2005
Framework Convention on Climate Change (FCCC)	April, 24,1995
Kyoto Protocol of the Climate Change Convention	July 28, 2005
Montreal Protocol on Substances that Deplete the Ozone Layer	March 2, 2005
Convention on International Trade of Endangered Species (CITES)	14August, 1995
Convention to Combat Desertification (CCD)	14August, 1999
International Treaty on Plant Genetic Resources for Food and Agriculture	April 10, 2002

At the national level there are policies, strategies and plans that are supportive and relevant to biodiversity conservation that require intensive consideration for sustainable and effective management of the nation's biodiversity. As emphasized in NBSAP (2015), various national institutions cooperate on policies related to biodiversity conservation. The key existing policy and legal instruments are believed to make positive impacts in biodiversity conservation and development.

In this context, the first measure taken was to develop macro-policy actions, which were formulated in 1994. Environmental issues constituted a major part of this Policy Paper and a special chapter is devoted to providing policy guidance on environmental protection, including policy guidance on the introduction and development of impact assessment, the conservation of biological resources (Macro policy1994). The policy was developed in a way that considered the interests of present and future generations, that is the need to ensure the management of

natural resources in a balanced and sustainable manner. As part of the environmental policy measures, the first step that was taken was the establishment of an interim secretariat to prepare a National Environmental Plan for Eritrea (NEMP-E). (GoE, 1995). The document clearly states the need for environmental impact assessments to determine the potential environmental consequences of major investment decisions. It recognizes the negative impacts of some traditional farming practices on crop productivity, as well as progressive environmental degradation attributed to increasing demands for fuel wood, and inadequate soil and water conservation measures. Furthermore, the document reiterates the commitment required from the government to allocate financial resources to promote the rehabilitation, conservation, development and proper exploitation of natural resources.

In line with the development of NEMP-E, in relation to the land ownership issue, the government issued land proclamation known as Proclamation No.58/1994. This law provides that all land is owned by the State and citizens have usage rights only (GoE, 1994). This proclamation provides tenure security and has been described as a framework for the evolution of grassroots action against land degradation. Furthermore, the proclamation provides an opportunity for the establishment of protected areas for any potential biodiversity conservation areas in the country. To minimize the impact of mining on biodiversity, in the same year as the development of NEPM-E, other legal instruments were enacted such as the Proclamation to Promote the Development of Mineral Resources No. 68/1995. This Proclamation, in addition to the regulations of mining operations, lays out some general requirements for environmental management and protection of negative impacts on biodiversity (GoE, 1995b).

In accordance with the proclamation for the Establishment of Local Governments No. 86/1996, in addition to regional decentralization of administration in the control and implementation of developmental policy and planning, it also encompasses responsibilities of environmental protection at the regional level and highlights the need to ensure any policy of biodiversity conservation and sustainable use (GoE, 1996a).

To raise public awareness on biodiversity conservation, the Press Proclamation No 90/l996 also incorporated environmental issues (GoE, 1996b). According to this proclamation, the Ministry of Information has the potential to facilitate and disseminate biodiversity-related information in collaboration with the institutions concerned with biodiversity conservation and management.

Taking the biomass energy in to consideration, the main threat for biodiversity conservation, include various intervention options being initiated by the Government including rural electrification through grid extension; improvement of biomass energy resources through various afforestation and reforestation programs as well as dissemination of improved stoves. To date nearly one million improved stoves have been distributed in the country (MoA, 2021) and this is likely to contribute for the improvement of vegetation cover of the country, which eventually secures the habitat of wildlife.

The other remarkable commitment is Tourism Development Policy and Strategy of 2000 -2020. This document specifies many aspects of biodiversity issues such as the need to develop tourism in a manner that encourages conservation and enhancement of the natural environment, especially protection of scenic areas, watersheds, ecosystems, biodiversity, and expansion of forests and wildlife populations (MoT, 1999)

The Government of Eritrea (GoE) in pursuant to Article 5 of the convention to the United Nation Convention to Compact Desertification (UNCCD), has prepared a National Action Program (NAP) that identifies factors contributing to desertification and practical measures necessary to combat it and mitigate the effect of drought. In relation to biodiversity conservation and sustainable use, NAP has identified key concerns and threats to flora and fauna. The action plan emphasized the need for creation of protected area system (in situ conservation) and recommend actions that strengthen the ex-situ conservation capacity of the nation on biodiversity resources (MoA, 2002).

To support the endeavors undertaken on ecosystem restoration, the Forestry and Wildlife Conservation and Development Proclamation No. 155/2006 is in place. This proclamation, in addition to the regulations for the issuance of forestry permits (Legal Notice 111/2006) and regulations for the issuance of wildlife permits (Legal Notice 112/2006) provides the framework for the conservation and development of forests and wildlife resources of the country (GoE, 2006).

The proclamation has particular relevance to conservation and the sustainable use of biological resources including the establishment and management of protected areas for the conservation of biodiversity, sites of special scientific interest or preservation of landscapes. Article 24 of the proclamation prohibits unauthorized exploitation, transporting and processing of wood and non-wood forest products for commercial purposes, cutting live trees for domestic use and

clearing land for agriculture and other purposes Article-21 prohibits the importation of exotic trees and wildlife and their products without getting permits. It requires verifying that the exotic species is not invasive and does not affect the conservation and sustainable management of the indigenous species and ecosystem

As a mechanism to avoid and mitigate environmental damage through coordinated planning and implementation of activities and minimizing unknown risks using the precautionary principle in the coastal areas, a strategy to establish an Integrated Coastal Area Management (ICAM) was enacted. As a tool, ICAM enables conservation of ecosystems by managing development activities (MoMR, 2007). In addition to ecosystem conservation benefits, ICAM enhances the value of coastal assets through defining the location of facilities and development activities in line with national needs and sustainability as opposed to investor preferences only in the coastal area and resolving and mitigating conflicts of interest over the assets.

Furthermore, in 2017 a comprehensive legal instrument is in place that is the Eritrean Environmental Law Proclamation (GoE, 2017). The proclamation has four objectives: (i) establishing the foundation of environmental management and protection laws and provide the institutions and legal instruments for their implementation and enforcement, (ii) advancing an environmental policy framework consistent with sustainable development; (iii) guaranteeing and promoting maximum public and community participation in the conservation, protection and enhancement of the environment and (iv) setting up the basis for Eritrea's effective contribution to and benefit from international cooperation in the global efforts for environmental protection.

Currently the Department of Environment is entrusts with the development and elaboration of national policies, programs, and strategies for the environment. The environmental issue is complex and aims to create proper conservation and utilization of environmental resources. Various line ministries and other government institutions address environmental management issues within their portfolios (GoE, 2017). The environmental proclamation gave a mandate for relevant institutions to manage environment related issues. For instance, the Ministry of Agriculture addresses environmental issues related to agricultural activities and the Ministry of Marine Resources addresses issues specific to marine activities, etc. In this case, the Department of Environment plays a coordinating role.

The active involvement of community based organizations/Civil Society Organizations in the conservation and management of the environment is apparent. Among others, the National Union of Eritrean Women (NUEW) which is one of the major players in mobilizing local communities (especially women), in identifying and implementing programs and projects including resources management, afforestation, adaptation, water development and use, promotion and dissemination of alternative energy sources, income generating activities including the participation in policy planning and monitoring. It is of prime concern to the women of Eritrea, especially in the rural areas, which play a significant role in environmental issues. The other effective CBOs, which plays a crucial role in environmental rehabilitation, is the National Union of Eritrean Youth and Students (NUEYS), which is actively involved in biodiversity enhancement. Every summer vacation high schools studentsparticipate in greening activities such as planting seedlings, digging wells, terracing hillsides, and the well-being of the environment through NUEYS sponsorship in collaboration with other relevant sectors. The regional (Zoba) administration is the lead institution for all development activitis including biodiversity management through its powers of decentralized arrangement involving Sub-Zobas and local communities. Similarly, the sub-regional level administration is the lead organization responsible for the overall mobilization of communities around the sub region in the implementation of programs and projects related to natural resources development and management such as nature resources conservation, soil and water conservation, tree planting, dam construction etc (GoE, 1996a).

In order to create a conducive environment for the revival of biodiversity, the establishment of protected areas became a national priority (GoE, 1995a). In 1995, five sites were proposed as priority areas for flora and fauna conservation, namely; Semenawi-Debubawi Bahri (Green Belt), aimed to protect Eritrea's last remnant of mixed evergreen tropical and associated wildlife species. Gash-Setit elephant sanctuary, located within the watershed of the rivers Gash and Setit, was established to conserve Eritrea's remaining elephant population. Riverine habitat along the Gash and Barka Rivers, intended to conserve the riverine forest, Buri Peninsula and Dahlak Kebir Islands, a priority for marine and coastal area conservation.

In 1997 FAO, pre-investment study was undertaken to broaden the knowledge base used for planning support to the Ministry of Agriculture particularly for Forestry and Wildlife activities. The study has further increased the number of potential protected areas. By then 27 potential marine and terrestrial sites were identified (Fig 4.14).

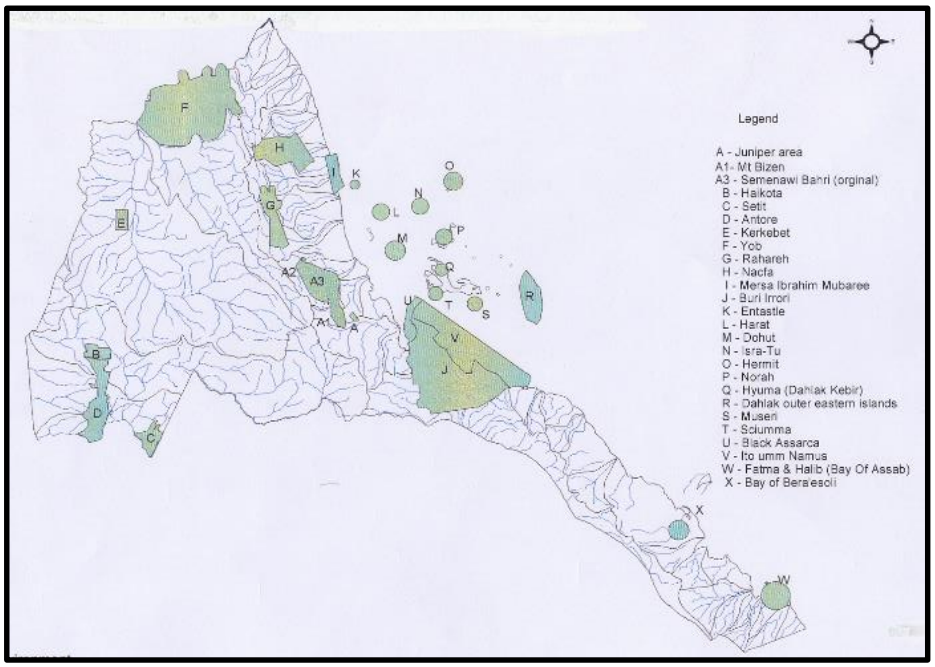

Figure 4.14. Sketch map of the proposed protected areas in Eritrea (FAO, 1997).

However, due to lack of capacity and the political turmoil of the region, the establishment of protected areas has been a slow process. Nevertheless, notable progress was made on 12 terrestrial and one island protected areas (Fig.4.15)

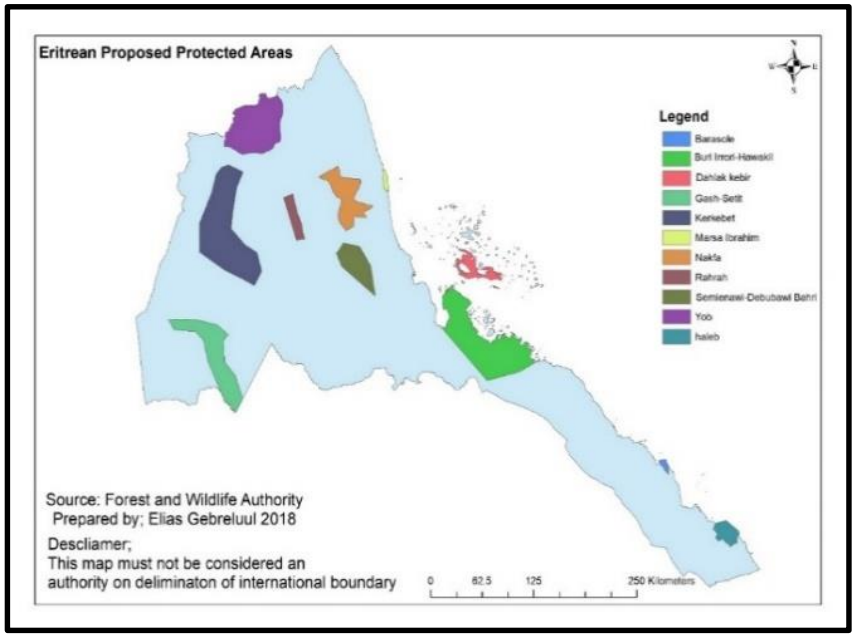

Figure 4.15. Sketch map of the proposed and defacto- terrestrial and island protected areas

An unpublished report of the Forestry and Wildlife Authority also revealed that recently more potential areas for the establishment of protected areas have been identified in Gash Barka region, these include Mensura-Duluk, Dige, Mahkelay-Shensheliyay (south western part of the

country) and Adobha (northern part). The recently identified protected areas are fundamental for the existence of the three gazelle species.

It is fortunate that viable population of gazelles are found in Buri-Irrori-Hawakil and Dahlak Island *defacto* protected area; in other places, they live in areas that are not protected. Thanks to the local people and members of the defense force for their collaboration in the conservation of these species

The study also found that in some cases, progress towards these goals is already underway. Among others, in the *defacto*-protected areas of Semienawi-Debubawi Bahri (Green Belt), Gash-Setit Elephant Sanctuary, Dahlak Island, and Buri-Irrori-Hawakil (Fig. 4.15) are contributing to the revival of wildlife including the three gazelles. Furthermore, in 2012 the commitment of the government to promote conservation showed advancement through upgrading the Forestry and Wildlife division into Authority level. With the establishment of the Forestry and Wildlife Authority (FWA), the endeavors of conservation and development of wildlife and their habitat gained momentum (Pers. obs, 2021)

Combating land degradation is also apriority at the national level; as highlighted earlier, Eritrea has ratified the Convention to Combat Desertification (CCD) in August 1996 (MoA 2002). Since independence relentness efforts are underway to combat land degradation and eventually to rehabilitate the degraded land of the country through active participation of the public (Fig 4.16). The rehabilitated land is likely to have a positive impact on creating a conducive environment on the revival and conservation of wildlife.

Figure 4.16. Exemplary active participation of the community in ecosystem rehabilitation

As part of the commitment towards combating desertification, a National Action Plan (NAP) has also been prepared and its implementation process is underway (MoA, 2002). Today activities of soil and water conservation, afforestation and reforestation are widely exercised throughout the country and significant degraded areas have been rehabilitated through afforestation and natural regeneration (DoE, 2019).

In recognition of Eritrea's commitment to marine environmental protection and management, in 1998, the Government initiated a Marine and Coastal Biodiversity Conservation Project in partnership with UNDP/GEF, one of whose aims is the establishment of marine protected areas (MoMR, 2007a) and endeavors are ongoing.

Conducting intensive public awareness in wildlife conservation is the other notable action. Efforts are ongoing to sensitize the entire public and policy makers, using various means including mass media and written materials. It is common to see wildlife posters featuring the three gazelles and signposts in public places written in three languages: Tigrigna, English, and Arabic (Fig, 4.17). The endeavors made on awareness raising are considered to have a great role in the revival of wildlife in the country.

Figure 4.17. Exemplary poster and signpost presented for public awareness.

In line with the awareness raising, efforts are also ongoing in law enforcement. Recruitment and training of rangers (forest and wildlife guards) is a continuous process and improvement in protection of wildlife and their habitat is in place. In this respect, the Proclamation No.155/2006 is playing a significant role in the enforcement of the ban of hunting. Furthermore, the establishment of a system of protected areas in the country is in the pipeline. The Ministry of Water, Land and Environment (MoLWE) in collaboration with its key partners

are working on this and it is expected that it will be enacted in the near future (DoE, 2020 draft).

The result of these courageous conservation interventions is showing promising achievements in the revival of biodiversity in general and wildlife in particular in the country including the three species of gazelles (Fig. 4.18).

It can therefore be concluded that there exists a promising opportunity for the continued existence of the three gazelle species in the face of the natural and human induced threats. This is because of the fact that people and government of Eritrea are keen and committed to conserve the remaining wildlife including the gazelle species and protect the wildlife. Most people look at the gazelles as a source of pride and inspiration. In recent years, people have also recognized that wildlife in general and gazelle species in particular are part of the natural heritage with potential for economic growth and prosperity in the form of ecotourism, and thus they are keen to conserve wildlife.

Figure 4.18. The revival of population of the three gazelle species is becoming promising

The ban on hunting and charcoal production as well as awareness-raising campaigns have played a strong role in the achievements made so far. The revival of wildlife in the country including the globally threatened species such as African Elephant; African Wild Ass and Eritrean gazelles are a witness to that. However, it is important to note that due to the existing

multiple threats combined with the persistent drought, there is still concern for the future of the wildlife in general and the three species of gazelle in particular.

In conclusion, this study has examined and evaluated the existing situation of the three gazelle species. The result revealed that the species are facing with multiple threats that could drive their future in to uncertain. Therefore, the information acquired will contribute in designing appropriate conservation strategy that could assure the continuous existence of wildlife in general and the three gazelle species in particular.

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Chapter 5 General Discussion, Conclusion and Recommendation

To the best of my knowledge, since the independence of Eritrea, this is the first study on the distribution, abundance and conservation status of the three threatened gazelle species (*Nanger soemmerringii, Gazella dorcas* and *Eudorcas tilonura*) in the country. The study was conducted through mixed approach methods that included roadside transects, questionnaire surveys, interviews and focus group discussions. As stated by Saunders *et al.* (2009), such an approach is useful because it allows a researcher to use different data collection methods to improve the validity of the data collected. This approach was also found to be useful to design conservation strategy in the mixed-use areas where human wildlife conflicts are widely pronounced.

This chapter attempts to evaluate the findings presented in chapters two, three and four. The combined information obtained from the ground and questionnaire surveys brought empirical information on the local distribution, abundance and habitat interaction, prevalence of threats and conservation status of the three gazelle species in Eritrea. Therefore, the three main research outputs are appraised as follows.

Ecological distribution of the three gazelles species

Understanding species distribution has a crucial role in designing management strategies that help in ensuring the continuous existence of the species. However, to date no systematic study has been conducted on the distribution of the three gazelle species in the country and thus gaps in our knowledge of the distribution of the species is evident. Therefore, the study aimed to bridge these gaps and comeing up with information that can help the conservation of these threatened gazelle species (IUCN, 2017). In this context, the findings of the study confirm that the three gazelle species are distributed in diverse ecosystems of the country, which are endowed with varied landscapes of climate and foraging cover found in different parts of the country. This goes in line with Bailey et al., (1996), who highlighted that the choice of any species to a specific habitat is dictated by abiotic and biotic factors that influence the way herbivores use rangeland. Furthermore, as stated by Krebs (2006), the distribution of animals is also restricted on a landscape scale by behavioral reactions. Therefore, animals through innate behaviour tend to adapt to certain habitats. This study discovered that the three gazelle species, although still existing in most of their historical range in the country despite their distribution being influenced by the effect of climatic change and anthropogenic activities, were forced to disperse around their preferred habitat. It was noted that either in certain areas

the three species were observed to share the same habitat and in others two of the species shared the same habitat or only a single species existed. An overview of the distribution of the respective species in the country is shown below.

Soemmerring's gazelle (*Nanger soemmerringii*)

The results of the combined surveys indicated that *N. soemmerringii* although its historical range is some how diminishing but it is widely distributed in the country, including, the Red Sea coastal area, Dahlak Kebir Island, and Southwestern and Northeastern parts of the country. Using the data from the species occurrence (presence/absence) and ground surveys, the distribution of the species in the country was mapped together with the other two gazelle species (Figures 5.1, 5.2 and 5.6). *N. soemmerringii*'s distribution in the country was estimated to cover an area of 53,093 km^2, comprising 637 km^2 on the island, 38,002 km^2 in the coastal area, and 14,454 km^2 in the mainland areas. In the western lowlands, *N. soemmerringii* was observed to coexist with *G. dorcas* and *E. tilonura*, while in the coastal area it was roaming with *G. dorcas,* while in Dahlak Kebir Island no other gazelle species exist.

The population of the species in the coastal and western lowland areas appears to have similar morphological and horn structures, whereas the population in Dahlak appears smaller with irregular horns. The study suggested that the variation of the soil in the respective sites had a likely impact on the type and growth of the vegetation, and that inturn is likely to affect the morphology of the gazelles; the difference in smectite is particularly interesting. As stated by Setti *et al.* (2000), smectite is an important mineral because it is responsible for ionic exchanges and above all for capturing organic molecules.

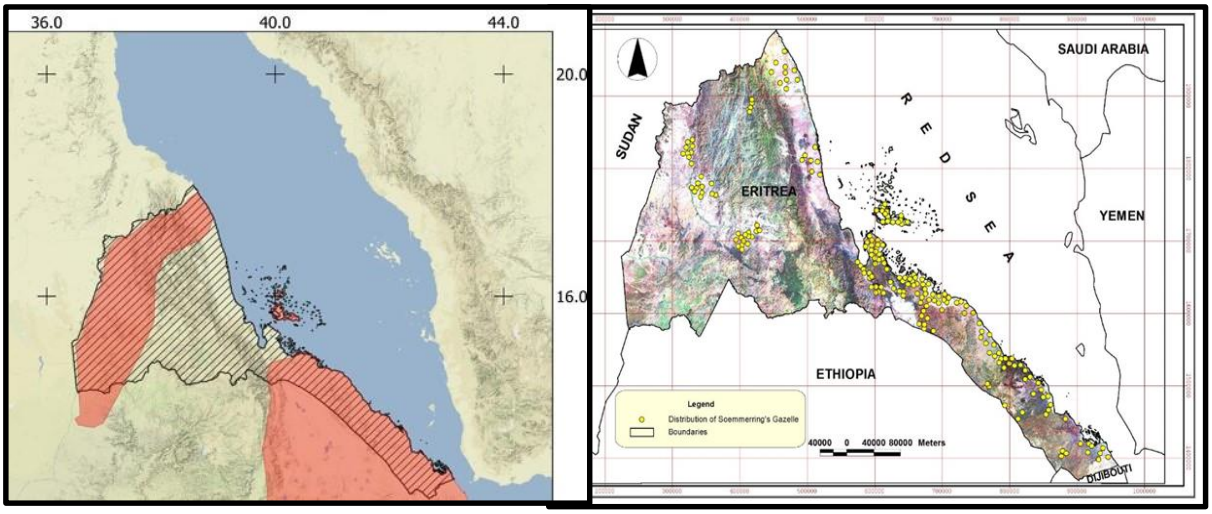

Figure 5.1 Historical (left) and current (right) distribution of *N. soemmerringii*'s in Eritrea

Dorcas Gazelles (*Gazella dorcas*)

Prior to this study, no attempts had been made to study the species in the country, thus the status and distribution of the species in the country was not known. As Abaigar T. (2018) has reported that, the Dorcas Gazelle has been under pressure for some time across its range, with numbers now significantly lower and the populations more fragmented than was the case a few decades ago and Eritrea is no exception. Even though statistical data are not in place, information from the respondents agree with the Abaigar (2018) report. The respondents' views in the respective study areas indicated that the population of *G. dorcas* has showed drastic decline. Nonetheless, after the independence of the country, the species is starting to recover at a slow rate and the hunting ban has been credited for the revival of the species.

The survey revealed that the species is still fairly distributed in most of the historical range except in the highlands (Fig.5.2). It is widely distributed than the other two species in the country. This includes the coastal area mainly south and north of the port of Massawa, extending to the borders of Djibouti and Sudan respectively; and in the Danakil depression, extending up to the border of Ethiopia. In the western lowlands, the species occurrence was confirmed in the subregions of Monsura, Akurdet, Mogolo, Dige, Gogne, Forto-sawa, La'ela gash, Golij, Kerkebet, Sela'a, (south-western region), and Nakfa and Adobha (northern part of the country). The species distribution in the country was estimated to cover an area of 87,759.19 km2, comprising 39,295.41km^2 in the coastal area and in the western lowlands 48,464 km^2. The range of the species shares a boundary with Djibouti, Sudan and Ethiopia (Fig 5.2), showing its transboundary character.

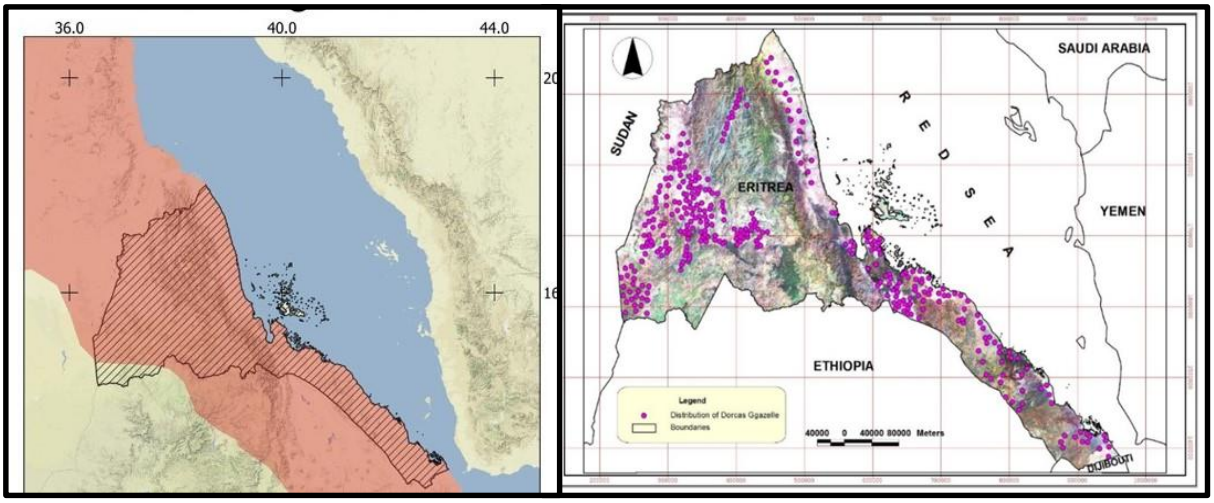

Figure 5.2. Historical (left) and current (right) distribution of *Gazella dorcas* in Eritrea

The species was observed repeatedly to stay in association with Soemmerring's Gazelle, and occasionally with Eritrean gazelle in the respective ranges of the species.

Interestingly, the Dorcas gazelles observed in this study had phenotypes matching three different subspecies. Two sub species, *G. d. Isabella* and *G. d. becarrii*, were observed in the mainland (western low land) (Fig 5.3).

Figure 5.3. The two sub species of Dorcas gazelle observed in the mainland
G. d. Isabella (left) and *G.d. becarrii* (right)

While in the coastal areas, only *G. d. pelzelni* was observed to occur (Fig 5.4). This finding probably confirms for the first time the existence of these subspecies in the country. The localities where they were recorded matched their distribution in *Mammals of Africa* (Scholte and Hashim 2013).

Figure 5.4. Male and female of *Gazella dorcas pelzeln* observed in the coastal area

Eritrean gazelle (*Eudorcas tilonura)*

Similar to the Dorcas Gazelle, prior to the study there has been no study carried out with regard to *Eudorcas tilonura* to the best of my knowledge. In fact, its existence after the independence of the country was confirmed only in 2019 (Hagos, 2019) and no further study has yet been conducted to assess its status. For this reason, lack of information on its distribution and status of this species was evident. This study revealed that the species is exclusively a mainland dweller, specifically in the southwest lowlands of the country, mainly around Monsura-Duluk, Mogolo, Gogne, Forto-Sawa, Laelay Gash, areas of the Golij sub region that drain to Setit River, and Dige. Scattered individuals were also observed around Kerkebet and the northern parts of the country, mainly Agraee (Nakfa), and the total area covered by the species was estimated at 48,660 km^2. The findings of the study indicated that there is significant difference on the distribution of the species from that indicated by IUCN (2017) (Fig 5.5). Therefore, the populations that occur around Monsura, Duluk, Dige, Kerkebet, Agraee (subregion of Nakfa) and Adobha appeared outside of the historical range of the species. The species distribution is considered to share a boundary with Ethiopia and Sudan; hence, there is a possibility of an interchange of populations.

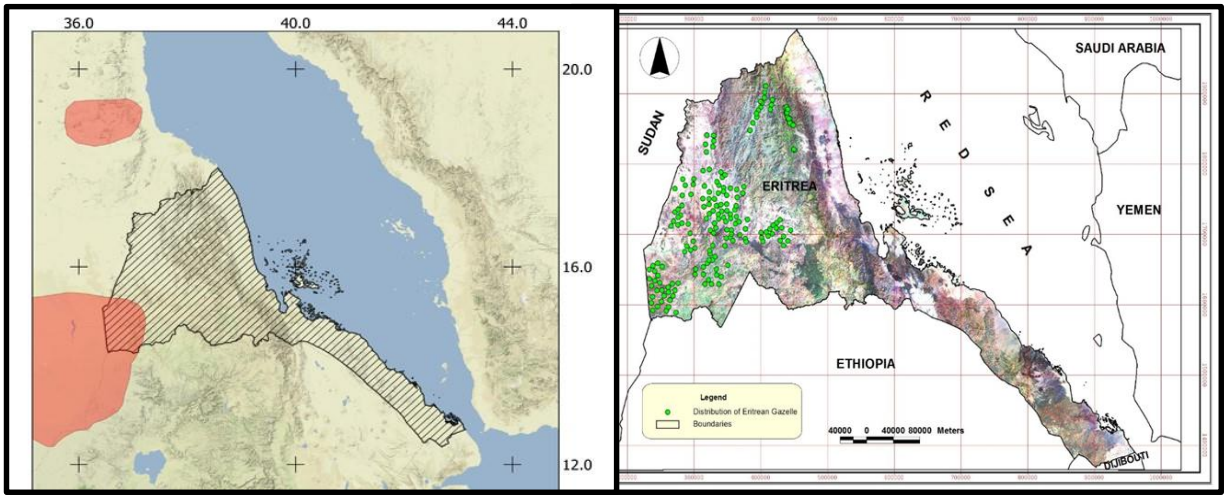

Figure 5.5. Histroical (left) and current (right) distribution of *Eudorcas tilonura* in Eritrea

Eritrean Gazelle has been observed to overlap with Dorcas Gazelle and an observation was made of them utilizing the same area with Soemmerring's Gazelle in different seasons around Duluk (subregion of Akurdet). However, further investigation is needed to corroborate this observation.

Abundance estimation of the three gazelle species

The study indicated that the coastal area appears to harbour a higher abundance of Soemmerring's and Dorcas Gazelles than the western lowlands. According to the model in the six successive surveys, the total observed maximum count ($N_{max.}$) of Soemmerring's Gazelle in coastal area found to be 521 individuals and 155 for the Dorcas Gazelle. In the western lowlands, the observed maximum count ($N_{max.}$) was 252 and 85 for Soemmerring's and Dorcas gazelles respectively (Appendix IX). Notably, eventhough due to the incomplete survey, statistical data were not obtained. Howerver, a viable population of *Nanger soemmerringii* exists on Dahlak Kebir Island. During the single survey made on the island, nearly 400 individuals were detected, thus Dahlak Kebir island can be considered to be one of the the area with the highest abundance of Soemmerring's Gazelles.

Based on the combined survey data the relative abundance of these two species of gazelle in Eritrea was mapped (Fig 5.6).

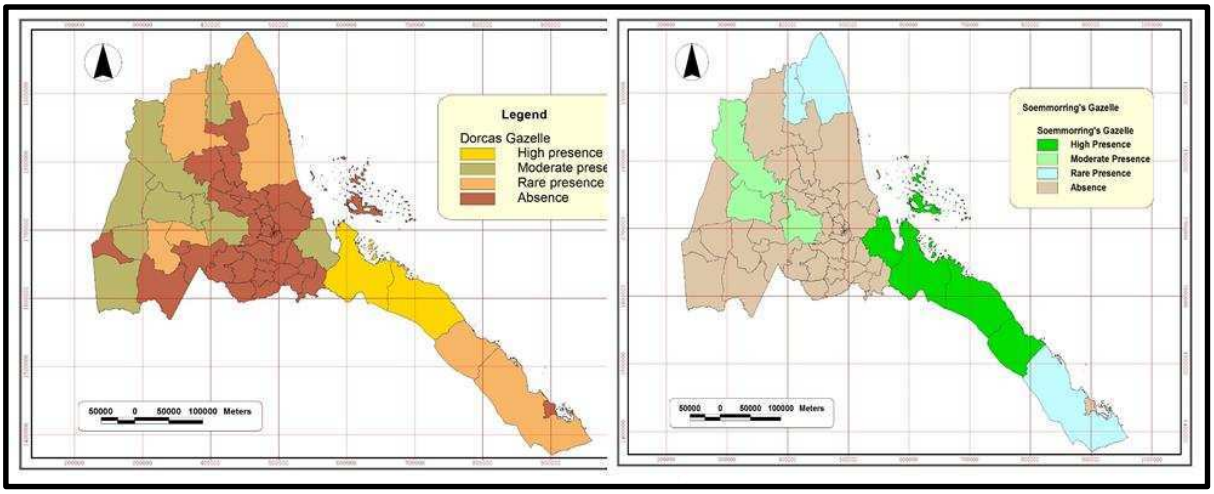

Figure 5.6. Relative abundance of *Gazella dorcas* and *Nanger soemmerringii* in Eritrea

The highest mean group sie of *Eudorcas tilonura* species was observed in the Monsura-Duluk area than kerkebet area. The model indicated that the total observed maximum count ($N_{max.}$) of the species in the former sampel area was 57 individuals and in the second area was 47 Individuals.

The land cover and human-related land uses such as agricultural activities and settlements in the respective study areas were found to dictate the pattern of abundance of the three species. This goes in line with the argument made by Hieronimo et al., (2014), which suggests that the abundance of the species is most likely influenced by various factors such as the distribution and abundance of habitat resources. Gazelles tend to aggregate or disperse depending on the

forage availability which is interlinked with seasonal variation, particularly rainfall because rainfall influences the structure and productivity of vegetation and determines food supply and water availability (Gichohi *et al.* 1996). However, seasonal surveys showed that there was no significant difference in habitat or in seasonal variation of the abundance of the three species. Such results imply that the gazelles undertake local rather than regional migrations. When food is scarce, they are likely to be concentrated in areas with patches of green vegetation, specifically in ravine vegetation, and this is likely to have a negative impact on the detectability of the species. Because transects are only crossed certain parts of such habitat, thus detailed assessment of the ravine habitat was not possible.

Arid and semi-arid areas are less likely to attract pastoralists and this could give the gazelles an opportunity to undertake cross-border migrations. For instance, gazelles found in the Danakil depression (Colluli) freely move between Ethiopia and Eritrea, and similarly with Djibouti. Further study is needed in order to evaluate the movement patterns of gazelles in the Horn of Africa.

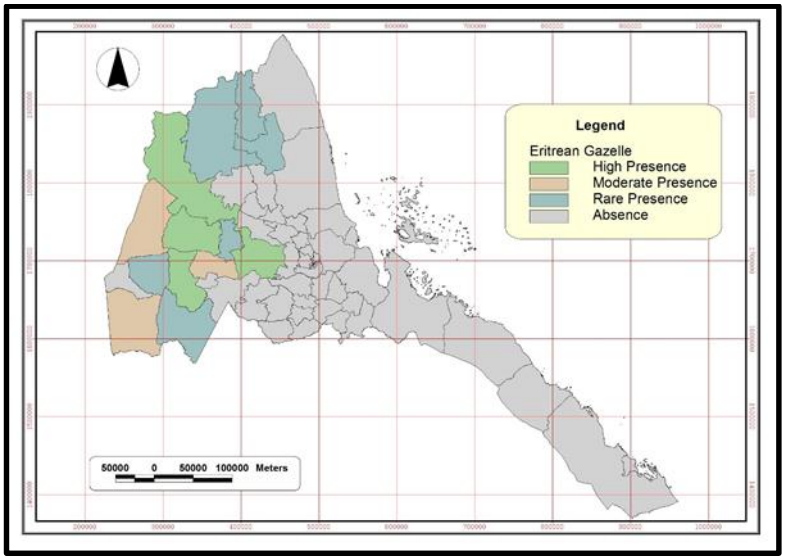

Figure 5.7. Distribution and relative abundance of *Eudorcas tilonura* in Eritrea

Prevalence threat and conservation status

Gazelles in their respective areas are faced with multiple threats associated with natural and anthropogenic activities. The respondents' views and ground surveys revealed that agricultural expansion and successive droughts exacerbated by climate change seriously deteriorate the habitat of gazelles'. As is widely known, climate change is the major threat that exists everywhere and it cannot be reversed by local actions (Parmesan & Matthews, 2006). Apart the Island area, vast swathes of wildlife habitat have deteriorated either by human activities,

such as intensification of agriculture and overstocking, or due to the effect of drought. Therefore, unless immediate action is taken to reverse the trend, it is likely to reach an irreversible situation that will eventually lead to the disappearance or else extinction of gazelles, because habitat destruction and degradation are the primary causes of biodiversity loss at all levels (Groom & Vynne, 2006).

The study also found that, in some cases, a promising opportunity exists for the continued existence of the three gazelle species in the face of natural and human-induced threats. This is because the people and government of Eritrea are committed to conserve the remaining wildlife, including the gazelle species, and cause less harm to wildlife. Most people look at the gazelles as a source of pride and inspiration. In recent years, people have also recognized that wildlife in general and gazelles in particular are part of their natural heritage with potential for economic growth and prosperity in the form of ecotourism, and thus they are keen to conserve wildlife.

At the national level there are also policies, strategies and plans that are supportive and relevant to biodiversity conservation that require serious consideration for sustainable and effective management of the nation's biodiversity. The bans imposed on hunting and charcoal production in ccordination with public awareness raising campaigns have played a strong role in the achievements made so far. The revival of wildlife in the country includes globally threatened species such as African Elephant (*Laxodonta africana*), African Wild Ass (*Equus africanus somaliensis*) and Eritrean Gazelle (*Eudorcas tilonura*).

The courageous interventions made are showing promising achievements in the revival of biodiversity in general and wildlife in particular. In order to create a conducive environment for the revival of biodiversity, the establishment of protected areas has become a national priority. However, it is important to note that, due to the existing multiple threats combined with persistent drought, there is still concern for the future of wildlife in general and for the three species of gazelle in particular.

Limitation of the study

The most pressing limitation of the study was finance. Due to the constraints of fund, the number of field days was limited to five and only two sample sites were surveyed in the inland (western lowland) study area. In addition, the author had to cover partial of his fieldwork and the entire data analyses and thesis write-up expenses from his own pocket. The other constraint was genetic analysis, although attempts were made to assess the genetic relationships (Phylogeography) of the gazelles that exist in different parts of the country and ten samples

from the three sites sample sites (coastal area, the island and western lowlands) were collected. All the samples were shipped to Milan for analysis but without success due to some technical problems.

Conclusion

This study of the three indigenous species of gazelles in Eritrea revealed that each of the three gazelle species occurred in an immense area with putatively viable populations despite that fact remained under threat. The identified threats are likely to have a crucial role in conservation planning and management of wildlife. The study also examine that promising opportunities exist for the long-term persistence of the three globally threatened species of gazelle in the face of natural and human-induced threats. This is because of the fact that the people and government of Eritrea are committed to conserving the remaining wildlife that has survived in the country, and to causing less harm to the wildlife. Most people look at the gazelles as sources of pride and inspiration. In recent years, people have also recognized that wildlife in general and gazelles in particular are our natural heritage with potential for economic growth and prosperity in the form of ecotourism.

The ban on hunting and charcoal production, as well as the campaign of awareness raising, has played a strong role in the achievements made so far. However, since most of these gazelles occur in areas which are not legally protected, and because of the prevailing persistent drought in the country, there is still fear for the future of wildlife in general and the three species of gazelles in particular. Therefore, developing appropriate conservation strategy and establishment of protected areas are fundamental if these charismatic and resilient gazelles are to thrive in Eritrea.

All in all the findings of the study is expected to fill a gap of knowledge on distribution, abundance, threats and conservation status of the three gazelle species in the country and in turn to have a substantial part in the development of appropriate conservation strategies for the gazelles and wildlife in general.

Recommendation

Based on the findings of the study, this section presents some of strategies and actions that are needed to overcome the existing challenges and threats to wildlife conservation and management in general, and the three gazelles in particular. Hence, the following recommendations are put forward:

- With full participation of all concerned bodies, protected areas need to be established in the potential habitat of the gazelles. Priority should be given to areas that face serious human-wildlife conflict, for instance the Monsura-Duluk area, Dige, Kerkebet and Golij (Gash Barka), because in those areas expansion of agriculture is a common phenomenon.
- The type of protected area preferably needs to be IUCN category VI because such protected areas could address the conflicts that may arise between pastoralists/agriculturalists and the conservation of gazelles.
- The existing *defacto* protected areas need to be reinforced with necessary management capacity.
- Effective censuses of the gazelles need to be undertaken throughout the range of the respective species in order to estimate their populations in the country. The findings will play a great role in updating both the national database and the IUCN Species Survival Commission African Antelope Database.
- The ongoing endeavours on awareness raising are showing promising results and need to be intensified to share the indigenous conservation ethics of the Afar people with other parts of the country.
- In order to measure the genetic relationships of gazelles in different areas, a robust genetic analysis is of paramount importance.
- Regional study of the species is also needed to examine whether there is gene flow between the respective populations of gazelles that exist in Eritrea, Ethiopia and Sudan.
- Detailed study is paramountly important on the population of the gazelles that exist in northern part of the country in order to substantiate the data collected through questionnaire and eventually evaluate the existing situation of the gazelles.
- To address and mitigate the effects of climate change and biodiversity loss, the ongoing greening campaign needs to be intensified giving emphasis on afforestation and establishment of protected areas in a way that aligns with the agro-ecology of the area.
- The expansion of *Prosopis* species particularly in western low land is seriously threatening the existence of the gazelles because it is encroaching the wildlife habitat at an alarming rate. Therefore, urgent control mechanism need to be in place in order to tackle the threat. In addition, action in habitat enrichment also paramountly important to address the existing habitat degradation.

- The capacity of the local institutions that deal with wildlife conservation and management needs to be enhanced, in order to have effective and efficient management skills and facilities.
- A road map on the conservation of the gazelles needs to be prepared and it should be aligned with the IUCN SSC 2020-2029 conservation strategy.
- The agricultural pioneer front is a source of potential conflict within communities. The creation of Pastoral Reserves alongside Wildlife areas predominantly in western lowland could partly mitigate latent conflicts by developing spaces reserved for livestock.

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Courses and Seminars

During my stay in the university of Pavia, I have received specific training at the Museo di Storia Naturale di Milano for ten days in the following subjects:

1. Ecological transects: theory (experimental design; how to choose representative transects in accordance with the study aims) and practice (use of GPS and rangefinder in a field situation).

2. Geo-referenced data analysis techniques in the QGIS environment (an introduction to QGIS software and how to find useful geographic resources in the web)

3. Zoological samples (bones, tissues, fecal samples) for anatomical and genetic study: proper collection, preparation and preservation (with special reference to artiodactyls)

4. Use of genetic data in phylogeographic and taxonomic studies. A theoretical introduction to genetic analysis techniques

5. Free and accessible bibliographic resources on the web (Google Scholar, Research Gate, Academia and other) and how to prepare a good reference list.

6. How to write a scientific article: theory and practical tips.

As a whole, the training course requested 56 hours lessons at the Museum and 12 hours field practice. In addition during the data collection process in 2020, I received practical training for two weeks by Prof Mauro Fasola during data collection process. The training included; experimental design; how to choose representative transects in accordance with the study aim and how to conduct road strip counts method.

During data analyses, I learned GIS techniques from the GIS expert working in Ministry of land and Environment of the state of Eritrea for three months in 2022. The training included introduction to GIS (Arc view 3.3 software and GIS 10.5 Software. Furthermore, I took training on intermediate GIS (Advance GIS) using the above software.

Meetings

I have attended a meeting of regional analysis of the national reports of Convention of Migratory species held on Bonn, Germany, December 2019 and in February 2020, I was participated as representative of the country on 13th meeting of the conference of the parties of Convention of Migratory species, held in Gandhinagar from 15-22.

After February 2020, due to the COVID 19 restrictions, travelling abroad was not possible. However, during 2020-2023, I had an opportunity to attend different virtual international meetings related to wildlife conservation and development. These include, three times in high-level, multi- party discussions: in 2020, there were two meetings, which took three, and four hours respectively; in 2021 one meeting conducted for four hours. The agenda in each instance was Human-Wildlife Conflict organized by Elephant Protection Initiatives (EPI), in 2020, 2021 Zoom, and email-based discussions with group in the School of Biological Sciences at Southern Illinois University Carbondale (USA). The discussion was mainly on the findings of collaborative research subsequently was published in a peer-reviewed journal. Furthermore, the discussion was also included on the design of fieldwork for the acquisition of Soemmerring's gazelle samples for a genomic study in Eritrea. In 2021 and 2022 I attended two preparatory meeting for conference of parties (CoP) 19 of the Convention on International Trade for Endangered Species (CITES), event meeting African Elephant Coalition (AEC), I also participated in three meetings on Biodiversity and Protected Areas Management Program (BIOPAMA). In 2022 I attended in preparatory meeting of CoP 15 for Convention on Biodiversity Diversity (CBD). Finally, on June 2023, I have attended on Eastern and southern Africa regional virtual meeting on the status of protected and conserved areas report preparation.

Publications

- **Hagos F.,** Yemane T., Ibrahim K., Marco M. and Roberto S. 2023. Combined Effects of Clime, Vegetation, Human-Related Land Use, and Livestock on the Distribution of the Three Indigenous Species of Gazelle in Eritrea. *Animals* 2023
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- December 2020: Ibrahim, K. M., Williams, P. C., Olson, A., Torounsky, R., Naser, E., **Hagos F. Ghebremariam**, & Masri, M. A. (2020). Genetic variation in morphologically divergent mainland and island populations of Soemmerring's gazelles (Nanger soemmerringii). Mammal Research, 65(2), 403-412.
- On December 2020: **Hagos F**., & Michael Madl Apis (Micrapis) florea Fabricius, 1787 (Hymenoptera: Apidae) discovered in Eritrea.. Zeitschrift der Arbeitsgemeinschaft Österreichischer Entomologen 72: 109-112 Wien, Dezember 2020 ISSN 0375-5223
- **Hagos Futsum**. J. Githaiga, J. Kanya (2019). Population distribution, genetics and conservation of African wild ass (***Equus africanus somaliensis***). Published by Lambert Academic Publishing, Germany.
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Biography

Futsum Hagos Gebremariam was born 1972 in Asmara, Eritrea. His primary and secondary school accomplished in Asmara. Soon after the independence 1992, he completed his certificate study in general Agriculture and joined Ministry of Agriculture worked as extension agent. After two years, 1994 he got scholarship and went to Tanzania, College of African Wildlife Management (Mweka), and graduated 1996 with Diploma in Wildlife Management.

From 1997-2000 worked in the Ministry of Agriculture, Northern Red Sea Region as head of the Wildlife Conservation and development. In September 2000, he joined Asmara University, and graduated in 2004 with BSc degree in Land Resources and Environment study.

From 2004 up to 2013, he worked in the head quarter of Ministry of Agriculture as National protected Areas coordinator. In September 2013 pursued his postgraduate study in the University of Nairobi (Kenya) and graduated in 2015 with MSc degree in Conservation of Biology.

From 2015-2021, he worked as Director of wildlife conservation and development in the Forestry and Wildlife Authority. Since 2021 in line with the PhD study, he worked in Hamelmalo Agricultural College as par- time lecturer.

Futsum Hagos is happily married with Mrs Helen GebreHiwet and he is a father of two daughters and one son.

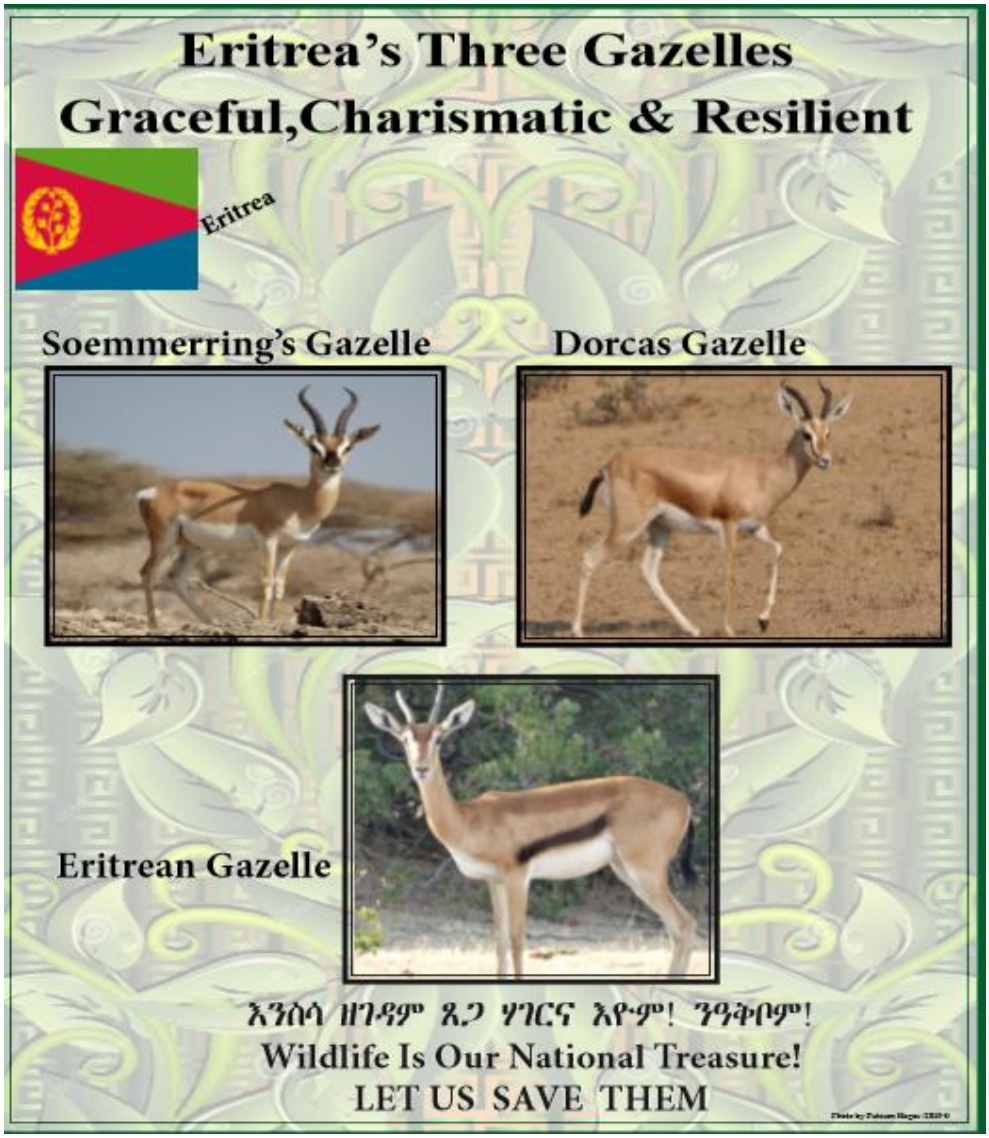
Appendix I. Questionnaire, the study of the three gazelles species occurrence in the country

Zoba (Region)..............................Subzoba............................Specific location........................
Date----------------------   Name of the data collector...

S/N	Observed species	Number	Northing	Easting	Habitat	Date	Status of occurrence

Occurrence articulated **as:**
Rare - few occasionally species detection (species observation is hardly ever),
Not frequent- for sporadic species detection, (observation is not common) and
Frequent- stands for common (regular) species**.**

Poster attached with the questionnaire to aid for species identification



Appendix II. Date sheet for situation assessment of the Three Species of Gazelles.

Zoba (Region) _____ Sub Zoba _____ GPS Reading _____
Date_____ starting Time_____ End_____
Data collector _____

Respondent, Age grade (range) _____

Group size of respondent _____

1. Your job_____

2. Average duration (yrs.) of attachment with area (sub zoba) _____

3, what type of wildlife are available in your area; _____

4, do you see gazelles? Yes [ ] No [ ]

4.1 Which species? Dorcas [ ] Eritrean [ ] or Soemmerring's [ ]

4.2 How often do you see them; (a) occasionally [ ] b) seasonally [ ] c) Frequently [ ]

4.3. When was your last time that you saw either species _____?

4.3 How big is their size; low (1-4) ____ fair (5-30) _____ good (>30) _____

5. How is their number; increasing [ ] decreasing [ ] No change [ ]

5.1. How do you evaluate their conservation status_____?

6. Is there any threat facing to the gazelles conservation Yes_____ No_____

6.1. If yes what sort of threat_____

6.1.1 Can you rate the severity of the threat by giving five to the highest and one to the least?

1_____

2._____

3._____

4._____

5._____

7. Where do you think their most favorite habitat
_____?

8. Where is their watering point's
_____?

8.1 Can you list the permanent watering points_____?

9 How is the pattern of relationship between local people and wildlife _____?

9.1 Is there any conflict reported between Local community and gazelles Yes [ ], No [ ]

9.1.1. If yes please describe_____

9.1.2 If there is conflict, what sort of measure/action do you take to address the conflict _____?

9.2 Is there any traditional believes or customs on wildlife/Naturals resources conservation Yes [ ], No [ ]

9.2.1 Is yes please describe _____

10. Any additional comment in relation to gazelle's conservation_____

Appendix III. Field data sheet

Study Area_____ Transect Name _____ Date_____

S/N	Way point	Easting	Northing	Alt (met)	Year	Month	Time	Observed Species	Dist. (M)	No	Sex	Age	Habitat	Activity	Feed on	Note

Appendix IV. The number of subtransect for each transect and their average length
Site = segment of the original transect; Transect = original transect name; Region = area where transect were set; Length = length (in meters) of the transect segment used as site (see methods for details).

Site	Transect	Region	Length (m)
bp_1	Buri Peninsula	coastal 1	9741
bp_2		coastal 1	9733
bp_3		coastal 1	9734
bp_4		coastal 1	9733
bp_5		coastal 1	9737
bp_6		coastal 1	9740
bp_7		coastal 1	9725
bp_8		coastal 1	9723
bp_9		coastal 1	9740
bp_10		coastal 1	9727
gb_1	Garsa Bededa	coastal 2	8579
gb_2		coastal 2	8577
gm_1	Garsa Marsafatuma	coastal 2	9724
gm_2		coastal 2	9724
m_1	Morah	coastal 2	7240
m_2		coastal 2	7240
m_3		coastal 2	7241
m_4		coastal 2	7228
ma_1	Marsafatuma Adayto	coastal 2	7306
ma_2		coastal 2	7307
ma_3		coastal 2	7307
k_1	Kerbebet	mainland 1	9074
k_2		mainland 1	9074
k_3		mainland 1	9061
k_4		mainland 1	9068
k_5		mainland 1	8992
k_6		mainland 1	9067
md_1	Monsura-Duluk	mainland 2	9563
md_2		mainland 2	9549
md_3		mainland 2	9553
md_4		mainland 2	9568

Appendix V. Detection histories for the three gazelles in the 31 sites.
Surveys: 1 = December 2020; 2 = January 2021; 3 = March 2021; 4 = May 2021; 5 = July 2021; 6 = September 2021. Numbers represent raw counts.

	Species																	
	Gazella dorcas						*Nanger soemmerringii*						*Eudorcas tilanura*					
surveys / *sites*	***1***	***2***	***3***	***4***	***5***	***6***	***1***	***2***	***3***	***4***	***5***	***6***	***1***	***2***	***3***	***4***	***5***	***6***
bp_1	0	2	0	2	0	4	23	0	33	0	21	0	0	0	0	0	0	0
bp_2	10	3	4	7	8	5	48	42	31	38	27	50	0	0	0	0	0	0
bp_3	3	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0
bp_4	7	4	3	3	0	3	15	10	12	18	18	21	0	0	0	0	0	0
bp_5	0	0	0	0	2	0	5	3	0	0	0	0	0	0	0	0	0	0
bp_6	2	2	1	1	0	3	17	6	11	7	14	11	0	0	0	0	0	0
bp_7	5	1	4	3	0	2	36	21	30	10	0	33	0	0	0	0	0	0
bp_8	0	2	2	4	4	6	4	16	16	12	11	27	0	0	0	0	0	0
bp_9	3	3	3	0	0	0	22	17	18	12	12	0	0	0	0	0	0	0
bp_10	3	0	3	1	2	5	4	8	23	8	15	27	0	0	0	0	0	0
gb_1	22	9	9	1	2	3	42	42	17	17	17	25	0	0	0	0	0	0
gb_2	1	0	0	13	0	5	6	0	16	4	0	0	0	0	0	0	0	0
gm_1	8	11	8	9	7	4	22	31	29	44	0	21	0	0	0	0	0	0
gm_2	11	8	5	4	3	3	12	9	27	14	28	25	0	0	0	0	0	0
k_1	8	2	1	3	2	6	16	0	0	0	0	15	3	0	0	0	0	4
k_2	0	4	7	4	4	0	0	4	17	14	0	0	4	0	0	0	5	5
k_3	1	4	0	0	3	4	0	0	0	0	0	0	0	0	0	1	0	4
k_4	0	0	5	7	0	3	0	0	0	11	0	12	4	2	0	0	2	0
k_5	4	11	9	4	11	10	44	16	18	29	39	7	9	0	7	4	6	8
k_6	3	5	6	5	4	6	8	11	25	27	24	19	3	0	4	0	5	11
m_1	3	3	5	1	4	3	14	16	0	0	0	15	0	0	0	0	0	0
m_2	5	3	0	5	2	4	0	0	23	0	10	0	0	0	0	0	0	0
m_3	1	0	2	0	0	5	17	4	0	0	0	17	0	0	0	0	0	0
m_4	9	5	4	8	1	5	30	14	7	17	15	0	0	0	0	0	0	0
ma_1	5	6	3	2	3	4	12	0	15	15	17	13	0	0	0	0	0	0
ma_2	2	2	5	5	3	13	13	15	29	30	15	18	0	0	0	0	0	0
ma_3	7	6	0	3	6	2	15	9	11	10	20	15	0	0	0	0	0	0
md_1	5	17	13	6	9	9	19	29	30	18	15	0	7	8	6	10	9	9
md_2	8	2	3	4	0	0	25	15	16	25	16	24	0	2	5	5	5	11
md_3	6	9	9	6	7	8	28	13	41	19	29	14	20	7	0	9	9	10

Appendix VI. List of vegetation identified in the mainland study area

- List of Trees and Shrubs

S.N	Species Name	Family	Growth Form
1.	*Abutulionbidentatum*	Malvaceae	Shrub
2.	*Acacia asak*	Fabaceae	Shrub
3.	*Acacia mellifera*	Fabaceae	Shrub
4.	*Acacia nilotica*	Fabaceae	Tree
5.	*Acacia oerfota*	Fabaceae	Shrub
6.	*Acacia Senegal*	Fabaceae	Shrub
7.	*Acacia tortilis*	Fabaceae	Shrub/tree
8.	*Aervajavanica*	Amaranthaceae	Shrub
9.	*Aeschynomenabyssinica*	Fabaceae	Shrub
10.	*Balanitesaegyptiaca*	Balanitaceae	Tree
11.	*Bosciasenegalensis*	Capparidaceae	Shrub
12.	Caddabalongifolia	Capparidaceae	Shrub
13.	*Cadabarotundifolia*	Capparidaceae	Shrub
14.	*Calotropispocera*	Asclepiadaceae	Shrub
15.	*Capparis decidua*	Capparidaceae	Tree
16.	*Carallumaacutangula*	Asclepiadaceae	Succulent
17.	*Chrozophoraoblongifolia*	Euphorbiaceae	Shrub
18.	*Cissusquadrangularis*	Vitaceae	Climber
19.	Combretumaculeatum	Combretaceae	Shrub/ tree
20.	*Commiphora Africana*	Burseraceae	Shrub
21.	*Commiphoraerythraea*	Burseraceae	Shrub
22.	Cordiasinensis	Boraginaceae	Tree
23.	*Delonixelata*	Fabaceae	Tree
24.	Dodonaeaangustifolia	Sapindaceae	Shrub/small tree
25.	*Doberaglabra*	Salvadoraceae	Tree
26.	*Ecoboliumviride*	Acanthaceae	Shrub
27.	*Fagoniaindica*	Zygophyllaceae	Shrub
28.	*Faidherbiaalbida*	Fabaceae	Tree
29.	*Grewiatenax*	Tilliaceae	Shrub
30.	*Grewiavillosa*	Tilliaceae	Shrub
31.	*Hibicuscannabinus*	Malvaceae	Shrub
32.	*Hibicuscrasinervosus*	Malvaceae	Shrub
33.	*Hyphaenethebaica*	Arecaceae	Tree
34.	*Indigoferaspicata*	Fabaceae	Shrub
35.	*Justucia sp.*	Acanthaceae	Shrub
36.	*Lagenariasiceraria*	Cucurbitaceae	Climber

S.N	Species Name	Family	Growth Form
37.	*Lawsoniainermis*	Lythraceae	Shrub
38.	*Leptadeniaarborea*	Asclepiadaceae	Climber
39.	*Leptadeniapyrotechnica*	Asclepiadaceae	Climber
40.	*Maythenussenegalensis*	Celastraceae	Shrub/ small tree
41.	*Momordicabalsamina*	Cucurbitaceae	Climber
42.	*Momordicacymbalria*	Cucurbitaceae	Climber
43.	*Ocimum sp.*	Lamiaceae	Shrub
44.	*Pentatropisnivalis*	Asclepiadaceae	Climber
45.	*Premnaresinosa*	Verbanaceae	Shrub
46.	*Prosopisjuliflora*	Fabaceae	Shrub
47.	*Racinuscomminus*	Euphorbiaceae	Shrub
48.	*Salvadorapercica*	Salvadoraceae	Shrub
49.	*Sennaalexanderina*	Fabaceae	Shrub
50.	*Sennaitalica*	Fabaceae	Shrub
51.	*Sesbaniapachycarpa*	Fabaceae	Shrub
52.	*Solanumforskaollii*	Solanaceae	Shrub
53.	*Solanumincanum*	Solanaceae	Shrub
54.	*Tamarindusindica*	Caesalpinioideae	Tree
55.	*Tamarixaphylla*	Tamaricaceae	Tree
56.	*Tamarixnilotica*	Tamaricaceae	Tree
57.	*Tephrosiapentaphylla*	Fabaceae	Shrub
58.	*Vignaunguiculata*	Fabaceae	Climber
59.	*Withaniasomnifera*	Solanaceae	Tree
60.	*Ziziphusspina-christi*	Rhamnaceae	Tree

❖ List of Herbs and Grasses

S.N	Species Name	Familiy	Growth Form
1	*Amaranthuscaudatus*	Amaranthaceae	Herb
2	*Andropogongayanus*	Poaceae	Grass
3	*Aristidaadscensionis*	Poaceae	Grass
4	*Aristidamutabilis*	Poaceae	Grass
5	*Boerhaviacoccinea*	Nyctaginaceae	Herb
6	*Commelinalatifolia*	Commelinaceae	Herb
7	*Commicurpushelenae*	Nyctaginaceae	Herb
8	*Corchorusolitoius*	Tilliaceae	Herb
9	*Crotolariaimpressa*	Fabaceae	Herb

S.N	Species Name	Familiy	Growth Form
10	*Cuscutacampestris*	Convolvulaceae	Herb
11	*Cyprusrotundus*	Cyperaceae	Herb
12	*Dactylocteniumaegyptium*	Poaceae	Grass
13	*Daturainnoxia*	Solanaceae	Herb
14	*Daturametel*	Solanaceae	Herb
15	*Dicanthiumannulatum*	Poaceae	Grass
16	*Digeramuricata*	Amaranthaceae	Herb
17	*Digitariaciliaris*	Poaceae	Grass
18	*Echinocloacolona*	Poaceae	Grass
19	*Eragrostiscilianensis*	Poaceae	Grass
20	*Eragrostistenella*	Poaceae	Grass
21	*Euphorbia hirta*	Euphorbiaceae	Herb
22	*Heliotropium sp.*	Boraginaceae	Herb
23	*Indigoferahochstetteri*	Fabaceae	Herb
24	*Ipomeablepharosepala*	Convolvulaceae	Herb
25	*Leucusmartinicensis*	Lamiaceae	Herb
26	*Loranthus acacia*	Loranthaceae	Shrub
27	*Melanocenchrisabyssinica*	Poaceae	Grass
28	*Merremiaaegyptia*	Convolvulaceae	Herb
29	*Monsoniasenegalensis*	Geraniaceae	Herb
30	*Oldenlandiacorymbosa*	Rubiaceae	Herb
31	*Pancratiumtenuifolium*	Amaryllidaceae	Herb
32	*Panicumdeustum*	Poaceae	Grass
33	*Panicumhochstetteri*	Poaceae	Grass
34	*Panicumlaetum*	Poaceae	Grass
35	*Paspalidiumdesertorum*	Poaceae	Grass
36	*Peristrophepaniculata*	Acanthaceae	Herb
37	*Plucariacrispi*	Asteraceae	Herb
38	*Polygala rupicola*	Polygalaceae	Herb
39	*Pupalialappacea*	Amaranthaceae	Herb
40	*Schoenefeldiagracilis*	Poaceae	Grass
41	*Sesamumlatifolium*	Pedaliaceae	Herb
42	*Sesuviumhydaspicum*	Aizoaceae	Herb
43	*Setariaverticillata*	Poaceae	Grass
44	*Sorghum arundinaceum*	Poaceae	Grass
45	*Stipagrostishirtigluma*	Poaceae	Grass
46	*Tetrapogontenellus*	Poaceae	Grass
48	*Tragus berteronianus*	Poaceae	Grass
49	*Trianthemaportulacastrum*	Aizoaceae	Herb

S.N	Species Name	Familiy	Growth Form
50	*Tribulusteristeris*	Zygophyllaceae	Herb
51	*Vernoniasp.*	Asteraceae	Herb

Appendix VII. List of vegetation identified in the coastal and island study areas

- ❖ Trees and shrubs

S.N	Species	Family	Growth form
1	*Acacia asak*	Mimosoideae	Tree
2	*Acacia ehrenbergiana*	Mimosoideae	Shrub
3	*Acaia laeta*	Mimosoideae	Shrub
4	*Acacia mellifera*	Mimosoideae	Shrub
5	*Acacia oerfota*	Mimosoideae	Shrub
6	*Acacia tortilis*	Mimosoideae	Tree
7	*Avicennia marina*	Verbenaceae	Shrub
8	*Balanites aegyptiaca*	Balanitaceae	Tree
9	*Cadaba farinose*	Capparidaceae	Shrub
10	*Cadaba glandula*	Capparidaceae	Shrub
11	*Cadaba longifolia*	Capparidaceae	Shrub
12	*Cadaba rotundifolia*	Capparidaceae	Shrub
13	*Calotropis procera*	Asclepiadacea	Shrub
14	*Capparis tomentosa*	Capparidaceae	Shrub
15	*Combretum aculeatum*	Combretaceae	Shrub
16	*Commiphora africana*	Burseraceae	shrub
17	*Commiphora schemperi*	Combretaceae	shrub
18	*Commiphora erythraea*	Burseraceae	Tree
19	*Cordia africana*	Boraginaceae	Tree
20	*Delonix elata*	Caesalpinioideae	Tree
21	*Dichrostachys cinerea*	Mimosoideae	Shrub
22	*Dobera glabra*	Salvadoraceae	Tree
23	*Grewia tenax*	Tiliaceae	Shrub
24	*Hyphaene thebaica*	Palmae	Tree
25	*Lantana camara*	Verbenaceae	Shrub
26	*Leptadenia pyrotechnica*	Asclepiadaceae	Shrub
27	*Maerua crassifolia*	Capparidaceae	Shrub
28	*Maerua oblongifolia*	Capparidaceae	Shrub
29	*Premna resinosa*	Verbenaceae	Shrub
30	*Rhizophora mucronata*	Rhizophoraceae	Shrub
31	*Solanum cordatum*	Solanaceae	Shrub
32	*Solanuim schimperi*	Solanaceae	Shrub
33	*Sterculia Africana*	Sterculiaceae	Tree
34	*Suaeda monoica*	Chenopodiaceae	Shrub
35	*Tamarix aphylla*	Tamaricaceae	Tree
36	*Ziziphus spina-christi*	Rhamnaceae	Tree
37	*Aerva javanica*	Amaranthaceae	Herb
38	*Commelina latifolia*	Commelinaceae	Herb
39	*Crotalaria persica*	Leguminosae	Herb
40	*Cynodon dactylon*	Gramineae	Grass
41	*Eragrostis ciliaris*	Gramineae	Grass
42	*Euphorbia aegyptica*	Euphorbiaceae	Herb
43	*Euphorbia granulata*	Euphorbiaceae	Herb

S.N	Species	Family	Growth form
44	*Fagonia ovalifolia*	Zygophyllaceae	Herb
45	*Indigofera spinosa*	Leguminosae	Herb
46	*Lasiarus hirsutus*	Gramineae	Grass
47	*Tephrosia nubica*	Leguminosae	Herb
48	*Tribulus terrestris*	Zygophyllaceae	Herb
49	*Aerva javanica*	Amaranthaceae	Herb
50	*Commelina latifolia*	Commelinaceae	Herb
51	*Bromusm adritensis*	Poaceae	Grass
52	*Cenchrus ciliaris*	Poaceae	Grass
53	*Cenchrus setigerus*	Poaceae	Grass
54	*Chloris virgata*	Poaceae	Grass
55	*Dactyloctenium aegyptium*	Poaceae	Grass
56	*Dicanthium annulatum*	Poaceae	Grass
57	*Digitaria ciliaris*	Poaceae	Grass
58	*Echinocloa colona*	Poaceae	Grass
59	*Eragrostis ciliaris*	Poaceae	Grass
60	*Eragrostis cilianensis*	Poaceae	Grass
61	*Eragrostis tenella*	Poaceae	Grass
62	*Melanocenchris abysssinica*	Poaceae	Grass
63	*Panicum deustum*	Poaceae	Grass
64	*Panicum hochstetteri*	Poaceae	Grass
65	*Panicum laetum*	Poaceae	Grass
66	*Paspalidium desertorum*	Poaceae	Grass
67	*Schoenefelde agracilis*	Poaceae	Grass
68	*Setaria verticillata*	Poaceae	Grass
69	*Sorghum arundinaceum*	Poaceae	Grass
70	*Stipagrost hirtigluma*	Poaceae	Grass
71	*Tetrapogon tenellus*	Poaceae	Grass
72	*Tragus berteronianus*	Poaceae	Grass
73	*Bromusm adritensis*	Poaceae	Grass
74	*Cenchrus ciliaris*	Poaceae	Grass
75	*Cenchrus setigerus*	Poaceae	Grass
76	*Chloris virgata*	Poaceae	Grass
77	*Dactyloctenium aegyptium*	Poaceae	Grass

Appendix VIII. Annual rainfall of the coastal and mainland study areas

Yr	Mean C&I (mm/yr)	SD	Sum	Min	Max	Mean ML mm/yr	SD	Sum	Min	Max
1996	12.8	9.4	38.33	3.92	22.67	25.08	3.54	50.17	22.58	27.58
1997	22.62	18.	67.85	2.48	37.38	18.21	7.49	54.64	10.48	25.42
1998	10.05	4.3	30.15	5.11	13.11	26.58	13.1	79.74	16.82	41.47
1999	9.75	6.5	19.50	5.17	14.33	29.76	13.7	89.29	14.02	39.23
2000	10.11	3.2	20.2	7.88	12.34	18.99	8.28	56.98	10.66	27.23
2001	2.78	3.4	5.6	.40	5.17	24.06	8.85	72.18	14.94	32.63
2002	4.65	1.9	9.29	3.32	5.98	16.75	11.2	50.26	4.87	27.11
2003	4.16	0.5	8.33	3.84	4.48	28.48	5.28	85.43	22.53	32.63
2004	5.68	1.4	11.35	4.70	6.65	10.51	2.90	31.54	8.21	13.77
2005	18.38	4.5	36.76	15.3	21.58	26.23	20.9	104.9	7.60	55.58
2006	8.17	DF	8.17	8.17	8.17	26.12	28.7	52.23	5.86	46.38
2007	4.50	1.53	8.99	3.42	5.58	30.98	6.45	92.95	23.63	35.71
2008	11.08	.94	33.25	10.5	12.17	12.53	5.33	37.58	6.38	15.83
2009	4.94	5.67	14.83	.50	11.33	13.94	6.76	41.83	6.14	17.93
2010	4.88	.88	9.75	4.25	5.50	33.42	13.4	100.3	18.51	44.45
2011	8.10	.80	16.21	7.54	8.67	18.72	7.84	56.17	10.71	26.37
2012	1.67		1.67	1.67	1.67	20.74	14.9	62.22	3.53	30.13
2013	8.40	7.96	25.21	1.08	16.88	19.05	12.6	57.16	8.93	33.13
2014	8.42	.94	16.83	7.75	9.08	26.15	6.99	78.45	18.69	32.54
2015	10.45	-	10.45	10.45	10.45	10.51	3.95	31.53	6.28	14.08
2016	10.49	9.85	31.48	3.17	21.69	17.96	6.05	53.88	13.30	24.79
2017	7.71	1.12	23.13	6.42	8.38	8.71	3.33	26.12	5.03	11.50

2018	8.86	3.05	26.58	6.00	12.08	26.77	2.55	80.31	24.29	29.38
2019	7.99	2.63	23.98	5.00	9.92	19.60	6.68	58.81	12.98	26.34
2020	12.39	5.50	37.17	7.00	18.00	14.35	7.31	40.58	8.43	17.69
2021	9.90	4.42	29.70	4.92	13.33	25.21	29.9	53.19	6.69	47.41

Note: C&I: Coastal and Island, ML: Mainland SD: Standard deviation Max: Maximum Min: Minimum mm: millimeter Yr: Year

Appendix IX. The total observed Nmax. of species in the study areas.

Coastal Transect			Species											
			G. dorcas				*N. soemmerringii*				*E. tilanura*			
			Mean	Sum	Standard Error of Sum	Standard Deviation	Mean	Sum	Standard Error of Sum	Standard Deviation	Mean	Sum	Standard Error of Sum	Standard Deviation
	Buri	Nmax	5	48	7.57	2.39	26	238	38.07	12.69				
	Other costal	Nmax	10	107	17.05	5.14	26	283	33.53	10.11				
	Total	Nmax	7	155	21.57	4.71	26	521	49.34	11.03				
Mainland Transect			Species											
			G. dorcas				*N. soemmerringii*				*E. tilanura*			
			Mean	Sum	Standard Error of Sum	Standard Deviation	Mean	Sum	Standard Error of Sum	Standard Deviation	Mean	Sum	Standard Error of Sum	Standard Deviation
	Kerkebet	Nmax	7	43	5.67	2.32	23	116	28.78	12.87	6	37	7.50	3.06
	Monluk	Nmax	11	42	8.72	4.36	34	136	15.58	7.79	14	57	9.29	4.65
	Total	Nmax	9	85	11.08	3.50	28	252	35.24	11.75	9	94	17.27	5.46