UNIVERSITY OF NAIROBI

FACTORS AFFECTING POPULATION, NESTING HABITS, AND CONSERVATION OF GREY CROWNED CRANE (*BALEARICA REGULORAM,* BENNETT 1834) IN LAKE OL' BOLOSSAT BASIN, KENYA

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2022

DECLARATION

I, Stephen Wanyoike Wamiti, declare that this thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

This thesis is devoted to my wife Lucy Njoki and the adorable trio of Alex Wamiti, Owen Ndegwa and Ivana Wanjiru, and to all those who support cranes conservation work around the world.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEWA	African-Eurasian Migratory Waterbirds Agreement
ANOVA	Analysis of Variance
CCV	Cranes Conservation Volunteers
CGN	County Government of Nyandarua
CITES	Convention on International Trade in Endangered Species of Fauna and Flora
EAWLS	East African Wild Life Society
EMCA	Environment Management and Coordination Act
EWT	Endangered Wildlife Trust
GPS	Geographical Positioning System
ICF	International Crane Foundation
IUCN	International Union for Conservation of Nature and Natural Resources
ISSAP	International Single Species Action Plan
KWS	Kenya Wildlife Service
LULC	Land Use and Land Cover
MEMR	Ministry of Environment and Natural Resources
MEWNR	Ministry of Environment, Water and Natural Resources
NABU	Nature and Biodiversity Conservation Union (BirdLife Germany)
NEMA	National Environment Management Authority
UNDP	United Nations Development Programme
UNESCO	United Nations Education, Scientific and Cultural Organisation
USA	United States of America
USGS	United States Geological Survey

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ABSTRACT

Birds are significant drivers of ecosystem processes and are therefore sensitive to natural and human-induced changes. Cranes are a highly threatened bird family and Grey Crowned Crane *(Balearica regulorum)* is listed as Endangered primarily because of human-related activities, such as habitat modifications. This study investigated the population characteristics, nesting habits, seasonal variation in abundance and biomass of potential food, effects of Land Use and Land Cover changes, and threats affecting this species in Lake Ol' Bolossat basin, Nyandarua County, Kenya. Five comprehensive population surveys were conducted during the study period (2017-2020) showing that the basin supported a highly variable population, ranging from 521 and 1,115 birds corresponding to 15% and 5% of the species' national and global population respectively. The resident population present year-round was estimated at 250-350 cranes. The population comprised of 11.65% young birds which is a good sign of a healthy population. Group sizes ranged from 1-332 cranes with a mean of 28.2±3.24. Marshes and wheat fields were the most utilised habitats throughout the year. Factors influencing nest-site selection were investigated from a sample of 30 nests. Four out of the 12 measured factors were considered in Generalized Mixed Linear Model to determine if they had an influence in nest-site selection. Except for grazing intensity, all other three factors had a significant influence ($p < 0.05$): water depth (50cm), offshore distance (100m), and vegetation height (60-90cm). A minimum of 103 territorial pairs were recorded in the lake compared to 20 pairs in upland wetlands. Thirty-one clutches (mean 2.23 eggs; range 1-4 eggs) were described. Except for water surface temperature that didn't show a significant seasonal variation ($t = 1.89$, $p > 0.05$), all the other parameters were significant. This variation in water parameters significantly affected abundance of macro-invertebrates ($F = 4.161$; df = 5, 94; $p < 0.05$). Crane's breeding coincided with the wet season when food was abundant. Major Land Use and Land Cover changes were observed between 2010 and 2020 including an increase of 83% of open water causing a significant decrease of 73% marshes. During the same decade, native grasslands cover had a >50% decrease probably due to cultivation which increased by 64%. Loss of marshes and grasslands has potential negative impacts on the crane's population due to loss of foraging and breeding habitats. A total of 102 respondents were purposively selected to rank 16 predetermined threats. The most severe threats were those affecting cranes breeding activities by reducing the quality of nest-sites, reduced chicks' survival, and an increased loss of eggs and chicks. These threats must be addressed to boost reproduction in addition to: zonation of breeding sites, implementation of gazettement notice and the management plan, allocation of funds in support of conservation and community development, law enforcement, control and management of invasive alien species, annual population monitoring, and consideration of listing the lake as a wetland of international importance and annexing it to the Aberdares UNESCO World Heritage Site.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Gaston (2010) defines biological diversity as life's variety in all of its many appearances including plants, animals, and microorganisms found on Earth. Conservationists, biologists and scientists around the world have tirelessly lobbied for protection and preservation of the earth's biodiversity, actions that led to the birth of conservation biology as a discipline. This mission-driven discipline emerged in mid-1980s and ccomprises both pure and applied sciences, and, according to Meine (2010), conservation biology is concerned about studying, providing protection and ensuring preservation of biological diversity at all levels at which biological diversity manifests itself. It is a discipline that applies scientific knowledge to address biodiversity conservation problems and challenges facing species, communities and ecosystems, most of which are under threat from human activities or environmental variability. Conservation on the other hand refers to the activities that are anticipated to create, develop or maintain a harmonious relationship between man and nature (Sandbrook, 2015).

Kenya is a country rich in animal species, majority of which have little published information (Bennun & Njoroge, 2001). Her biological diversity is critical to the national development agenda through derivation of ecological resources and services (MEWNR, 2015). Kenya's diversity is distributed in four major ecosystems (human-modified ecosystems, moist grasslands, and arid/semi-arid land, wetlands, and forests (NEMA & UNDP, 2009). Kenya is also bestowed with different and charming patchwork of diverse landscapes (MEWNR, 2015).

Kenya's commitment to environmental protection is enshrined in the Preamble of the new Constitution 2010, which recognizes the need for respect of the environment as a natural heritage (Articles 42 and 43 on Bill of Rights), which guarantees every citizen privileges comprising the right to a unpolluted environment (Kenya Law Reforms Commission, 2010). The citizens are also called to duty in Article 69(2) to actively participate in environmental and natural resources fortification. The Constitution is supported by an array of laws and policies governing the management, protection and conservation of our natural resources. These include: EMCA (1999), Water Act (2002), and Wildlife Conservation and Management Act (2013), together with policies on land, wildlife and wetlands.

Kenya has consented to a number of International Environmental Agreements related to biodiversity and environmental conservation. These include African Resolution on the Conservation of Nature and Natural Resources, 1968 (revised 2003), Convention on Wetlands of International Importance (1971), Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES; 1973), Convention on Biological Diversity (CBD; 1992), Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA; 1995), and International Convention of Blue Economy (2018). There are also a number of government institutions, such as Kenya Wildlife Service, National Museums of Kenya, and Kenya Water Towers Agency, where matters on biodiversity are addressed, including research, protection, conservation, management and reporting.

Western *et al.* (2015) pronounced that over 65% of Kenya's wildlife populations and a majority of her biodiversity are found in privately-owned human-modified landscapes. Examples include Kinangop Plateau, a site once considered to host the largest population of the Kenyan endemic, globally threatened, and grassland-dependent Sharpe's Longclaw (*Macronyx sharpei*) (Bennun & Njoroge, 2001). In their review of approaches to conservation of biodiversity in African National Parks, Muhumuza & Balkwill (2013) noted the need to put emphasis on the role of people in biodiversity conservation. In Kenya, certain weaknesses have been realized in legislations, and are being corrected. For example, the Forest Act (2016) have recognised the need to give local communities living adjacent to forests an opportunity to partake in managing forest resources through sustainable utilization.

The earliest threats to Kenya's natural resources can be heaved back to the start of the colonial times and arrival of modern weapons and new technology in the late 1800s (MEWNR, 2015). These threats include "pollution, human population increase alongside escalating poverty levels, poor land use practices, climate change agricultural expansion, inadequate involvement of local communities, weak management systems, overexploitation, habitat destruction, and spread of invasive species" (Convention on Biological Diversity, 2020).

Conservation efforts of the 15 extant species of cranes at the global level started in 1973 at the birth of International Crane Foundation (ICF) in Baraboo, Wisconsin, USA. Currently, ICF works in over 50 countries (including Kenya) to conserve cranes and their habitats by engaging people to resolve threats facing cranes and landscapes through provision of skills and self-realization, guidance and motivation. The Grey Crowned Crane is one of the Kenyan avifauna representing some of the species listed as threatened while Lake Ol' Bolossat is an example of a wetland facing eminent threats and where this crane species has been known to breed in the past (Gichuki, 2002). The species has also be reported from several other localities in Kenya such as Kitale (Gichuki, 1996), Rift Valley lakes, central Kenya and Nairobi area (Nasirwa & Owino, 2000), and Laikipia plains, Amboseli basin and Mt. Kenya region (Wamiti *et al.*, 2020).

1.2 Problem Statement

The Grey Crowned Crane population is reported as rapidly declining across its range, especially in Kenya and the eastern Africa region. Two major direct threats facing the species (and other cranes) are habitat loss and illegal trade. Habitat loss is in form of conversion of native grasslands and reclamation of wetlands for agriculture leading to loss of habitats (Austin *et al*., 2018a). The removal of individuals and eggs from the wild for illegal trade markets was cited as a serious threat affecting all the four resident crane species in Africa (Morrison *et al.*, 2007). This affects recruitment leading to severe population declines. Conservation efforts of the species are obstructed by a deficiency of basic understanding on its ecology including distribution and population size and density at specific sites recognized or assumed to be important for survival, besides determination of breeding densities and a description of breeding sites (Gichuki, 1993). Estimation of population size and demography have been reported as a pressing knowledge gap (Morrison, 2015). Lake Ol' Bolossat is a highly threatened wetland ecosystems and is home to bird species of international conservation concern (Wamiti *et al.*, 2009). Threats to this lake, waterbirds and habitats were poorly understood. Other reported knowledge gaps include breeding productivity, adult and juvenile survival, habitat requirements (e.g. characteristics of nesting-sites), movements, and an understanding of crane-human interactions (e.g. land use changes). Genetic mapping is listed as a medium priority knowledge gap since such studies have not been carried out or are few on the species (Morrison, 2015). Counting animals has benefits e.g. knowing the number of individuals, and their age composition, spatial-temporal distribution, and habitat needs is important in guiding conservation decisions (WWF, 2004). Desire to contribute to some of these knowledge gaps were the foundations of this study.

1.3 Justification of the Study

1.3.1 Grey Crowned Crane

Grey Crowned Crane, a wetland-grassland dependent species, is an indicator on the status and health of these habitats. As an omnivore species, cranes play crucial roles in ecosystem for instance energy flow, nutrient cycling and seed dispersal. It is enumerated as an Endangered species on the IUCN Red List of Threatened Species. It's East African population has been experiencing a long-term decline (BirdLife International, 2020a). It is also on Appendix II of

CITES (CITES, 2020) and Appendix I Category 3(c) of AEWA (Wetlands International, 2005). Further, the species is safeguarded in Kenya by the Wildlife Conservation and Management Act (2013). Wetlands and grasslands, its primary habitats, are highly threatened by human activities through cultivation, grazing and settlement. The effects of activities of human origin on the reproduction and survival of this species are not well understood across the species' range and at specific sites holding substantial population like Lake Ol' Bolossat basin. The local communities should find interest and take it as an individual and collective responsibility to conserve this species since it is their heritage in the landscape.

1.3.2 Lake Ol' Bolossat

Lake Ol' Bolossat is a little-known and Kenya's only lake in the central highlands, and a site where Grey Crowned Crane is known to occur and breed. Specific information has however been lacking on population size and density, an estimate and distribution of territorial pairs, as well as the distribution of suitable breeding and foraging habitats. The effects of human and livestock disturbances on the local crane population were unknown. This wetland is of regional and national importance. The lake contributes significantly to regional economies downstream as its water feeds River Ewaso Ngiro (North) along whose course are livestock production systems, wildlife conservation areas and tourism developments (Thenya, 2001).

1.3.3 National and International Significance

Links to National Planning Process: This study has an input on Kenya's Vision 2030 that emphasizes the importance of protection of sites of high biological diversity outside the protected areas system significantly contributing to local, regional and national economic development. This study also contributes to the aspirations of Nyandarua County Government's Integrated Development Plan that crave for knowledge to guide in sustainable utilisation and conservation of the lake's natural resources.

Links to Multilateral Environmental Agreements (MEAs): The identified knowledge gaps that this study is addressing are essential and a priority in AEWA's International Single Species Action Plan for the Conservation of the study species (Morrison, 2015). This study addressed Sustainable Development Goal No. 15 that calls for protection of life on land, including halting biodiversity loss through better management, conservation and restoration. The Grey Crowned Crane is a species listed by CITES, and hence this study builds on knowledge to inform decisions regarding the specie's information in this Convention. The findings too will be useful in annual country reporting to these and other MEAs such as Convention on Biological Diversity.

1.4 Research Questions

1. What are the characteristics of Grey Crowned Crane population in Lake Ol' Bolossat basin?
2. Which factors influence selection of a nesting site by Grey Crowned Crane in the study area?
3. Do seasons have an influence on abundance and biomass of potential cranes food items in the study area?
4. What are the impacts of land use changes and threats on Grey Crowned Cranes and their habits in the study area?

1.5 Research Objectives

1.5.1 Overall objective

The overall goal of this study was to determine the status of Grey Crowned Crane population and its habitats in Lake Ol' Bolossat basin.

1.5.2 Specific objectives

1. To determine the characteristics of Grey Crowned Crane population in Lake Ol' Bolossat basin.
2. To investigate the factors that influence nest-site selection and clutch characteristics of cranes in the study area.
3. To evaluate the seasonal variation in abundance and biomass of potential food items for the cranes in the study area.
4. To examine the impacts of land use changes and threats on cranes and their habitats in the study area.

1.6 Research Hypotheses

1. The Grey Crowned Crane population in Lake Ol' Bolossat basin is stable in size, structure and flocking behaviour.
2. The selection of a nest-site by the cranes in the study area is not influenced by environmental factors in the study area.
3. There are no seasonal differences in the abundance and biomass of potential food for the cranes in the study area.
4. There are no impacts of land use changes on cranes' habitats while threats are of uniform severity across the study area.

1.7 Conceptual Framework

The conceptual structure shown in Figure 1.1 represents the four main objectives of this study, the activities (including some methods) and results. These will contribute to an 'enabling environment' that is conducive to support a thriving population of Grey Crowned Crane in the study area. A feedback in the system is expected between these processes to help in identification of weaknesses and implementation of lessons learnt in to achieve overall goal.

Role played by individuals and organisations in this process is important. The participation of groups such as Cranes Conservation Volunteers, Nyahururu Bird Club, and Lake Ol' Bolossat Community Conservation Group should be encouraged. The residency status of their members means they are conversant with conservation challenges, and would thus identify the most appropriate approaches. Their work however requires the input of stakeholders in terms of capacity building, project design, reporting, and most important, provision of financial resources. Such stakeholders include: NABU, ICF/EWT Partnership, EAWLS and Nature Kenya. The support of the National Museums of Kenya in guiding research, and the County Government of Nyandarua, and National Government agencies such as Kenya Wildlife Service and National Environment Management Authority is critical in enforcement of laws and regulations, is essential.

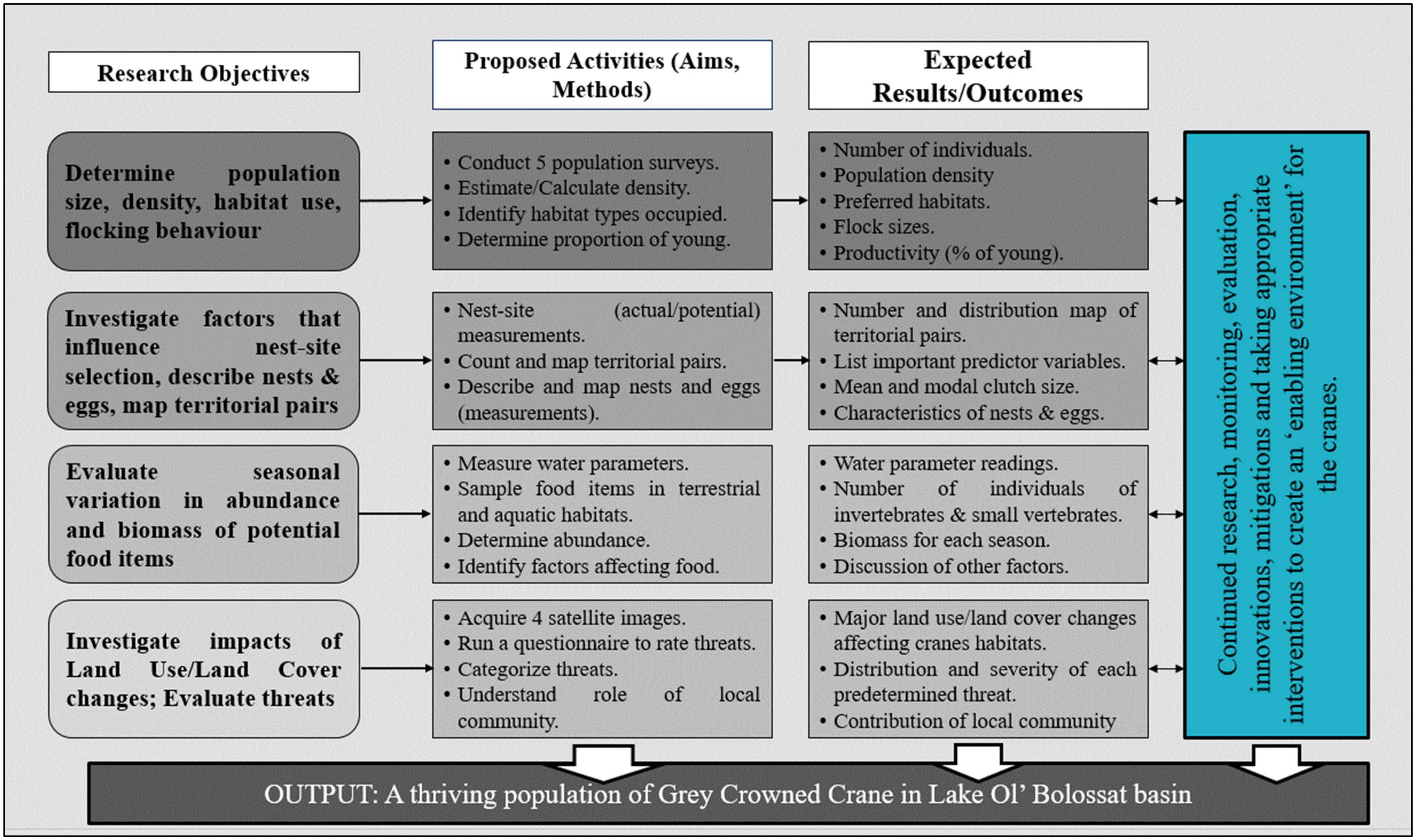

Figure 1.1: A conceptual framework showing the relationship and interactions of key components towards realising effective conservation and protection of Grey Crowned Cranes and their habitats in Lake Ol' Bolossat basin.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Role of wetlands in biodiversity conservation

The Ramsar Convention Secretariat (2013) considers wetlands as areas where water is the main factor governing the environment and the related plant and animal life thereof. Wetlands are among the most important and productive habitats all over world to both humans and wildlife species. Provision of breeding, drinking, feeding, resting, shelter and social interactions habitat for birds is the best known function of wetlands (Stewart, 2020). Wetlands also support spectacular variety of specialised wildlife e.g. Hippopotamus (*Hippopotamus amphibious*), and a variety of vertebrates, invertebrates, and a dearth of plants species that provide foraging niches and cover for wetland-dependent animals.

Despite their considerable contribution to Kenya's economic development in relation to livestock production, energy, fisheries and tourism (Convention on Biological Diversity, 2020), wetlands are among the utmost susceptible ecosystems due to climate modifications, human activities and transformations (MEWNR, 2015). Most wetlands face threats such as pollution, degradation of catchment areas, encroachment, and siltation from soil erosion. There are 170 species of birds in Kenya classified as waterbirds of which 8.8% (15 species) are listed as globally-threatened (BirdLife International, 2021). Examples comprise Black Crowned Crane (*Balearica pavonina,* VU), and non-waterbirds that are highly dependent on wetland's vegetation such as Papyrus Gonolek (*Laniarius mufumbiri,* NT) and Basra Reed Warbler (*Acrocephalus griseldis,* EN) (Bennun & Njoroge, 2001).

2.2 Conservation status of cranes

Archibald & Meine (2019) reviewed the global population status of the 15 extant species of cranes while BirdLife International (2020b) regularly evaluates their status on the IUCN Red

List of Threatened Species. Most species' populations are reported as declining and alteration of natural environments (forests, wetlands, and grasslands) to agricultural landscapes cited as a major driver causing stern population deteriorations for 11 of the 15 species (Austin *et al.*, 2018b).

2.3 Distribution and diversity of cranes (Gruidae)

Cranes are distributed across the world and are hence found in all regions of the world except Antarctica, and only marginally in the Neotropics (Table 2.1) (Beilfuss *et al*., 2009; Harris & Mirande, 2013). Information on distribution and population estimates is provided by Allan (1996), Archibald & Meine (1996) and Austin *et al.* (2018). East Asia has the highest species diversity (eight breeding) and a ninth, Eurasian Crane, is shared with Europe. Africa has four resident species (Blue, Wattled, Grey Crowned and Black Crowned), and two migrants (Eurasian and Demoiselle). North America has two species (Sandhill and Whooping) while Australia also has two (Brolga and Sarus), the latter being shared with Asia. Species in the temperate regions usually migrate over long distances while those in the tropics are more sedentary, although they may make seasonal movements related to food availability and breeding requirements.

Table 2.1: Global population, distribution and conservation status of the 15 extant species of family Gruidae (Cranes).

Sub-family		English name	Scientific name	Global population estimates and distribution	IUCN Status
Balearicinae	1.	Black Crowned Crane	*Balearica pavonina*	**28,000 - 47,000**; AF: ne, c, western	VU
	2.	Grey Crowned Crane	*Balearica regulorum*	**26,500 - 33,500**; AF: e and s Africa	EN
Gruinae	3.	Siberian Crane	*Leucogeranus leucogeranus*	**4,000**; EA: nw and e-c Siberia	CR
	4.	Sarus Crane	*Antigone antigone*	**5,000 - 10,000**; AS, AU: n India, se Asia, n Australia	VU
	5.	Brolga	*Antigone rubicunda*	**50,000**; AU: Australia and portions of New Guinea	LC
	6.	White-naped Crane	*Antigone vipio*	**8,000**; EA: se Siberia, ne Mongolia	VU
	7.	Sandhill Crane	*Antigone canadensis*	**827,000**; NA: widespread	LC
	8.	Demoiselle Crane	*Anthropoides virgo*	**170,000 - 220,000**; EA: sw Russia, n China, n Africa, e Turkey	LC
	9.	Blue Crane	*Anthropides paradiseus*	**25,500 - 30,000**; AF: South Africa	VU
	10.	Wattled Crane	*Bugeranus caranculatus*	**9,600**; AF: Ethiopia, Democratic Republic of Congo, Tanzania to Botswana, Zimbabwe & South Africa	VU
	11.	Common Crane	*Grus grus*	**700,000**; EU: widespread	LC
	12.	Hooded Crane	*Grus monacha*	**15,000**; EA: se Russia and n China	VU
	13.	Whooping Crane	*Grus americana*	**689**; NA: c Canada and eastern USA	EN
	14.	Black-necked Crane	*Grus nigricollis*	**6,600 - 6,800**; AS: Tibet and w-c China	VU
	15.	Red-crowned Crane	*Grus japonensis*	**1,600**; EA: se Siberia, ne China and Japan	EN

KEY: **AF** Africa; **AU** Australia; **EA** Eurasia; **EU** Europe; **NA** North America; **AS** Asia. Abbreviations e, n, w, s and c refers to east, north, west, south and central respectively. Population estimates follows Archibald & Meine (2019) except for the Black Crowned Crane (BirdLife International, 2020c). Taxonomy and IUCN Status follows BirdLife International (2020b) while distribution is adapted from Austin *et al.* (2018). **IUCN Red List Status**: **LC** = Least Concern; **VU** = Vulnerable; **NT** = Near-Threatened; **EN** = Endangered; **CR** = Critically Endangered.

The Grey Crowned Crane ranges in 15 States from eastern parts of DRC to Uganda and Kenya in the north down to south-eastern parts of South Africa with isolated populations in Angola and Namibia (Figure 2.1; Mirande & Harris, 2019).

Figure 2.1: Geographical distribution of Grey Crowned Crane. (*Source*: Mirande & Harris, 2019).

A recent northward range extension has been recorded in South Sudan, probably following the River Nile (Morrison, 2015). Wamiti *et al.* (2020) present the species' distribution in Kenya from results of a countrywide census that proposed six populations.

The other species of sub-family Balearicinae, the Black Crowned Crane, is a species of the Sahel zone of Africa from Senegal to Ethiopia and north-western parts of Kenya (Archibald & Lewis, 1996). Gitahi (1996) reported a count of 104 individuals near Lotagipi (Lotikipi) Swamps located within Ilemi Triangle, and c.100 km west of Lake Turkana, Turkana County. Current population status and distribution in Kenya consequently deserves to be established, especially now that there are development interests in the area such as oil and gas explorations.

2.4 Nest-site selection and nesting behaviour

Factors influencing nesting success, breeding density and habitat preferences in birds and other animals have been reported. Donazar *et al.* (1993) observed low breeding densities in Bearded Vulture (*Gypaetus barbatus*) in areas of high potential human disturbances such as presence of paved roads. Smith (2003) showed clear evidence of habitat preferences and predation as important factors in relation to tundra nesting shorebirds, while Mosher (1986) observed rising water levels and wind and wave direction being main factors influencing hatching success in Black Tern (*Chlidonias niger*).

According to Lomáscolo *et al.* (2010), understanding the influence of habitat on nesting triumph of birds is often indispensable to successful conservation exertions of the species. A nest's surrounding environment features is linked to successful nesting which is important in increasing our understanding of specific habitat needs of a species (Dalley *et al.*, 2008). There have been some studies on nesting site preferences, nesting success rate, breeding behaviour and causes of nesting failure for some of the crane species (see Table 2.2). The table shows that cranes breeding performance, including nest-site location, is upset by numerous factors, for example water depth, human activities and abundance of food in the breeding habitats.

Table 2.2: **Breeding behaviour reported in various species of cranes.**

Crane species	**Breeding behaviour reported**	**Source**
Sandhill Crane *Grus canadensis*	40% hatching success; nest failure attributed to predation and flooding.	Maxson *et al.* (2008)
Black-necked Crane *G. nigricolis*	Water depth, exposure to predation, and human-related activities were important in nest-site selection.	Chandan *et al.* (2006); Wu *et al.* (2009)
White-naped Crane *G. vipio*	Nests were associated with shallow water-bodies and low grazing intensity.	Bradter *et al.* (2005)
Sarus Crane *G. antigone*	Nests closer to roads had a lower success rate (a human-related mortality).	Sundar (2009)
Hooded Crane *G. monacha*	Water depth and shrub coverage had an influence on nest-site selection.	Luo *et al*., (2012)
	Food abundance and disturbances affected the flock sizes.	Yang *et al.* (2015).

Studies on incubation behaviour in wild birds are numerous. Eggs apparently lose their weight during incubation (Jarrett *et al*., 2003). Weight is therefore an important parameter to measure in clutches as it can be used to determine expected hatching date or work backwards to incubation initiation date. In this study, knowing the expected hatching date was used by the local Cranes Conservation Volunteers to deploy an observer (mostly herdsmen and fishermen) in the area to keep watch and reduce threats (such as poachers, stray dogs and livestock). This action was important and effective in increasing chicks' survival to fledging.

2.5 Cranes diet and influence of seasons on food abundance

Except for two of the cranes species (Blue and Demoiselle) that typically forage in dry habitats, the rest of the species primarily feed and breed in wetlands (Allan, 1996). Plant food materials include fresh tips of grasses, seeds, leaves, fruits, waste grains, and tubers while animal materials include small birds, mammals and fish, insects, lizards and frogs, and a variety of invertebrates (Pomeroy, 1980; Johnsgard, 1983; Archibald & Meine, 1996). They can adjust to thrive in uncommon food sources where habitat loss is ruthless and most regular habitats are unavailable. This includes adapting to human-modified ecosystems such as croplands (Nowald *et al*., 2018), although this has resulted to crane-farmers conflicts in some places due to crop depredation.

Food availability and abundance are important in determining animal distribution (Hanya & Chapman, 2013). Climate and weather are similarly crucial as these could sometimes lead to collapse of food webs (Lister & Garcia, 2018). The intensity of use and management of a given type of land is known to influence the profusion and variety of arthropod prey, which in turn affects insectivore bird species diversity and abundance (Zahn *et al*., 2010). Seasons too perform a crucial function in distribution and species diversity of insects. Consequently, the diet of animals such as cranes change depending on food availability and nutritional needs on a daily or seasonal basis (Archibald & Meine, 1996).

2.6 Land use changes, threats and crane-human interactions

2.6.1 Impacts of Land Use and Land Cover changes on biodiversity

Human encroachment on native habitats such as wetlands and grasslands has led to various effects on species and populations. Ge *et al.* (2011) showed that a highway construction affected the vigilance behaviour of Snowfinches (Passeridae). Human disturbance led to increased vigilance by the Red-crowned Crane resulting to less foraging time in areas with more disturbance (Wang *et al.,* 2011). Gichuki (1993) however noted that breeding densities of cranes were not affected by presence of crops, pasture grass and human activities on land adjacent to marshes. Increase in livestock numbers leads to overgrazing resulting to undesirable influences on nesting birds through habitat dilapidation and disturbance (Bradter *et al.,* 2005).

2.6.2 Cranes-human interactions

Cranes hold special positions in many communities and cultures. In China, they are symbols of longevity and happiness (Yugong, 2001). They are also expressed as powerful and auspicious totems in almost all cultures in being appreciated as symbols of wisdom and cleverness, and are associated with loyalty, balance, grace, longevity, secrecy, protection, success and fortune. Astrology prescribes them as symbols of freedom, intelligence, good fortune, long-lasting marriages, and maternal love. The Grey Crowned Crane is a representative of elegance and prosperity.

Cranes, although sometimes taken as or confused with storks and herons, are important in many societies' spiritual lives. In Christianity for example, the spring's return of cranes is a symbol of Christ's resurrection and incarnation representing obedience and knowledge (Isaiah 38:14; Jeremiah 8:7). Muslims recognise cranes as favoured animals in architecture and decoration of palaces, and in the fables and legends assuming roles usually played by humans (Rodrigues, 2008). In Japan, young men use crane tattoo designs as a pride in efforts to improve oneself (https://nextluxury.com/mens-style-and-fashion/japanese-crane-tattoo-designs-for-men/).

The Grey Crowned Crane has a remarkable appeal to humans due to its colourful plumage and charismatic large size. Many cultures celebrate this species because of their prettiness and charisma (Morrison, 2015) – a threat to their survival as they are captured for live keeping in homes and gardens. It is Uganda's national bird where it is embodied on the flag and coat of arms, and in the emblem of Makerere University. In Kenya, it graces the emblems of the Nairobi City County Government (bears the Armorial guard), Kisii University and the University of Nairobi. Cranes are also in the coins and stamps of many countries (Archibald & Meine, 1996). The Common Crane is the corporate logo of the Germany national airline, Lufthansa, who directly support its research and conservation.

2.7 Conservation status of Lake Ol' Bolossat

A rapid assessment focusing on birds in the forested springs, fish, plants, macro-fungi, aquatic invertebrates, and reptiles was undertaken recently (Terer *et al.*, 2019). In 2008, an Integrated Management Plan of the lake was initiated but was not implemented well owing to lack of financial resources and land tenure complications. The plan has since been revised with a ten year (2020-2030) duration. The lake resulted to being nominated as an Important Bird Area following the confirmation of globally-threatened avifauna (Wamiti *et al*., 2009). The government gazetted 147 km^2 around the lake as a Protected Wetland Area (Legal Notice No. 179 of 4^{th} July 2018) (National Council for Law Reporting, 2018).

2.8 Research activities in Lake Ol' Bolossat basin

Literature on research activities in and around Lake Ol' Bolossat is scarce and/or unavailable, most of what is available being on birds. Other focus have been on: water quality (Mwaura *et al*., 2002; Mwaura, 2006); aquatic biodiversity (Mergeay *et al.*, 2006); description of the lake (Krhoda, 1992); effects of land use changes (Muriithi *et al*., 2013), and ecological status and socio-economics (Thenya *et al*., 2011).

Gichuki & Gichuki (1991) conducted a study on flocking and foraging behaviour of Grey Crowned Crane. Gichuki (1996) raising concerns over the deteriorating condition of the lake and the riparian grasslands. Oyugi & Owino (1998) conducted the first session of the African Waterfowl Census recording 213 Grey Crowned Cranes. Gichuki (2002) established a population of between 900 and 1200 African Snipe (*Gallinago nigripennis*) making localized altitudinal foraging movements between the lake and upland wetlands. Kiama *et al*. (2021) explored the reservoir of microorganisms from sediments and water recording 35 bacterial isolates. Activities on the status of the Grey Crowned Crane begun in mid-2015 that involved a survey to identify major threats and most affected sections of the lake (Muigai, 2016).

2.9 Knowledge gaps addressed

Section 1.2 has identified some of the knowledge gaps related to Grey Crowned Crane. Focusing on the Lake Ol' Bolossat basin's population, this study addressed some of the gaps as follows.

- Establishment of population size and density.
- Determination of breeding (nesting) densities.
- Description of breeding sites (nesting habitat requirements).
- Synthesis of human-crane interactions through analysis of changes in Land Use and Land Cover, and
- Identification of various threats and their severity.

CHAPTER THREE

3.0 STUDY AREA, GENERAL MATERIALS AND METHODS

3.1 Location and description of study area

3.1.1 Geographical location

This study was conducted in Lake Ol' Bolossat basin and its adjacent upland wetlands. It lies between latitude 0°2'32.70"N and 0°12'43.88"S; longitude 36°22'18.50"E and 36°27'7.64"E, at an altitude of 2,330 m. It is found in the central highlands of Kenya on the northwest foothills of Nyandarua Mountains (popularly known as Aberdare Ranges) in Nyandarua County (Figure 3.1). A small portion (c.1% of its area) in the northern end is in Laikipia County. The lake is in a basin whose eastern edge is bounded by the steep Sattima escarpment rising up sharply from eastern side of the lake at 2,330 m towards the Aberdares (highest peak, Sattima 3,999 m), and the gently sloping western margins of Dundori ridge whose Nyandundo peak reaches 2,850 m (Appendix IV).

3.1.2 Climate

The Lake Ol' Bolossat basin is situated in Agro-climatic zone II, a semi-humid type of climate suitable for agriculture (Infonet Biovision, 2020). The north-eastern portion of the study area (Leshau and Ndaragwa) is nonetheless in an overlap of zones II and III. Climate is intensely controlled by the geographical features of the adjoining highlands, namely Nyandarua Mountains and Dundori ridge. The local climate and weather are also influenced by the Inter-Tropical Convergence Zone since the area lies astride the Equator which pass in the northern section (Gichuki, 2002). A bimodal rainfall pattern is concentrated in two seasons where the extended rainy season falls between April-June and the short rains in October-November.

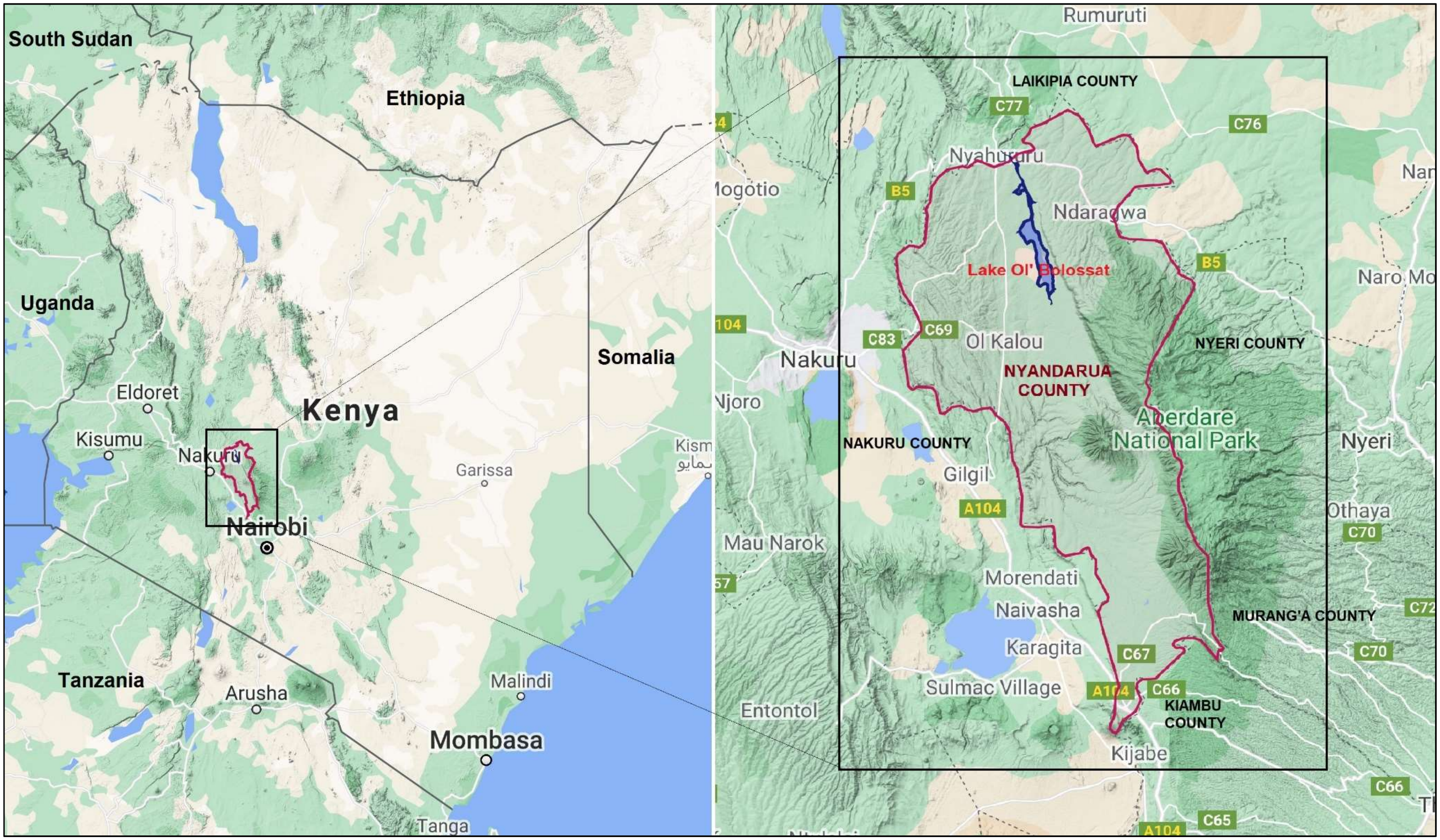

Figure 3.1: Geographical position of Lake Ol' Bolossat in the northern part of Nyandarua County at the northwest foothills of Nyandarua Mountains (Aberdare Ranges). (Map developed and improved from Google My Maps).

Rainfall ranges between 975 mm (northern end) and 1,000 mm (southern end), while the temperature ranges between 8.6 ^{0}C and 26 ^{0}C (Figure 3.2). A dry spell may however be experienced between January and March in some years.

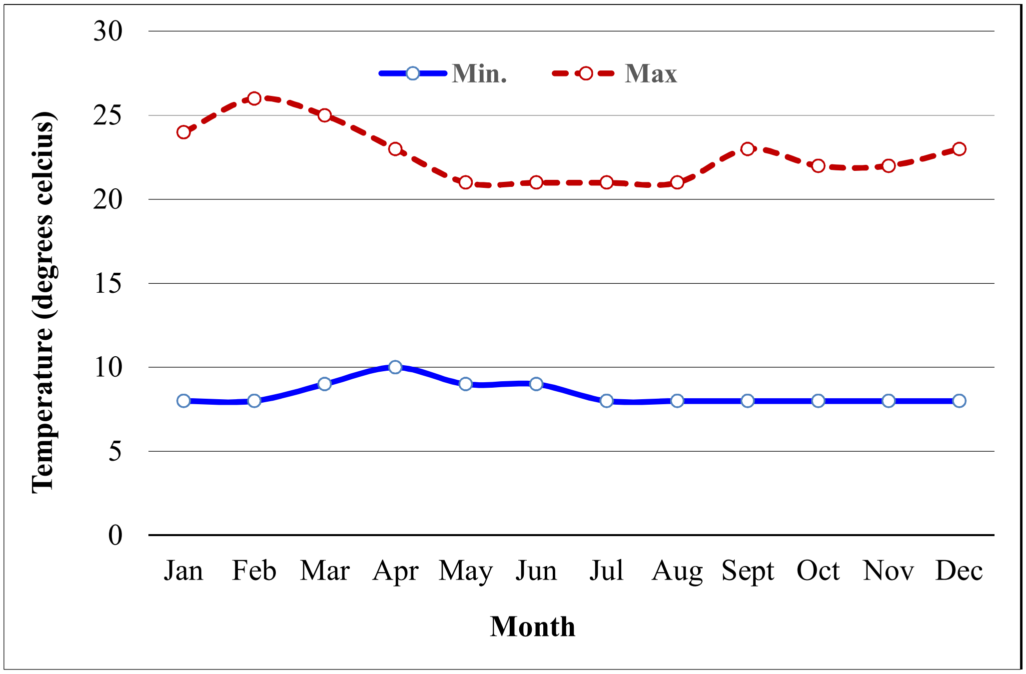

Figure 3.2: Mean monthly temperatures in Lake Ol' Bolossat for the year 2020.

(*Source*: https://www.ncdc.noaa.gov/).

3.1.3 Drainage and Hydrology

The lake has features typical of the Rift Valley lakes system with an utmost water depth of 4 m (Thenya *et al.* 2011), width range of 0.16-3.4 km, and a c.30 km stretch oriented in a north-south direction (this study). Mergeay *et al.* (2006) and Macharia (2011) reported a water pH range of 6.5 to 9.6 and an average depth of 2.0 m. Two rivers drain to the lake basin at its north-western end. River Simba originating from Kibindo reservoir in the south-west of Ol' Joro Orok town confluences with Nyakariang'a stream draining through Njunu-Kianjata marshes where it is joined by the perennial Njunu spring. Chamuka River (flowing for c.30 km from its source in Gicaka and Barati valleys) joins Ngare Narok River at Kibathi to drain at Manguu swamp. Over 10 perennial to perpetual springs also feed the lake from the foothills of Satima escarpment (Gichuki, 1996).

The water departs the basin via Ewaso Narok River that begins at the tumbling waters of Nyahururu waterfall forming the headwaters of River Ewaso Ng'iro (North) that runs through the dry Laikipia, Samburu, and Isiolo Counties and finally draining to the extensive Lorian Swamp. Through its course, Ewaso Ng'iro support and drives the economies of various sectors such as crop farming in Rumuruti, livestock, and wildlife and tourism.

3.1.4 Natural Vegetation

Kirika & Mbale (2019) reported a total of 370 plant while Muchane *et al.* (2021) reported a further 42 species of macro- and arbuscular mycorrhiza fungi species bringing the total plant species for the basin to 412. The riparian grasslands are dominated by species such as *Pennisetum clandistenum* and *Eragrostis lascantha* (Infonet Biovision, 2020).

The marshes are dominated by *Schoenoplectus corymbosus* (Cyperaceae) and *Typha domingensis* (Typhaceae). *Cyperus papyrus* is only found in the northern end at Manguo. This vegetation is interspersed with Swamp Cut Grass *Leersia hexandra* (Poaceae), Knotweed *Persicaria* spp. (Polygonaceae), *Lythrum rotundifolium* (Lythraceae), and two invasive species, Mosquito Fern *Azolla pinnata* (Azollaceae) and Kariba weed *Salvinia molesta* (Salviniaceae). The forested springs along Satima escarpment hosts large trees such as *Albizia gummifera* (Leguminosae), *Croton megalocarpus* (Euphorbiaceae) and *Ficus* spp. (Moraceae). Figure 3.3 shows some of the native plants found in the basin.

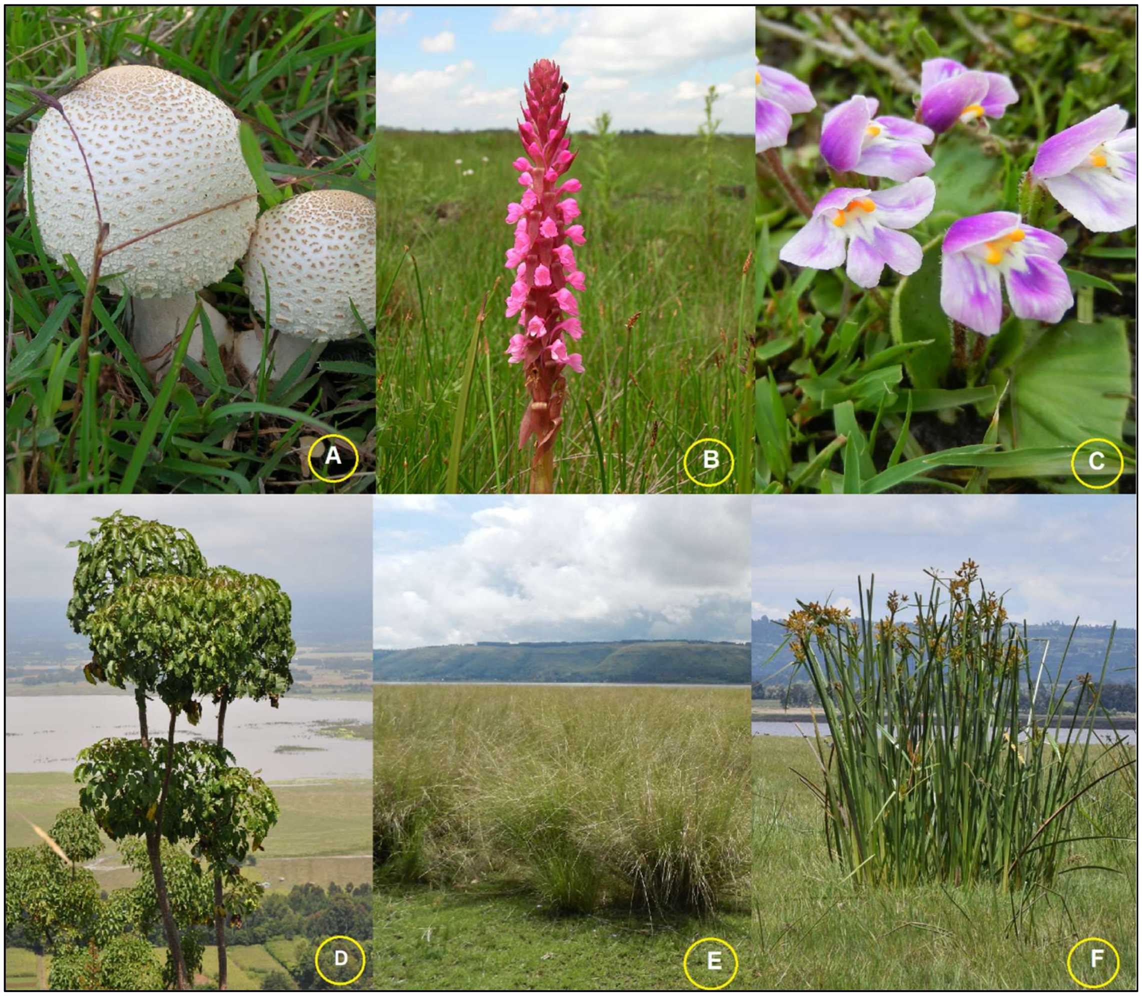

Figure 3.3: Examples of native plant species documented in different habitats in the study area. [**A**] *Macrolepiota dolichaula* (Agaricaceae); riparian grassland; [**B**] *Satyrium crassicaule* (Orchidaceae); marshes; [**C**] *Crasterostigma spicata* (Linderniaceae); riparian grasslands; [**D**] *Cussonia spicata* (Araliaceae); escarpment; [**E**] *Pennisetum sphacelatum* (Poaceae); riparian grassland; [**F**] *Cyperus exaltatus* (Cyperaceae); marshes.

3.1.5 Wildlife and Tourism

In terms of species richness, birds are the second most studied group after the plants in Lake Ol' Bolossat. Some of the terrestrial bird species are characteristic of the Afrotropical highland biome and the Kenyan Mountain Endemic Bird Area. They include Hartlaub's Turaco (*Tauraco hartlaubi*) and Hunter's Cisticola (*Cisticola hunter*). Among the various groups of birds (based on habitat choice), the waterbirds are the most diverse group with 106 species. Wamiti & Njoroge (2019) reported a total of 293 bird species acknowledged in the lake, riparian grasslands, forested springs, bush/scrublands and farmlands. Examples of species of conservation concern highlighted includes Maccoa Duck (*Oxyura maccoa,* NT) and Pallid Harrier (*Circus macrourus*, NT). Some of the mammals present in the lake are Marsh mongoose (*Atilax paludinosus*, LC), Cape hare (*Lepus capensis*, LC) and Hippopotamus (*Hippopotamus amphibious*, VU) as well as the invasive alien rodent Nutria (*Myocastor coypus*, LC). Ongoing efforts of grading access roads and development of facilities will improve visitor experience and growth of revenue from the tourism sector. Other unexploited tourism compendium is the area's rich colonial white settlers' history and suitability for high altitude sports.

3.1.6 Land tenure

Land ownership falls under different categories of land tenure. Agricultural lands are held under leasehold and freehold while other land types are public and trust lands (Kenya Forest Service, 2010). Land parcels vary from 0.05 to 120 hectares. Most of the land-owners are small-scale holders practising subsistence farming. Crop farming is chiefly rain-fed although irrigation is practical where spring water is reliable or where water is pumped direct from the lake and rivers.

3.1.7 Choice of study sites

The study area (Figure 3.4) was a block enclosing an area of c.646 km^2 which was determined during reconnaissance by observing daily foraging ranges of two resident flocks of cranes bearing colour rings marked in 1988/89 (Gichuki & Gichuki, *pers. comm.,* 28 April 2019).

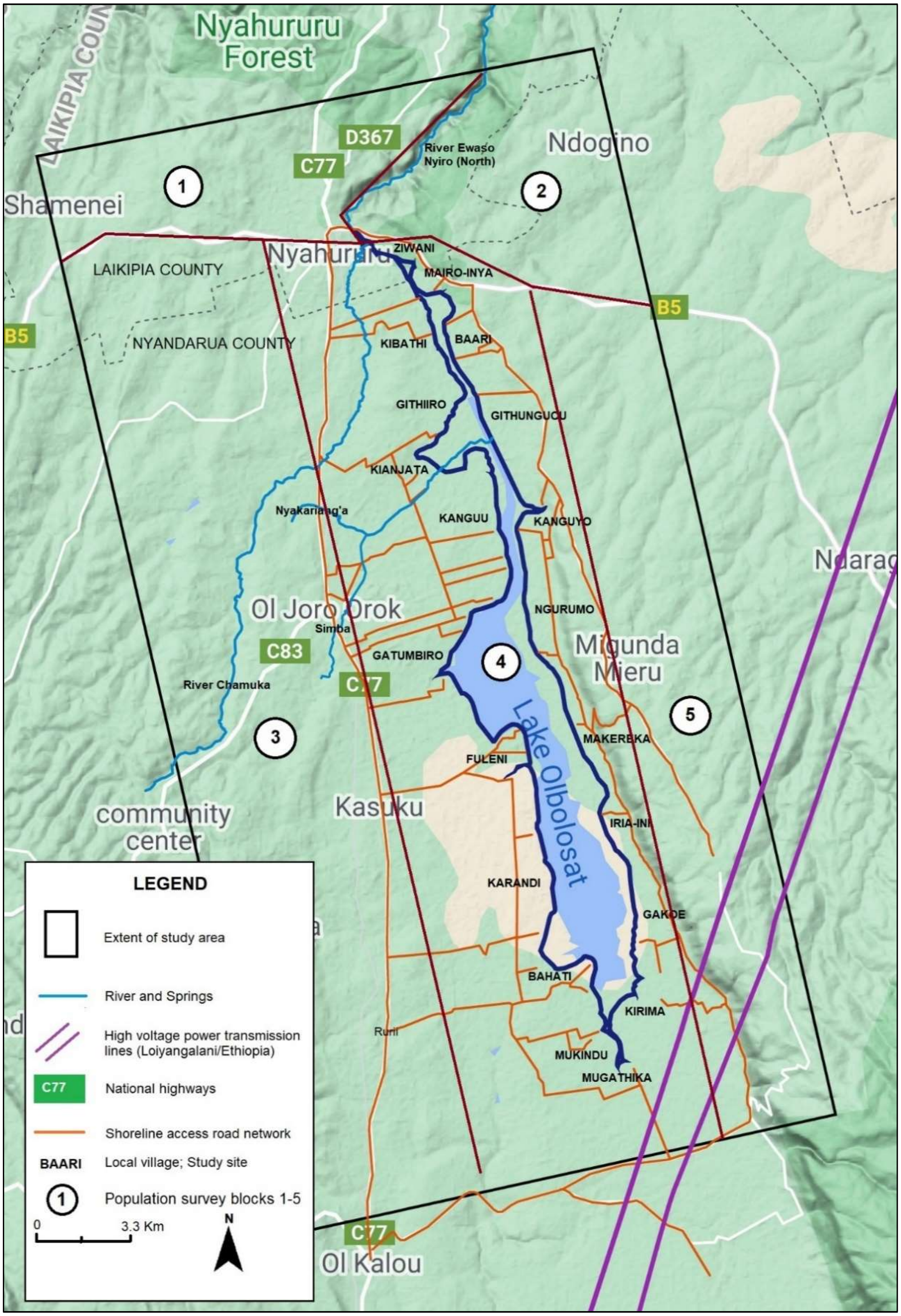

Figure 3.4: Map of the study area showing study sites, population survey blocks (1-5) and some infrastructure. Map developed and improved from Google My Maps.

3.2 Materials and Methods

3.2.1 Materials and Equipment

A pair of 10x42 binoculars and a telescope were constantly used to observe Grey Crowned Cranes. Additional field equipment included Nikon D90 digital camera, field notebook, pencil and a clipboard. The following were used when describing nests and eggs: digital scale, plastic dial veneer callipers, 5 m measuring tape and a pair of wader boots together with a 2 m bamboo walking stick to assist with wading, detection of ditches and water depth. A folding wooden ruler was additionally used when taking measurements at nest-sites. Ziploc bags and 800 ml pet jars were used to transport the invertebrates from the field to the laboratory. A hand-held water quality tester (ASPERA® Instruments, California, USA) was used to measure five water physico-chemical properties. These were pH, salinity, water surface temperature, conductivity and total dissolved solids. Water parameters are important in shaping the community characteristics that thrive or are partially dependent on wetlands (Drayer & Richter, 2016).

3.3.2 Field Methods

Fieldwork for this study was conducted from December 2017 to July 2020 (33 months). Data for population characteristics, habitat selection and threats were gathered within the whole study area. Data for characteristics of nesting-sites and description of eggs and nests was done throughout the study period and was concentrated on the population utilising the lake's marshes due to expected differences in characteristics between the lake (natural) and the upland wetlands under intensive use by local communities. Sampling of invertebrates as potential food items for the Grey Crowned Crane was carried out only in the dry and wet seasons. This was done using three techniques: sweeping with a standard Freshwater Biology Association D-frame pond net with a 1.5-meter-long handle and a sweep net and lying of pitfall traps in the riparian grasslands. A questionnaire was used to collect data on knowledge of local community on threats facing cranes in the area. The respondents were purposively selected. Protocols followed for each technique are elaborated in specific chapters.

3.3.3 Laboratory techniques

The invertebrate samples were taken to the laboratory for processing. They were poured out on a sorting tray to separate and count specimens of each taxa using soft-touch forceps into a vial containing 70% Ethanol. An indelible ink pen or pencil was used to prepare a label for each sample. Pitfall and sweep net samples were also sorted and preserved in the same way. Ethanol in the samples was drained and contents of each individual jar poured out on a petri dish for drying using a Gallenkamp™ Hotbox Oven set at 70^0 C until a constant weight was attained for each sample. They were weighed using a Sartorius™ laboratory sensitive balance (0.0001 g readability) to obtain their dry weight (biomass).

3.3.4 Statistical Considerations

Preceding all statistical tests, data were tested for normalcy (i.e. to find out if data was from a normal population or distribution or not) using the Shapiro-Wilk *test*. Non-normally distributed variables (i.e. those with Shapiro-Wilk W value of <0.5) were $\log_{10}$-transformed in an attempt to normalise them, and where this was not possible, non-parametric tests were then used. The predetermined alpha (α) level used as a significance criterion for all statistical tests was at $\alpha = p \leq 0.05$ (5%). Mean, standard error (SE) and standard deviation (SD) are reported in summary descriptive statistics. A Chi-square (X^2) test of goodness-of-fit (one sample) or a test of independence (several samples) was performed to determine variables distribution differences. A pairwise Student *t*-test was used to determine whether any two groups under comparison were significantly different or not, and in case of a single group, One-sample *t* test was used. In circumstances where any pairwise samples had unequal variances and/or unequal sample sizes, a Welch *F* test was used (Ruxton, 2006). One-way analysis of variance (ANOVA) was used to determine whether there were any statistically significant differences in variability of means of three or more groups. One-way ANOVA test in some cases was also followed by a multi-comparison test (and in case of unequal variances, Welch *F* test was used). Kruskal-Wallis *test* was used where assumptions of ANOVA were not satisfied. Spearman's correlation was used to describe relationship between two variables. Specific statistical tests are provided in methods and materials section in each chapter. Calculations and computation of statistical tests were done using Microsoft Excel ('Data Analysis' toolkit for descriptive statistics), Statistical Package for the Social Sciences (SPSS; for tools such as Cronbach's alpha and Fleiss's Kappa) and Paleontological Statistics (PAST; for tools such as univariate statistics, normality test and plotting) Ver. 4.03 (Hammer *et al*. (2001).

3.3.5 Research Authorisation

Conceded that the Grey Crowned Crane is a protected wildlife species in Kenya by the Wildlife Management and Conservation Act (of 2013), consent to conduct research was authorised by the Biodiversity Research & Monitoring Department of Kenya Wildlife Service (Permit No.: KWS/BRM/5001) and a wildlife capture permit (No.: KWS/904[2]). This study was also conducted in accordance with the National Museums of Kenya's mandate to collect, document and preserve Kenya's national and cultural heritage (National Museums and Heritage Act, 2006 [No. 6 of 2006]), and was jointly supervised at the Department of Biology of the University of Nairobi, and the Ornithology Section of the National Museums of Kenya.

CHAPTER FOUR

4.0 POPULATION CHARATERISTICS, HABITAT USE AND SOCIAL ORGANISATION OF GREY CROWNED CRANE

4.1 Introduction

In 1985, Urban (1988) estimated the global population of Grey Crowned Crane at over 100,000 individuals, while Beilfuss *et al.*, (2007) placed it at 50,000-64,000 in 2004 compared to 6,500-33,500 between 2014 and 2018 (Morrison 2015; Mirande & Harris, 2019). Meine & Archibald (1996) and BirdLife International (2020) reported the species as being abundant in eastern Africa where Kenya hosts the largest population (Table 4.1). The eastern Africa population has however been described as declining around the years as disclosed by Urban (1988) and Morrison (2015) (Table 4.1).

Table 4.1: Estimates of the East African population of Grey Crowned Crane.

Country	Urban (1988)	Morrison (2015)
Kenya	35,000	10,000 - 12,500
Uganda	35,000	6,500 - 8,000
Tanzania	<1000	600 - 1000
Rwanda	<1,000	50 - 500
Burundi	<600	10-100
South Sudan	0	0 - 10

The global population is thought to have declined from 35,000 to 10,000 over a period of 34 years (Figure 4.1). These estimates are from Urban *et al*. (1986), Gichuki (1993), Daut (1994), Beilfuss *et al.* (2007), Morrison (2015) and Wamiti *et al*. (2020) who based their estimate from a countrywide census. A large difference is however noted between estimations in the 1990s and 2020s, and may be explained by increased threats, such as land use changes.

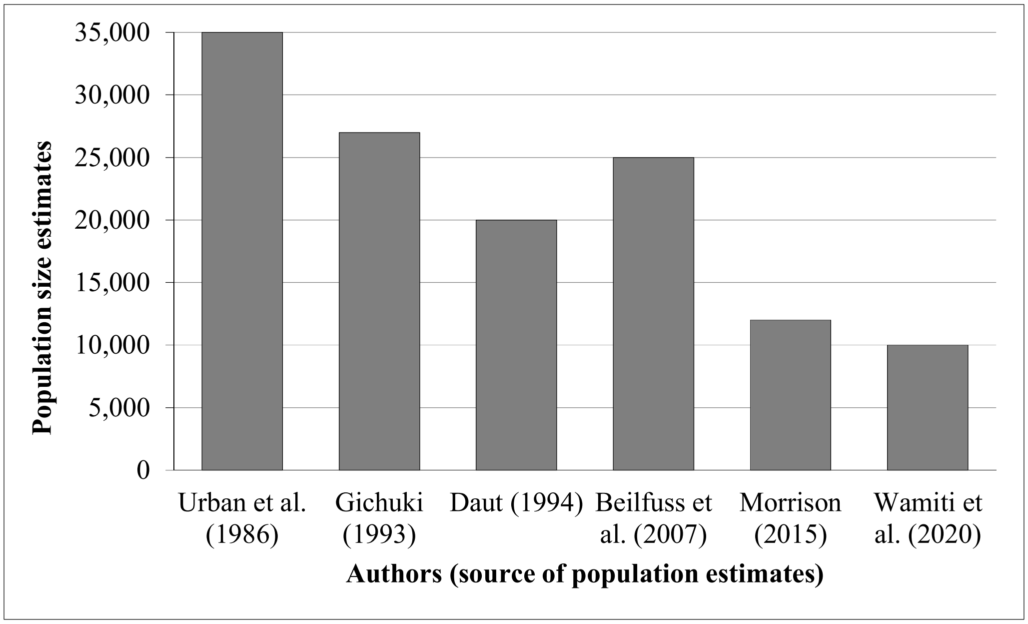

Figure 4.1: Estimates and trend of the Kenyan Grey Crowned Crane population.

Whilst there is a current national Grey Crowned Crane's population approximation in Kenya (Wamiti *et al.,* 2020), general lack of detailed information from emerging regional strongholds such as Lake Ol' Bolossat basin is proficient. Preceding 2019, Kenya had not organised a comprehensive countrywide census to establish its Grey Crowned Crane population, except two attempts by Ndede (1988) and Gitahi (1996) that were limited in their scope compared to attempt by Wamiti *et al.* (2020). In Kenya, Lewis & Pomeroy (1989) reports the species as occurring over 500 m above sea level and in areas that receive a minimum of 500 mm of precipitation. Recognised breeding sites comprise segments in the western parts of the country including Kitale and Lake Victoria basin, central and south Rift Valley, and the highlands east of the Rift Valley such as Laikipia, Nyandarua, Nyeri, as well as the greater Nairobi area, Amboseli basin and Tsavo.

There are many factors that influence the dispersal and density of organisms e.g. space, search for mates and food resources (Rémy *et al.*, 2013). Fire is important too with absolute and non-direct effects on vegetation structure and animals' composition. For example, Robinson *et al.*

(2014) observed that unburnt forest areas had a high abundance and a discrete composition of birds. Nevertheless, Hoffman & Bouwman (2009) remarked that species richness and densities enhanced in the burned areas instantaneously after burning but slowly returned to pre-burned conditions over time. Most of the cranes species are dependent on shallow wetland habitats where they meet both their feeding and nesting needs (Archibald & Meine, 1996). While most species of cranes are reliant on wetlands for breeding, the Blue and Demoiselle Cranes typically forage and nest in dry habitats (Allan, 1996). These two species have bustard-like short-toes (and bills) that are adapted for rapid running in grasslands (Archibald & Meine, 1996).

Living in groups is common in the animal kingdom, and quite often, the composition of the group is defined by birth, death and/or arrival or departure of members. Social behaviour in animals is adaptive and ultimately increases an animal's fitness (McGlynn, 2010). Cranes are some of the animals whose individuals come together, groups being individuals, pairs, families and flocks. While group living behaviour can bring several costs such as deepened conflict around reproduction (Huchard & Cowlishaw, 2011), it also have several survival advantages such as lowered predation risk (Sorato *et al*., 2012). While the social behaviour of Grey Crowned Crane is relatively known, the flocking pattern such as group sizes and seasonal distribution in specific key sites such as Lake Ol' Bolossat basin remains unknown. The choice and use of different habitat types in different times of the year in this population is also undetermined as well as its social behaviour.

4.2 Aims

The purpose of this part of the study were:

i. To determine the population size, density, age structure, proportion of young, and a review of previous population estimates of Grey Crowned Cranes in Lake Ol' Bolossat basin.

ii. To assess the flocking behaviour and group size dynamics of cranes in the study area.

iii. To investigate the types of habitats selected during the dry (non-breeding) and the wet (breeding) seasons by cranes in the study area.

4.3 Materials and Methods

4.3.1 Population characteristics and flocking behaviour

While bird surveys can happen at whichever time of the year (Pomeroy *et al*., 2018), assessment of cranes in this study was done between October and March where five censuses were coordinated. The surveys were in February 2018, October 2018, January 2019, March 2019 and March 2020. This period overlapped with the crowning of the breeding season (usually lasting between October and January) when most breeding pairs were observed with chicks. During this time, most crops were harvesting and crop fields were prepared, especially for crops such as maize, wheat, barley and oats, thus appealing to cranes searching for fallen, exposed pieces of grains. February and March also coincided with the dry season when cranes were observed forming flocks which facilitated counting. This time of the year offered the best opportunities to obtain a minimum population estimate comprising of resident individuals, new recruits (juveniles) and immigrants.

Some parts within the 646 km^2 study area enclosed habitats that may be determined as unsuitable (i.e. parts that cranes never used or may never use in future) such as urban centres, railway line, forested habitats, bitumen paved and earth roads, and open waters. These areas were overlooked in determination of population density after Gichuki (1993). These excluded parts, amounting to an area of approximately 120 km^2, resulted to 526 km^2 of suitable to conceivably good crane habitats which was used in determination of the population density.

A complete (true) survey was adopted since it works well without correction for detectability, and is commended for large species that have a limited, particular choice of foraging habitat (Gregory *et al.,* 2004). A ground count, reported by Wetlands International (2010) as the simplest and most common form of counting waterbirds was adopted. The five counting blocks were covered on foot (along the lake shoreline) and using a motorcycle and vehicle. Other investigators have, however, used alternative methods to survey cranes such as aerial counts in Rwanda (Nsengimana *et al.,* 2019) and transect-based distance sampling in Tanzania (Amulike *et al.,* 2020). These methods were not reasonable for exploitation in Lake Ol' Bolossat basin due to challenges such as budget/cost implications and topography. The five census blocks (Figure 3.4) were thereforeof dissimilar areas. Factors such as road networks and their seasonal conditions (affecting accessibility), behaviour and distribution of the cranes relative to the lake, physical obstacles and landscape terrain (e.g. existence of water bodies, shallow to deep river valleys, and the escarpment) guided in determination of the sizes of the survey.

The study area was criss-crossed in two days. The shoreline and the riparian land (i.e. the adjacent grasslands and croplands) and the foraging fields around the lake were covered in day one. These two areas held the majority of the cranes population accounting for 83% of all the observations made throughout the study period.

The c.80 Km long shoreline was apportioned into six sections, with each section being assigned to two teams of two members each. The two teams in each section commenced counting along the shoreline (checking for cranes inside the marshes and adjacent grasslands) at the same point and time walking in reverse directions to meet another team when the counting of that section was completed. All the other survey units (blocks) were counted in the second day, generally targeting the breeding and territorial pairs nesting and foraging in the upland wetlands such as in Ndaragwa, Leshau, and the slopes of Dundori ridge. Chances of double counting were moderated by presence of cranes bearing colour rings in the flocks that were marked previously by other researchers. In each of these blocks, cranes were counted by different teams simultaneously over a period of four hours (08:00 hr to 12:00 hr). This approach further reduced chances of double counting since cranes usually foraged in a single field with very minimal movements within the survey window. Any double counting that may have happened was therefore insignificant and usually only involved individuals or pairs, and the results were therefore not very biased.

Whenever an individual or a group of cranes were spotted, the following data were recorded: time of observation, date, estimated are of the field (ha) and its GPS, habitat type, and cranes data (number of individuals in each age category i.e. young and adults). Precise counts were managed for individuals (also known as singletons), pairs, family groups (4-6 cranes) and small flocks (<30 cranes) while a tally counter was used to accurately count or estimate average-sized (31-100 cranes) and bigger (>100 cranes) flocks. In the latter flock sizes when these were busy (i.e. when individuals were very close to each other, frequently moved and mixed), counting was undertaken three times and the highest count used (with a variance of five cranes considered as being adequate). Two broad age categories of cranes (juveniles and adults) are identifiable in the field, and were determined from physical appearance and plumage features. These categories were used in calculating proportion of young in the population as an indicator of recruitment. Data were also divided into two other categories: breeding and non-breeding seasons.

4.3.2 Habitat selection and spatial-temporal distribution

Grey Crowned Crane group sizes, number of individuals in each age category and habitat type occupied were recorded throughout the study period. The size of the field was estimated while in the field and confirmed by use of Google Earth Pro's '*Add Polygon*' tool. Each observation of group sighting was recorded as independent including at different times of the same day since flocks' sizes were dynamic as cranes flew in and out although this happened only a limited time due to expansiveness of the study area and challenges in poor condition of access roads limiting same-day return to observed groups. Flocks were also considered as independent observations on same fields in different days. Recording the date of observation was important in determination of the season as either breeding or non-breeding although cranes bred for most of the months in the year (see chapter 5). Three categories of habitat types were identified following Gichuki (1993): cultivated crop fields (e.g. wheat, barley, fallow, maize, oat and other crops), shallow wetlands (streams/springs, man-made and natural marshes) and grasslands (both natural grass and cultivated pasture fields).

4.3.3 Review of African Waterfowl Census reports

A review of the number of Grey Crowned Cranes was conducted from records held by the African Waterfowl Census in selected wetlands since its inception in Kenya in 1991. This was from reports and published information. Although the programme has over 20 wetlands that are surveyed, only four wetlands (Lakes Bogoria, Nakuru, Elmenteita and Naivasha) are considered in this review because of regular counting and proximity to the study area.

4.3.4 Statistical analysis

Student *t*-test was used to test for significance of resident population and density estimates between census periods. Density was expressed as the total number of individuals in each unit area. Mann-Whitney *U*-test determined the significance of proportion of young between the non-breeding and breeding seasons while One-Way ANOVA analysed for differences among the various sizes of crane flocks. Pearson's Chi-square test was used to detect for association of cranes between the breeding and non-breeding seasons. Descriptive statistics are provided for characteristics of population, group sizes and habitats.

4.4 Results

4.4.1 Population abundance

The Grey Crowned Crane population in Lake Ol' Bolossat basin ranged from 521 to 1,115 individuals (Figure 4.2). The presence and observation of previously marked individuals confirmed movement of cranes in and out of the study area. Thus, the local population had a wider range outside Lake Ol' Bolossat basin. The mean population size for the entire study period was 760.4±107.8 cranes. The data indicated considerable variation in the abundance of cranes in Lake Ol' Bolossat basin. The estimates of the resident population of cranes differed significantly among the five census periods (One sample *t* test: $t_4 = 7.163$, $p < 0.05$).

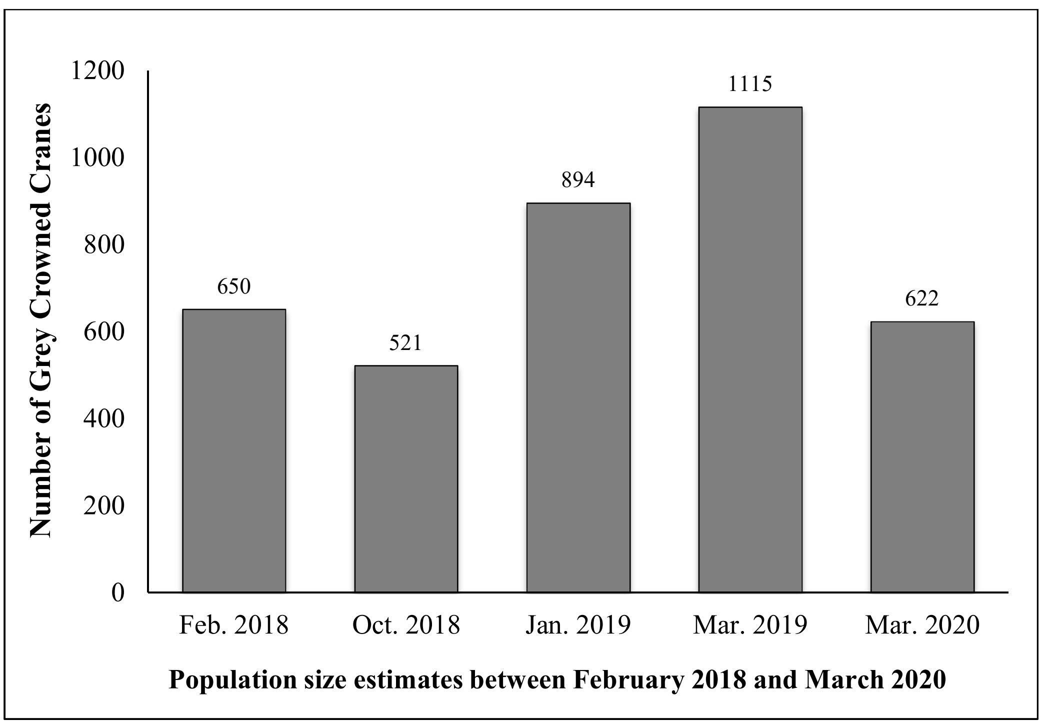

Figure 4.2: Temporal variation in the abundance of Grey Crowned Cranes in Lake Ol' Bolossat basin during the study period.

4.4.2 Population density

Density was determined by considering the number of cranes per unit area (526 km^2 of suitable to potential crane habitats). The overall density of cranes ranged from 0.99 cranes/km^2 to 2.12 cranes/km^2 (Table 4.2) with a mean of 1.57±0.204 cranes/km^2. Densities differed significantly between the five surveys (One sample *t* test: $t_4 = 7.741$; $p < 0.05$).

Table 4.2: Variation of Grey Crowned Crane densities in different survey periods.

Survey period	Density (cranes/km^2)
February 2018	1.24
October 2018	0.99
January 2019	1.69
March 2019	2.12
March 2020	1.18

4.4.3 Age structure

The average proportion of young cranes (new recruits) within all the five surveys (expressed as a fraction [%] of young birds over total cranes) was 11.65%±1.14. A greater ratio of young cranes was observed in the dry, non-breeding season (12.87% ± 1.43) compared to the wet, breeding season (9.49%±1.58). This discrepancy between the dry, non-breeding and the wet, breeding seasons was however insignificant (Mann-Whitney $U = 4792$, z = -1.113, $p > 0.05$), neither did it differ significantly between the various sizes of flocks (small 12.95%; medium 8.68%; large 6.45%) ($F = 1.831$, df = 218, $p > 0.05$).

4.4.4 Flocking behaviour

Two hundred and nineteen ($n = 219$) observations of Grey Crowned Crane groups were made in this study. The average group size was 28.21±3.24 cranes, and a range of 1 to 332 cranes while the modal group comprised of 1 to 20 cranes (n = 148; Figure 4.3). There were however only four sightings of single cranes which were presumed to be partners of a nesting (incubating) pair that were out to feeding during the nest relief (break). A total of 13 flocks in excess of 100 cranes were detected during the study period, 11 (85%) of these being observed during the dry, non-breeding season, while the other two flocks (15%) were observed during the wet, breeding season.

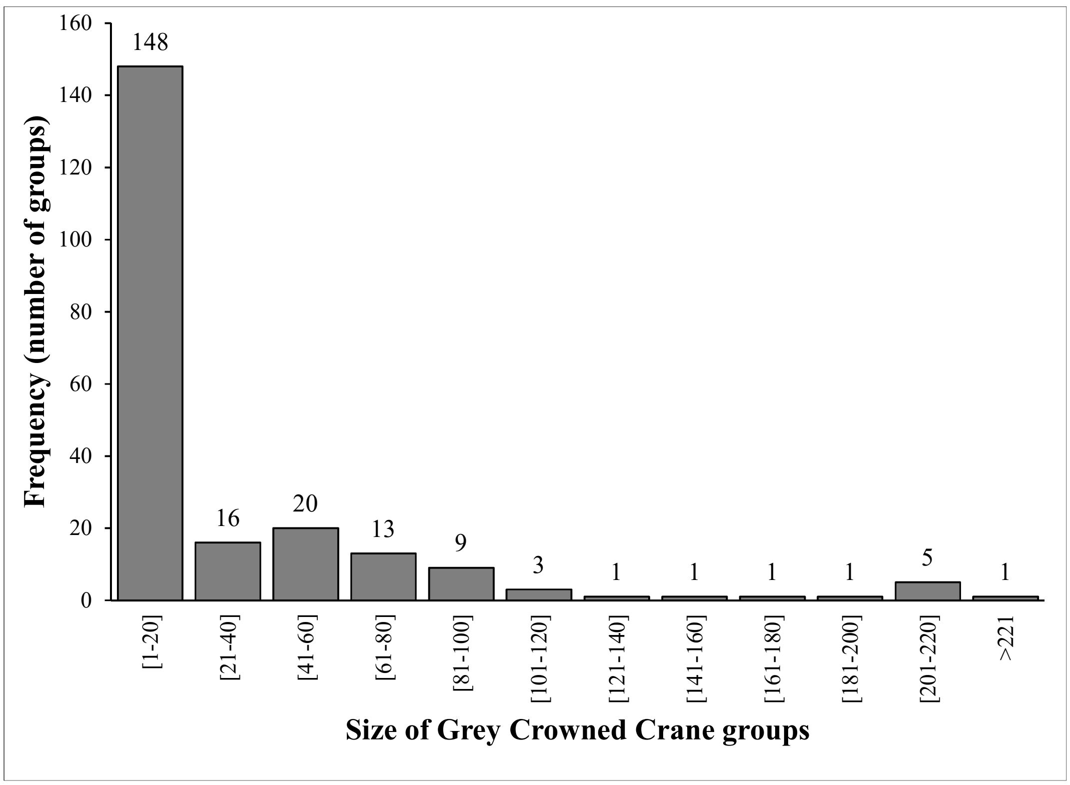

Figure 4.3: Distribution of Grey Crowned Crane group sizes observed in Lake Ol' Bolossat basin during the study period (n = 219).

The composition of the smaller groups of cranes (1 to 20 individuals) was dominated by mated (territorial and/or breeding) pairs that constituted 54% (n=80), while a further 27% (n = 40) were families of between 3-6 individuals (Figure 4.4). The rest of the groups (19%; *n*=28) were smaller flocks of between 7 and 20 cranes.

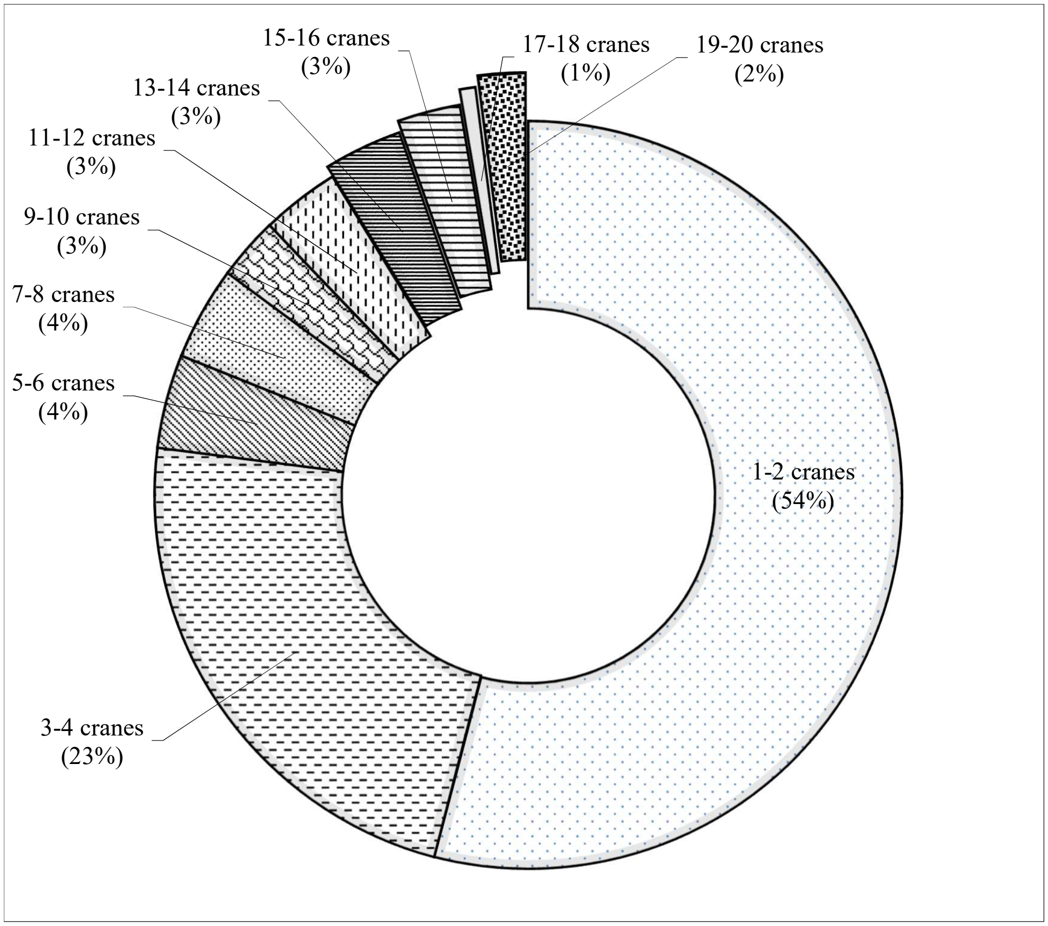

Figure 4.4: Distribution of the 1-20 crane units observed in Lake Ol' Bolossat during the study period.

4.4.5 Habitat selection and spatial distribution

Cranes were found to select and utilise dry substrates (terrestrial habitats) and wet substrates (wetland habitats especially the marshes), respectively accounting for 46% and 54% of the whole study period. A large number of cranes were observed occupying wet substrates particularly during the breeding season than during the dry, non-breeding season (X^2 = 489.28, df = 1, p <0.05). in all the observations made, 35.6% of the cranes were the mated (territorial and/or breeding) pairs that predominantly inhabited the lake's shoreline marshes, followed by the wheat fields at 29.2% (Table 4.3).

Table 4.3: Spatial distribution of Grey Crowned Cranes in different habitat types observed in this study.

Habitat types	Total cranes	No. of observations (*n*)	Mean group size	Proportion (%) of total observations
i) **Cultivated crop fields**				
Wheat	3,494	64	54.59	29.2
Barley	632	3	210.67	1.4
Fallow	591	9	10.11	4.1
Maize	377	6	62.83	2.7
Oats	253	5	50.60	2.3
Other crops	72	4	18.00	1.8
ii) **Grasslands**	209	9	23.22	4.1
iii) **Wetlands**				
Lake shoreline/marshes	741	78	9.50	35.6
Streams & springs	252	19	13.26	8.7
Water reservoirs	58	22	2.64	10.1
Total	**6,179**	**219**		**100.0**

Eight of the 13 large flocks observed (i.e. those in excess of 100 cranes) were recorded in the wheat fields, demonstrating the prominence of this human-modified habitat type in the survival of cranes as a foraging site. Cultivated crop fields was the most diverse among the terrestrial habitats in terms of sub-habitat fields with cereal crops (wheat, barley, oat, maize) being preferred most while other fields with crops like beans, peas, and potatoes were also rarely and utilised. The size of fields where cranes foraged ranged from 0.5 to 130 ha. Nevertheless, there was a indistinct relationship between the size of the feeding fields and size of flocks (Spearman

Rank Correlation $r_{108} = 0.005$, $p > 0.05$). The mean foraging flock density was 5.95±1.01 cranes/ha with a minimum of 0.09 and a maximum of 47.14 cranes/ha.

Distribution of cranes was observed to be highly influenced by availability of suitable breeding sites (in the shallow wetland marshes) and food availability in foraging areas. The pattern was therefore determined by distribution of these two habitat types. Majority of the observations were in the marshes along the lake shoreline that mostly occurred as paired individuals and in the cultivated (especially wheat and maize) fields located in the south-western part of the study area around Githungucu, Kanguu, Robert's dam and Karandi villages (Figure 4.5). While most of the large flocks were observed in terrestrial substrates, three of these were roosting located in shallow wetlands (along the shoreline) at Ngurumo, Iria-Ini and Kirima. The medium-sized flocks observed several times in Shamanei (Figure 4.5) was seasonally present after the wheat fields were harvested, ploughed and seeds sowed.

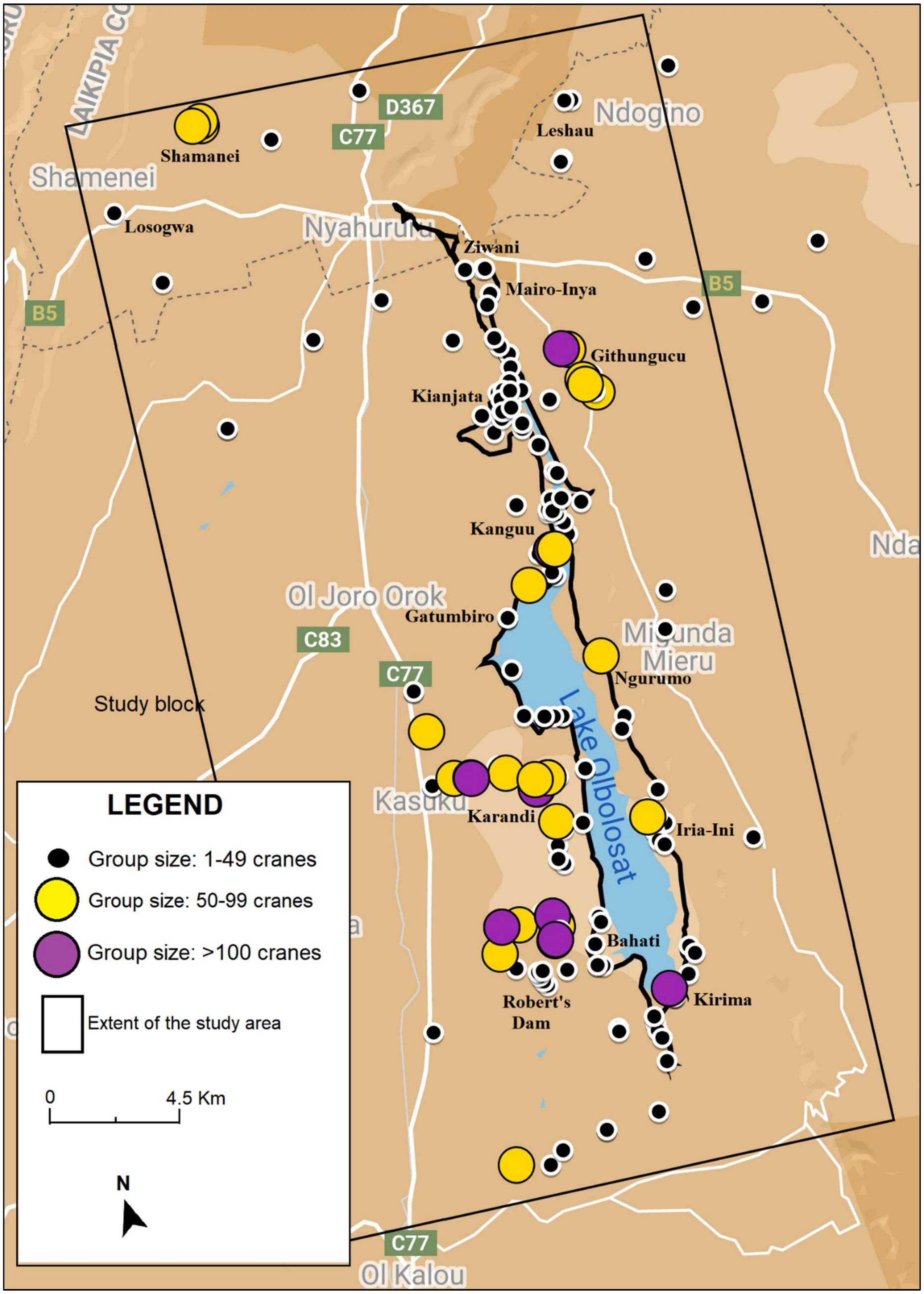

Figure 4.5: Spatial distribution of three group sizes of Grey Crowned Cranes in and around Lake Ol' Bolossat during the study period. Map developed and improved from Google My Maps.

4.4.6 Population of cranes in neighbouring wetlands

Data held by the African Waterfowl Census (courtesy of the Ornithology Section, National Museums of Kenya) in its early phases (e.g. Oyugi & Owino, 1998) and recently (e.g. Nasirwa *et al.,* 2018; Madindou *et al.,* 2019) sturdily denotes that Lake Ol' Bolossat has throughout the years supported an extraordinary number of Grey Crowned Cranes compared to other wetlands where waterbirds counting has been going on regularly (Table 4.4).

Table 4.4: Population estimates of Grey Crowned Crane in different wetlands with regular waterfowl counts, where (a) is the January session and (b) is the July session.

Year (Session)	Lake Nakuru	Lake Naivasha	Lake Elementaita	Lake Bogoria	Lake Ol' Bolossat	Total cranes
1998(a)[1]	12	8	8	18	213	259
1999(a)[2]	2	16	0	0	159	177
2007(a)[3]	23	0	4	1	91	119
2007(b)[4]	10	0	0	0	149	159
2009(a)[5]	0	8	9	0	676	693
2015(a)[6]	0	0	2	19	232	253
2018(a)[7]	15	115	0	0	504	634
2019(b)[8]	8	77	2	0	142	229

Data sources: [1]Oyugi & Owino (1998); [2]Oyugi & Owino (1999); [3]Musila *et al*. (2007); [4]Wambugu *et al.* (2007); [5]Ndithia *et al*. (2009); [6]Kimani *et al*. (2015); [7]Nasirwa *et al*. (2018); [8]Madindou *et al.* (2019).

4.5 Discussion

This study has established that the Grey Crowned Crane's units' range between 1 and 332 individuals in the study. Such huge flocks are seldom reported from other parts of Kenya, making Lake Ol' Bolossat basin a principal site for this species' existence and conservation. Observation of large flocks in the excess of 100 birds mostly occupying cultivated fields shows the species' adaptability in utilisation of human-modified ecosystems. Chapter seven of this thesis has revealed that there was an upsurge in area of land under cultivation between 2010 and 2020. This may further explain the presence of large flocks especially in medium-scale wheat farms where cranes feed on waste grain. Large roosting flocks were also observed in the shallow marshes.

The fluctuating numbers of Grey Crowned Crane across the five counts of this study indicates that the local population is composed of both resident and immigrant individuals, reaching a limit of 1,115 cranes during the non-breeding season. This population constitutes 5% and 15% of the global and national estimated populations respectively. Conservatively, it is estimated that the basin has a resident population of between 250 and 350 cranes, majority being mated pairs. The upland wetlands constitute 8.5% of the resident population while 23% is a resident flock comprising of mated non-breeding adults, sub-adults and new recruits. The largest flock recorded during this study had 332 cranes, compared to flock sizes of 2-130 reported by Gichuki & Gichuki, (1991). This is an indication that flock sizes may have grown bigger over the years. Large flocks however pose risks, for instance increased importance of disease and parasites transmission (Robb *et al*., 2008) and in sites like Lake Ol' Bolossat where cranes are in skirmishes with farmers, there are elevated risks of mass poisoning and trapping in retaliation to crop damage that cranes may cause. A total of 18 cranes were reported dead from suspected incidence of poisoning on a sown wheat field in Githungucu village (George Ndung'u, *pers. comm.*, 12 April 2021).

Waterfowl counts in Lake Ol' Bolossat have had some challenges e.g. several years of data run gaps, occasional partial coverage of the lake's shoreline, and exclusion of crane's foraging fields and upland wetlands in the census. Such data may therefore not represent a reliable picture of the local cranes population and its trend over time. Despite these challenges however, the available results are still worthwhile in highlighting the relevance of the lake as an essential site for the species given that, of the reports reviewed, 86% of the cranes were from Lake Ol' Bolossat.

The population density quantified in this study of 0.99 to 2.12 cranes/km^2 varied between the wet, breeding and the dry, non-breeding seasons resulting from the arrival and/or leaving of immigrant individuals from other areas, though it could not be determined how far this population came from or dispersed to. Rainfall and food availability, and nest-sites are however important factors reported as key in influencing this species' variable domestic and seasonal movements (del Hoyo *et al*., 1996). This density falls within previous estimates in other areas e.g. Kisii 1.14 cranes/km^2 (Burke, 1965), Uganda 1.0 cranes/km^2 (Pomeroy, 1980), 1.57 - 2.89 cranes/km^2 in Kitale, Kenya (Gichuki, 1993) and 2.4 cranes/km^2 in Tanzania's Ngorongoro Crater (Amulike *et al*., 2020).

Biologically, the number of young is anticipated to be higher during the breeding period. In this study, a higher proportion were observed after the breeding season. This is because, during the parenting stage, most crane families prefer to hide in tall marshes and foraged in areas with shorter vegetation including cultivated fields after their chicks fledged when they were easy to observe. This high proportion also resulted from arrival of immigrant cranes that breed outside the study area when they moved in with their juveniles. While the juvenile data comprised both the fledged juveniles and unfledged chicks (as these were ramped together during data gathering), a young to adult ratio of 11.63% is within range of 10-15% which is an indication of a healthy population (Archibald & Meine, 1996). The improvement in breeding success that was observed in this study is attributed to conservation efforts and initiatives by Cranes Conservation Volunteers within and around Lake Ol' Bolossat who are working with the resident communities to reduce impending threats such as eggs and chicks' collection, adults trapping, and reduced disturbances from livestock and humans at the breeding sites during incubation and chicks rearing stages.

Although majority of the population observed were either occurring as individuals, pairs, family groups or small flocks, we acknowledge challenge posed by estimating large flocks especially when these were constantly moving while foraging, taking up brief fights, dancing or flying out. To increase accuracy in the estimates of such flocks and entire local crane population, the use of UAVs (unmanned aerial vehicles) or drones could be adopted particularly when counting in inaccessible marshes with poor visibility. UAVs are emerging tools that provide a much safer, cost-effective, and calmer alternative to conventional research techniques. They have often been used to record abundance of various wildlife, animal behavior, habitat selection and use, and waterbird surveys (Chabot *et al.*, 2015; Christie *et al*, 2016). They also have the advantage of quick coverage of the ground (thus reducing incidences of double counting), reduction in human resource capital besides providing an early detection and reliable estimates of emergent and floating vegetation coverage such as *Salvinia molesta*. Christie *et al.* (2016) recommends that use UAVs with prudence as they can instigate behavioral and physiological responses in wildlife markedly when observing at a close range.

Abundance, food distribution, and availability of suitable nesting sites are some of the key ecological factors determining the size of the home range of the Grey Crowned Crane (Archibald & Meine, 1996). This species' habitat choice and use (for foraging, nesting and roosting) and local movements in Lake Ol' Bolossat basin remained unknown until the current study. The species is however reported as non-migratory, or no good information is available to suggest any significant movements of the eastern and southern African populations (Johnsgard, 1983), but it is known to make irregular local and periodic movements dependent on the richness and distribution of food, availability of appropriate nest-sites and rainfall (Pomeroy, 1980a; del Hoyo *et al*., 1996).

Cranes spatial distribution in the study area was strongly influenced by crop's growing seasons. Cranes observed in this study occupied a variety of different habitats in different times of the year and seasons. This is because, habitat choice and foraging ecology of cranes is highly influenced by seasonal fluctuations in environmental conditions (Nowald *et al.,* 2018). Seasonal flooding of grasslands and marshes around the lake and along streams and rivers provided foraging opportunities that spread the cranes in a much wider area during the wet seasons due to increased food abundance (see chapter 6). Small fields (usually ≤0.5 ha) that looked potentially appropriate for cranes but were surrounded by a fence were largely avoided. This is probably because cranes prefer open fields with a good view of approaching danger such as humans and uncontrolled dogs, and requirement for some running space to achieve buoyancy for take-off. In many cases where smaller fields containing preferred forage were inhabited, these were often lying adjoining to unsuitable but open fields. Hence, safety is conceivably superior to food availability in choice of a foraging site. Thus, the weak relationship observed between size of foraging field and size of flocks suggests that flock sizes are not influenced by size of the fields as it would be naturally expected (that large expansive fields would be occupied by large flocks). The selection of a field may consequently be influenced by other factors such as imminence to human disturbance (e.g. roads, footpaths and homesteads), a crop's growing stage, type of crop, and food abundance and its accessibility within a particular field.

The western side of the lake had more concentrations of cranes owing to the presence of relatively flat and considerably large farms where maize, wheat and oat are grown in medium-scale. Large cereal fields similarly occur on the eastern side of the lake over the Satima escarpment (e.g. around Mairi Tisa along Mairo-Inya – Shamata road). These fields were avoided and unoccupied by flocks but were occasionally utilised by breeding pairs nesting in some of the upland man-made wetlands such as Simbara, Maji Mazuri and Ng'ombe Nguû dams. Local habitat and landscape attributes such as angle of slope of the escarpment could explain this general absence of cranes in these farms. Since most cranes roost in the lake's marshes, they would avoid the steep escarpment (remarkably inclined from Makereka southwards to Kirima and Kaka) gaining a 15% slope inclination that would undoubtedly demand a lot of energy to maintain steady wing beats for generation of a sufficient lift and thrust to enable the crane climb over the steep escarpment. Girma *et al.* (2017) observed slope as a suitable predictor for bird species abundance in a forested habitat. Direction and speed of prevailing winds, visibility and distribution of the rising coverage of power infrastructure could also be other factors influencing this avoidance.

Cranes spent the night and rested on trees, in the marshes and shallow waters at the edge of the lake in small to medium-sized groups, in pairs or in family groups. There are three main roosting sites in the lake: in the middle section at Ngurumo and Fuleni, and in the south at Kirima. Documentation of roosting sites is important in cranes conservation because they come together at these sites and are therefore susceptible to various forms of disturbances. Roosting sites commands cranes habits such as dairy local dispersal and utilisation of surrounding foraging fields (Allan, 1996). Knowing the location and distribution of roosting sites may offer opportunities when counting cranes where several counting could result to increased accuracy in determination of a local crane's population size. For instance, Zelelew *et al*. (2020) used roosting sites to estimate the population of Common (Eurasian) Cranes in Ethiopia because of their wide dispersal to foraging fields making daytime counting difficult. An early morning and late afternoon timing is nonetheless very important while counting at roost as cranes leave or arrive.

Cranes that foraged in fallow fields and grasslands often occurred together with livestock. Pairs rearing chicks and juveniles were also seen pecking on dry and fresh cattle dung exploring insects such as adult dung beetles and larval stages. As food accessibility became scarce in the crop fields (e.g. in harvested wheat fields), cranes abandoned these fields but returned instantaneously after they were burned (to reduce crop residual) or were ploughed, to take advantage of the exposed, unburnt waste grains, or the uncovered seeds after sowing. Breeding pairs with flightless chicks however remained in their breeding territories until the chicks fledged. Social needs such as pairing and the introduction of juveniles to flocks are also important factors in habitat choice and flocking behaviour in cranes (Archibald & Meine, 1996).

Noting an age of 37 years for the Greater Sandhill Cranes *G. c. tabida* from several decades of ring recoveries, Drewien *et al.* (2010) noted that most information on longevity for a bulk of the crane species are based on captive individuals. During this study, two previously marked adult cranes each bearing a white plastic colour ring were observed in the lake, one rearing a pair of chicks (G. Muigai, *pers. comm.,* 2 March 2019). Consultations with past researchers in the area confirmed that the two observations were part of a one-month old cohort ringed between July 1988 and March 1989 (Gichuki & Gichuki, *pers. comm.,* 28 April 2019). These marked cranes present fresh information on the longevity of a Grey Crowned Crane living in the wild of up to 32 years being compared to 20 years reported previously (Allan, 1996).

4.6 Conclusion

This study has shown that Lake Ol' Bolossat basin holds a substantial population of Grey Crowned Crane and is thus a key site not only in Kenya but also globally. Its fluctuation in size, age structure and social organisation over time as observed during the study period shows that it is not stable. The null hypothesis that "this population is stable in size, age structure and social organisation", is therefore rejected. Instability is caused by annual recruitment, emigrants, and departure of individuals.

This population was observed to utilise both natural (native grasslands and wetlands) and human-modified habitats (agricultural fields) in almost equal proportions throughout the year. The conversion of native terrestrial habitats from grasslands or marshes to uses such as growing of cereal crops especially wheat and maize has a positive impact due to Grey Crowned Crane's ability to adapt and utilise human-modified agro-ecosystems. The distribution of flocks was positively affected by distribution of these crop fields. During the study period, group sizes varied across the period and even within observation times in a day. This is as a result of depletion of food resources in the fields, discovery of new food sources forcing splitting and movement of individuals, and other dynamics such as individuals exchanging incubation duties. These observations supports Ward & Zahavi (1973) hypothesis that "roosting assemblies of birds serve as information-centres wherein knowledge of the location of food is shared". In most instances, a few cranes would be observed in newly harvested or sowed wheat fields on the material or a little later, and would have several tens to hundreds of cranes (sometimes mixed with doves and geese) the following day. The seasonality of the crops was also important in the spatial-temporal distribution of individuals and flocks. The increasing acreage of land under commercial hay production (e.g. Rhode's grass *Chrolis gayana*) will influence the distribution pattern of cranes in the basin. This could also lead to concentration of cranes in a few fields which may increase cranes-farmers conflicts due to crop depredation.

The occurrence of a high number of mated pairs along the shoreline and upland wetlands is a good sign that this is largely a breeding population. While the modal group sizes were the smaller groups of 1 to 20 cranes, the existence of large flocks in excess of 100 cranes (reaching a maximum of 332 individuals) may be an indication of reduction of suitable foraging fields that would evenly disperse the cranes. Large flocks pose a big risk in incidences such as poisoning or an infectious disease breakout. This is hence a challenge in their conservation that must be addressed through initiatives that ensure cranes are spatially spread out. Initiatives such as introduction of supplementary feeding sites and control of overgrazing in the riparian grasslands to retain a stand of grass to support an abundance of invertebrates and small vertebrates. Control measures could also be employed e.g. use of decoys and scarecrows (Fakarayi *et al*., 2016) in sowed grain fields, and dressing seeds with distasteful but safe insecticides to deter depredation. An animal control permit may however be required from Kenya Wildlife Service.

CHAPTER FIVE

5.0 REPRODUCTIVE BEHAVIOUR OF GREY CROWNED CRANE

5.1 Introduction

Information of environmental characteristics that regulate habitat attributes is indispensable in developing operative strategies for preserving and restoring natural areas (Hobbs, 2003). Nest-site selection is an integrative behavioural process that evolved in species to maximize reproductive success (Catlin *et al.*, 2019). Therefore, understanding which fundamental variables motivate nest-site choice in a species is the first step regarding its effective management and conservation (Hobbs, 2003; Swaisgood *et al*., 2018; de Loock, 2019).

Nest-site selection involves the definite optimal conditions of a site in a habitat on which to construct a nest. Nest-sites are an important part of an animal's niche (Gould, 2008). They are a major determinant of reproductive success for many organisms since the quality of a nest-site is habitually connected to a species' breeding achievement (Jones *et al.*, 2014). It is also a fundamental factor in the survival of a species through generations and is often a scantily known component of many organisms' investment towards reproduction (Baden, 2018). The choice of a nest-site determines the existing resources and threats that the animal and its offspring have to struggle with, making it an essential fitness-related resolution (Tolvanen *et al*., 2018).

The Grey Crowned Crane is a solitary bird (living as a pair or a family unit) during the breeding season whereas non-breeders congregate in foraging fields forming flocks. Mating for life, the nesting behaviour starts with a courtship dance with the male as the aggressor (Walkinshaw, 1964). Archibald & Meine (1996) reported that the species breeds all year round in eastern Africa. However, this observation is site-specific and should not be generalized because of weather variability in the region. These cranes nest in moist habitats, preferring those with standing water 80-180 cm deep with knee- and shoulder-high sedges, where the nest platform is usually constructed over a mound of heaped aquatic vegetation collected around the nest-site by both sexes (Walkinshaw, 1964). A clutch of 1-3 (and very rarely 4) bluish-white eggs that turn brownish through the 28-30 days' incubation period are laid (Archibald & Meine, 1996).

Despite Morrison (2015) having omitted Lake Ol' Bolossat as one of Kenya's fundamental sites for the Grey Crowned Crane, the 2019 countrywide census elucidated the lake as a population stronghold, ranking second to Maji Mazuri, Eldoret (Wamiti *et al*., 2020). Information on total breeding pairs and densities in different parts of Kenya is currently scarce, with most of the published work being on conservation (Beilfuss *et al*., 2007) and population and ecology (Gichuki, 1993; Amulike *et al*., 2020). Morrison (2015) listed factors influencing breeding productivity as an essential knowledge gap that impede operative implementation and regulation of the species' conservation programmes. The outcomes of this study will be valuable in finding application in other parts where the species occur such as in addressing threats affecting their nesting habitats.

The variables measured at the nest-sites and statistically tested in this study were those known to have compelling biological influences on the choice of a nest-site location based on food and nesting materials availability and nest concealment and susceptibility to predation. Hence, it was hypothesized that cranes chose sections of the lake with water deep enough to deter terrestrial predators (Jedlikowski *et al*., 2014) and as a determinant factor in availability of macro-invertebrates and small aquatic vertebrates (Baumgärtner *et al*., 2008), but avoiding flooded areas close to the shoreline. Therefore, the preference for a nest-site was predicted to be positively related to both water depth and offshore distance of the nest. Factors that reduce the complexity of vegetation structure around the nest such as grazing might impede cranes from hiding their nests from predators. Therefore, nest-site selection was predicted to be negatively affected by grazing intensity and positively affected by vegetation height.

5.2 Aims

The intention of this part of the study was to add to the knowledge gap existing on key features that influence the selection of a nest-site by Grey Crowned Crane. The specific targets were:

i. To assess the environmental variables that persuade nest-site selection by the cranes in the study area.
ii. To determine the distribution and density of territorial pairs of cranes in the study area.
iii. To describe the characteristics of the nest and eggs of cranes in the study area.

5.3 Materials and Methods

5.3.1 Mapping territorial pairs and nest searching

Mapping of crane pairs occupying territories was carried out to determine the number and positions (distribution) of Grey Crowned Crane pairs utilising the lake for breeding. The entire 80 km long shoreline was accessed at appropriate locations that were 1 to 2 km apart, from where pairs of cranes were comprehensively searched in the marshes by means of a pair of 10x42 binoculars and a x60 zoom telescope. Since cranes prefer sites with high vegetation for cover during the breeding period, pairs are difficult to detect in their territories. Therefore, performing a regular survey protocol (systematic sampling of equally sized plots around the shoreline) required higher sampling effort. The shoreline was covered by walking or driving to detect territorial pairs. Searching was made easier because of the visibility of the cranes due to their considerable body size and prominent white wing patches.

Vegetation height may however have affected detection of pairs as this varied in different parts of the lake. When a pair was present, the location was marked with a GPS and its relative position inside the wetland was approximated in Google Earth Pro. The narrow (120-450 m) width of the lake, a contracted size of marshes occurring between the shoreline and the open water, and sometimes non-existence of emergent vegetation such as reeds and typha, improved detection of territorial and nesting pairs.

A territory is an area that an animal protects from access and use by other animals of the same or sometimes different species, and may sometimes involve being hostile to intruders. A crowned crane territory was hence considered as having been occupied by a pair if either or all of the following observations were made: i) nesting materials gathering, actual nest building or a pair present in a site with either a complete or incomplete nest, ii) seen lying on the nest hence contemplated as incubating), iii) feeding flightless chick(s), and to a lesser extent iv), pair recorded present more than once in a specific site and showed some intimate courtship behaviour, such as standing face-to-face with their bills touching, bobbing their heads or copulating.

Mapping and confirmation of pairs was held during the peak (December) of the 2017/2018 breeding season to detect numbers of pairs that had occupied breeding territories. Subsequent, infrequent visits continued throughout the study period to monitor breeding activities, detect new nests that were accessible for measuring, and to collect data for other objectives of the entire study like population and threats. A breeding season was contemplated as the period between the laying of the first egg and fledging of the last chick, the duration of which was not uniform in the three seasons comprehensively covered by this study.

Unlike mapping of the territorial pair survey whose period was specified, accessible nests were measured throughout the study period to increase the sample size and capture seasonal changes.

Location of nests was discerned from cues such as nesting pair behaviour when an individual was going for a nest relief. The pair of 10x42 binoculars and telescope were additionally used to scan in the marshes for incubating or feeding cranes. Collecting data on nesting waterfowl however involves feasible disruption to nesting birds, through direct (handling of eggs) or indirect (walking near birds on nests) effects (Austin & Buhl, 2008). Besides, Grey Crowned Crane nests are also difficult to locate from the ground (Morrison & Bothma, 1998). With these considerations, nests were not actively searched as this would have possibly resulted in trampling on vegetation in the breeding habitats, causing disturbance to nesting birds and exposing clutches and chicks to poachers. Nests were thus visited once to record measurements.

5.3.2 Nest and nest-site measurements

To determine the key features of a Grey Crowned Crane nest placement habitat, nests were searched in the marshes. Measurements of environmental variables of accessible nests and at potential sites were made during the first, and only visit to the nest-site. The following data were recorded:

- Habitat type (shallow wetland or deep wetland >1.5 m).
- Water depth around the nest (average of four samples gained at 1.5 m from the centre of the nest at each cardinal point: north, east, south and west).
- vegetation height around the nest (procedure was the same as for the water depth).
- Offshore distance of the nest (obtained by marking the nest position and the water edge, then using the GPS "go to" function which gave the actual distance).
- Estimated distance to the nearest active nest (to determine potential size of the territory).
- Grazing intensity which was scored as either: 0 (no faecal remains, vegetation intact, no spoors); 1 (low: scattered faecal, slight grazing, scattered spoors); 2 (medium: faecal

remains evident, vegetation grazing more evident: or 3 (high: faecal remains around the nest, dense spoors and intensive grazing), and

- Nest features: length and width, height above water, cup depth and cup/rim diameter.

The purpose of randomly selected potential nest-site for each active nest was to compare its characteristics with those of active nests. These were placed at 15-25m in any direction of the active nest to avoid territory overlap with neighbouring nests. Random nest-sites were not necessarily sites that cranes might never use or have never used, but were unused sites during data collection with potential characteristics for nesting, and could be used in the future.

5.3.3 Egg morphometrics

The following data and measurements were taken at each active nest (one with eggs and/or chicks): nesting stage (nest construction, laying, incubation or hatching/hatched), clutch size (number of eggs), and for each egg in the clutch, breadth (or width) and length (mm), weight (g), and a description of the shell colour of each egg. Grey Crowned Crane eggs change their colour from bluish-white at laying to brownish at hatching, the latter being as a result of stepping on and turning with muddy legs and bill respectively. This helped in estimation of laying and expected hatching date (see also section 2.4). A photograph of the clutch was also taken. Egg volume (cm^3) was calculated following formula after Hoyt (1979) and Chandan *et al.* (2019).

Volume = 0.51 (Length x $Breadth^2$), *where* 0.51 is an egg volume coefficient (K_v).

5.3.4 Statistical analysis

Generalized Mixed-Effects Linear Models were chosen assuming binomial family and logit link function to investigate how the selection of a nest-site (1, presence of nest *vs* 0, absence of a nest) was influenced by four (out of the 12 measured variables) that were considered as the most influential biologically. These four predictor variables were water depth, vegetation height, offshore distance of the nest and grazing intensity. The identity of the pair of nests (actual and potential nests) was included as a random intercept in the models to control for potential non-independence of paired nests. Tests for multi-collinearity (using the Variance Inflation Factor, VIF) and over-dispersion (computing the parameter Φ) were performed in all models, and predictor variables were log-transformed for normalization.

It is generally accepted that there are no perfect models and that they only predict reality. An information-theoretic approach was hence applied to examine the importance of each predictor variable included in the model (Burnham & Anderson, 2002). The full model including the four ecologically important environmental variables was compared against simpler models with all potential combinations of predictor variables (random factor and intercept always included) using the Akaike Information Criterion corrected for small sample sizes (AICc; Burnham & Anderson, 2002). Interaction and quadratic terms were not included in the analyses because no prior hypotheses justify including these terms, and the small sample size limits the capacity of inferring complex interactions between predictor variables. The significance values of the predictor variables in the best candidate model (i.e. the one with the lowest AICc) were then computed using Type III Wald chi-square test. This test (Wald) was used to find out if the explanatory variables in a model were significant (i.e. if they added any value) (Glen, 2020). Mixed-effect models were fitted using the R package *blme* (Chung *et al*., 2013) in R v3.5.3 (R Core Team, 2019).

To assess area of marshes in the lake's sections and an upland wetland for approximation of pair densities, the Google Earth's 'Add Polygon' tool was employed. Calculations, computations of statistical tests and descriptive statistics were accomplished using

Paleontological Statistics Program (PAST) Version 4.03 (Hammer *et al.*, 2001) and Microsoft Excel. The significance level for all the statistical tests was taken at $p \leq 0.05$.

5.4 Results

5.4.1 Distribution and density of territorial pairs

Lack of adequate detection probability data limited computation of pair densities since systematic sampling, where observation points are equally spaced in the study area, was not adopted. This is because of accessibility limitations in some parts, heterogeneity of aquatic vegetation, and absence of cranes breeding habitat (marshes) in a 4.5 km shoreline on the south-western part of the lake. A total of 123 pairs were mapped as occupying a territory during the peak of 2017/2018 breeding season in the month of December. A larger proportion (84%; 103 pairs) were recorded across the lake's marshes at a mean density of 5.00 pairs/km^2. The uppermost density of territorial pairs was recorded in the southern section of the lake at 6.24 pairs/km^2 with the middle section following at 5.42 pairs/km^2. Density in the northern section was the lowest at 3.23 pairs/km^2 despite this section having the largest area covered by marshes, e.g. the extensive Kianjata marshes had a density of 2.61 pairs/km^2. The study sites with the highest number of pairs were Ngurumo and Kirima, each with 10 pairs.

The rest of the (20) were distributed in the upland wetlands around the lake. The southern section of the study area however had the most pairs (12) occupying territories, majority (7) being at Robert's Dam at a density of 10.9 pairs/km^2 (0.12 pairs/ha). During the study period, 61% (62 pairs) of the pairs recorded in the lake made an attempt to breed compared to 80% (16 pairs) in the upland wetlands. Overall, the middle section of the study area had the highest number of territorial pairs (48) closely followed by the southern section at 44 pairs.

The population of herbivores (livestock and hippopotamus) that are dependent on the riparian grasslands and marshes for grazing were also estimated during the mapping of territorial pairs. In the wet season (October) livestock survey of 2019, sheep were most abundant at 60.59% followed by cattle (35.64%), while donkey, goats and feral domestic dogs comprised of 1.83%, 1.62% and 0.31% respectively. The southern section, in addition to having a relatively large number of territorial pairs, also had the highest number of herbivores because of the huge area of riparian grasslands. Table 5.1 shows the distribution of territorial pairs in every sector of the study area, the lake, and upland wetlands as well as their pair densities.

Table 5.1: Distribution of territorial pairs (Br.: breeding; Non-Br: non-breeding) and pair densities in each section of the study area.

Section of study area	**Lake Ol' Bolossat**			**Upland wetlands**			Section total pairs	Pair density (pairs/km^2) (lake only)
	Br.	Non-Br	Total	Br.	Non-Br	Total		
North	21	3	24	6	1	7	31	3.23
Middle	21	26	47	0	1	1	48	5.42
South	20	12	32	10	2	12	44	6.24
Total	62	41	**103**	16	4	**20**	**123**	**Ave. 4.96**

Figure 5.1 shows the spatial distribution of the territorial pairs in each section of the study area.

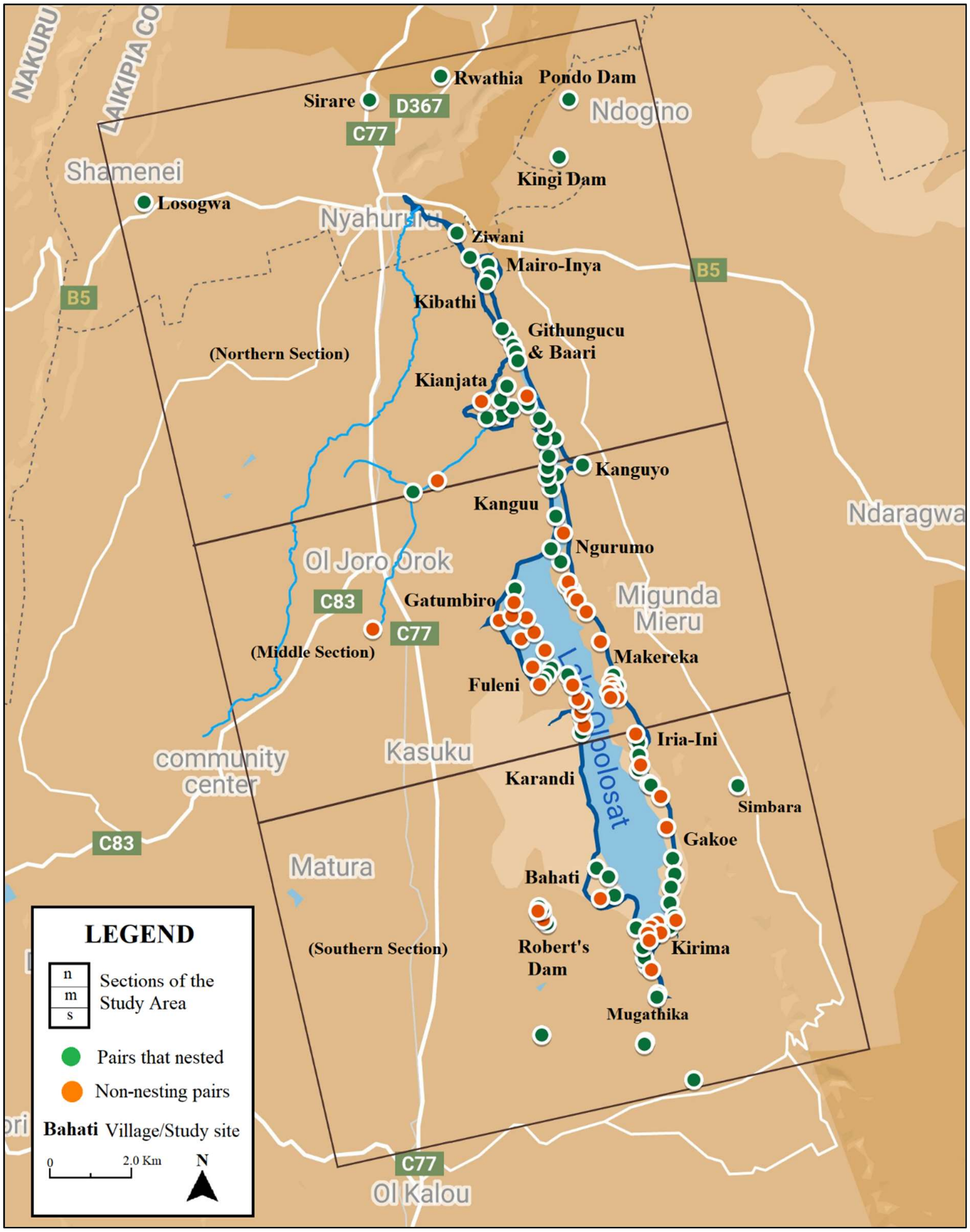

Figure 5.1: Spatial distribution of territorial pairs during the 2017/2018 breeding season in each of the three sections of the study area. (Map developed and improved from Google My Maps)**.**

The mean distance between any two neighbouring pairs was 302.53 ± 17.02 m, and a minimum and maximum of 47 m and 759 m respectively. The majority (20) of the pairs' nests positions were in the range of 201-280 m (n = 20, Figure 5.2). Nesting density (number of nests) was linked to distribution of marshes (a habitat variable) where territories were acquired and defended, nests constructed and chicks reared.

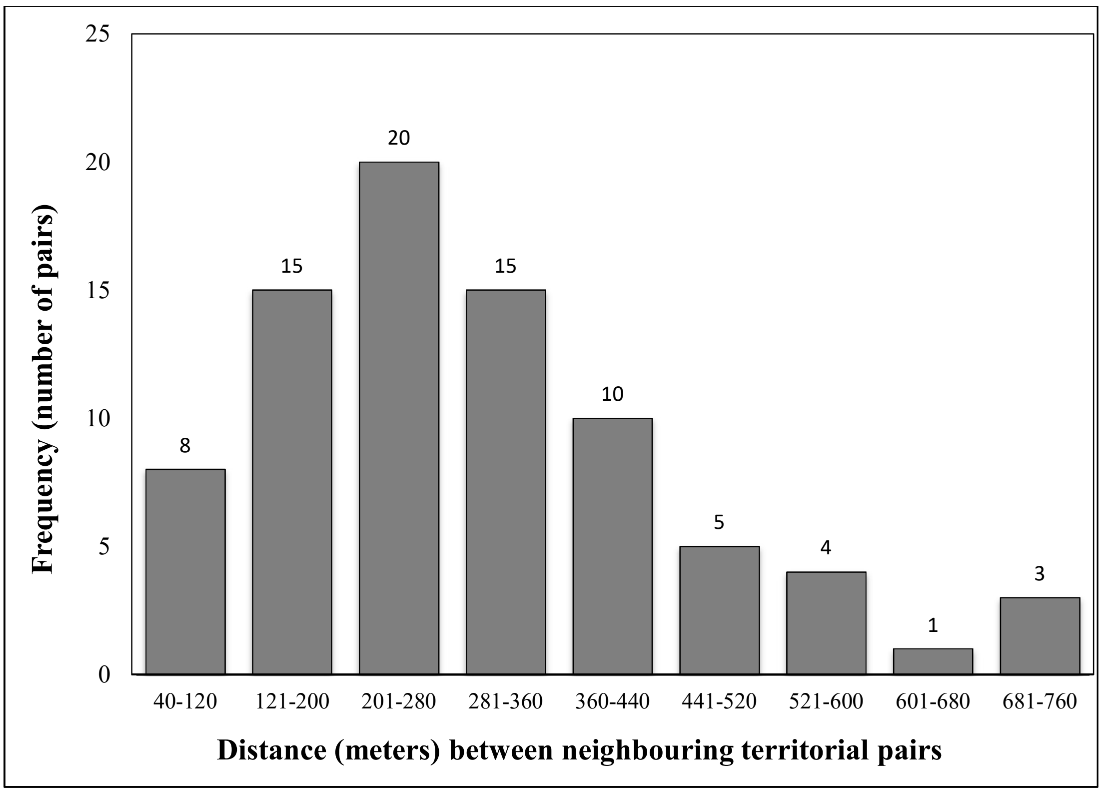

Figure 5.2: Distribution of Grey Crowned Crane territorial pairs in different bands of nest-to-nest distances.

These distances varied in different clusters of nests throughout the lake and would be expected to vary in different breeding seasons and in the future as new pairs take up or change territories and as conditions in the breeding habitat change, necessitating shifting of nest positions or abandoning breeding sites for new ones. Male cranes seldom fought each other over a territory. This made determination of territory size and foraging range difficult. However, in Kianjata marshes in the northern section, pairs with chicks foraged within an average area of 8.5 ha especially when chicks were big (> 8 weeks old) and marshes were much drier (signifying that a wider area was covered in search of food). Although not assessed in this study, much smaller sizes of territories may be held in sections of the lake where territorial pair density was higher such as in the middle (5.42 pairs/km^2) and southern part (6.24 pairs/km^2).

5.4.2 Factors influencing nest-site selection

A total of 30 accessible nests in the lake and three in the upland wetlands were measured. The 30 nests in the lake were unevenly distributed in the three sections (i.e. north 14, middle 9, and south 7) and were hence representative of cranes' breeding habitat. These nests were located in the lake's marshes surrounded by varying depths of standing water, where the mean water depths were: north (35.76 cm), middle (55.76 cm) and south (64.86 cm), with a range of 14.2–123.63 cm.

Among variables measured at the nests and random sites, four were considered as most important biologically and were therefore chosen for inclusion in the multiple regression model. These variables were water depth (Wd), vegetation height (Vh), offshore distance of the nest (OSD) and grazing intensity (Gr). One approach to determination of the most influential factors was to analyse the significance (*p* value) of each variable in a multiple regression model on which nest-site selection depended on these four variables. This approach was however inadequate since the significance level of each predictor variable depended on what variables were included in the model test (for example, Wd + Vh + OSD + Gr yields different results than Wd + Vh + OSD, or any other combination).

Akaike Information Criterion (AICc) was therefore used as an indicator to select the best combination of the four variables. In this case, the model with the lowest AICc is the one that gave the most influential variables and was described as the best-fitting model after which the significance level of each variable were calculated. AICc is important in estimating the quality of different models, and is useful in comparison and ranking of multiple models where the best-fitting model is defined as one that best approximates the more influential variables (Symonds & Moussalli, 2011).

Correlations between these predictor variables were first tested for multicollinearity. In regression analysis, multicollinearity is a statistical incident in which two or more predictor variables in a multiple regression model are highly correlated i.e. one predictor variable in a multiple regression model can be linearly projected from the other variables with a considerable degree of precision (Daoud, 2018). The Variance Inflation Factor (VIF) values were low (<1.3), and models did not show evidence of overdispersion ($\Phi \approx 1$), and therefore all predictor variables were included in the model without correcting for multicollinearity or over-dispersion.

The model selection procedure yielded a single best model (with ΔAICc <2 as an indicator of the best combination of variables) containing three (of the four tested) predictor variables (Table 5.2). In this table, each of the 15 rows contains one model (intercept + predictor variables + random factor), the number of degrees of freedom (df) of that model (i.e. number of parameters including the intercept, predictor variables and random factor), and AICc of the model as well as its weighted AICc (ΔAICc i.e. the difference between the AICc of that model and the AICc of the best-fitting model (Bernadou *et al.*, 2015)). The intercept is the point where the function crosses the y-axis i.e. the expected value of Y when X = 0.

As shown in the table (5.2), the AICc informs on whether including a new variable in the model significantly improves its predictive capacity. The best fitting model has the lowest AICc i.e., it explains more of the response variable with the minimum number of variables

(Wd + Vh + OSD). The table is thus ordered from the lowest to the highest AICc. The convention is that an increment >2 in relation to the model with the lowest AICc denotes that the model is significantly worse (Angelier *et al.*, 2011). In this case, the second model (the one in the second row, Tale 5.2) is already 2.17 higher than the first one (the best model, in the first row). There is therefore a single combination of variables that maximizes the explanatory capacity.

Table 5.2: Models selection: Each row is a candidate model, while the columns contains parameter estimates for predictor variables.

[(Water depth (Wd), vegetation height (Vh), offshore distance (OSD), Grazing intensity (Gr), and identity of pair of nests (included as a random factor, RF in the models)].

Intercept	Wd	Vh	OSD	Gr	RF	df	AICc	ΔAICc
-29.67	3.26	1.20	1.26		0.89	5	56.55	0.00
-26.82	2.98	1.06	1.20	-0.38	0.94	6	58.72	2.17
-21.96	2.95		1.45		0.67	4	59.18	2.62
-19.13	2.64		1.30	-0.73	0.74	5	59.22	2.67
-25.97	3.34	1.35			0.69	4	59.67	3.12
-21.70	2.88	1.13		-0.60	0.76	5	60.75	4.19
-12.72	2.43			-0.94	0.60	4	62.95	6.40
-15.62	2.82				0.50	3	66.11	9.56
-8.32		0.75	1.26	-0.80	0.70	5	69.26	12.71
-4.03			1.25	-0.94	0.62	4	69.91	13.36
-10.66		0.93	1.45		0.59	4	70.49	13.94
-5.77			1.51		0.51	3	73.91	17.35
-3.16		0.74		-1.07	0.54	4	74.72	18.17
0.98				-1.21	0.47	3	75.72	19.17
-6.03		1.10			0.40	3	81.73	25.17

Since the ΔAICc of all the other models are greater than 2, they are considered to be worse than the first model that has three parameters (excluding the grazing intensity). In other words, including the grazing intensity in the model does not improve the predictive capacity of the model. There is only one best-fitting model that does not contain grazing intensity. Therefore, it can be concluded grazing intensity is not an important factor since does not have a significant effect on nest-site selection.

The table 5.3 shows the parameter values of the best-fitting model, i.e. the estimate, standard error, Type III Wald chi-squared tests and the significance level (*p* values) for each parameter. The identity of the pair of nests is included as a random factor (RF). The three variables that had a significant influence on nest-site selection (Table 5.3).

Table 5.3: Significance levels of the best mixed-effect model that included the three most important variables.

Parameters	Estimate	Std. Error	Type III Wald χ^2	*p* value
Intercept	-29.67	9.26		
Random factor (RF)	0.79	0.89		
Water depth (Wd)	3.26	1.16	7.95	0.005
Vegetation height (Vh)	1.20	0.57	4.45	0.035
Offshore distance (OSD)	1.26	0.61	4.35	0.037

Figure 5.3 shows the relationship between nesting probability for each of the three most important predictor variables. The black circles indicate either the presence (active nest, top row) or absence (random/potential nest-sites, bottom row) while the curved lines and the shaded areas, respectively, shows the standard errors and fitted values (95% CI). The Grey Crowned Cranes hence seem to prefer to place their nests in water with a depth of

approximately 50-100 cm, vegetation of at least 60 to 90 cm high and at an offshore distance of over 100m.

The figure also shows that majority of the nests (33.3%) were located in a water depth region varying between 21-40 cm while 39.4% were positioned at 21-60 m from the water edge, and 57.58% were within a vegetation regime of 21-60 cm high. Tus, in all the three variables, cranes are seen trying to balance between accessibility to food resources (in the shallow marshes and adjacent riparian grasslands), visibility and concealment when incubating and safety of incubating adults, eggs and chicks.

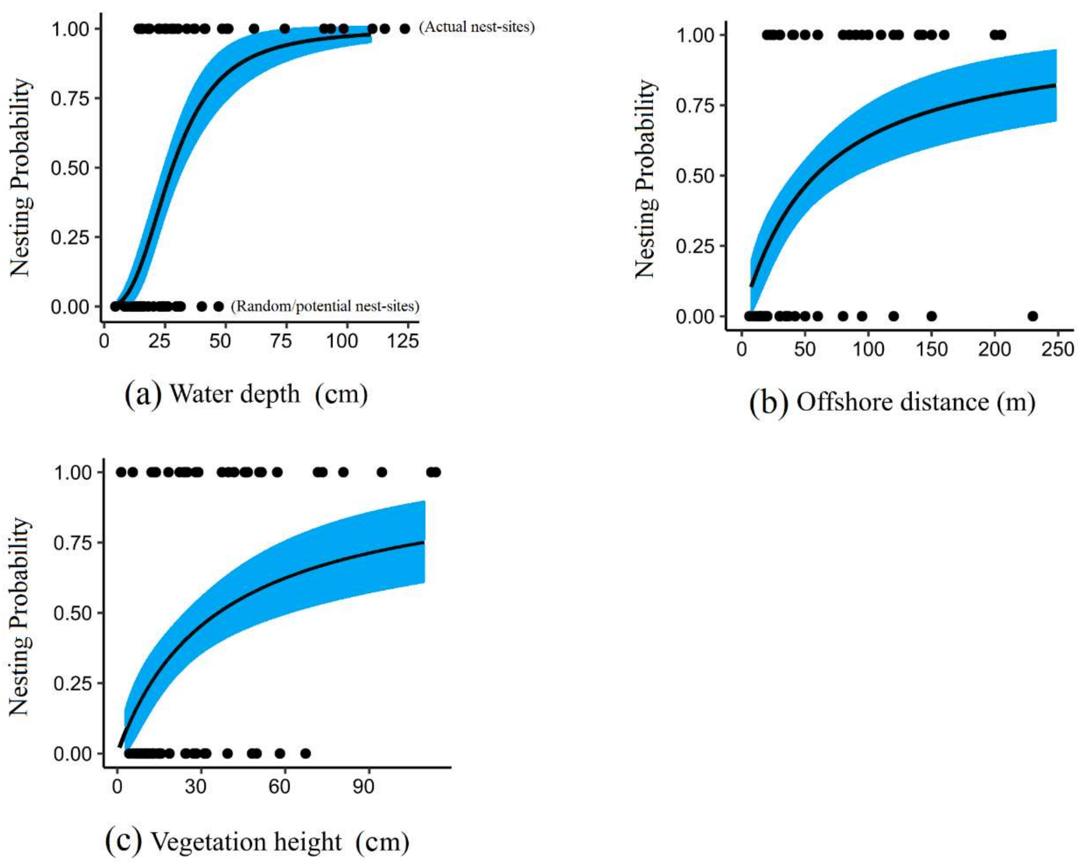

Figure 5.3: Relationship between nesting probability for the three predictor variables.

The influence of grazing intensity in nesting probability is illustrated in Figure 5.4. Since the intensity scores are discrete values of 0 to 3, it was not informative to show the actual presence/absence data (i.e. 0 or 1). Instead, the graph was plotted using the mean and standard error of the presence at each grazing level (i.e. mean proportion of nests and standard errors). Although there is a negative tendency, the standard error is very high (the error bars overlap among grazing intensity levels). Thus, the effect of grazing was non-significant in determining nest-site placement and consequently, it was precluded in the process of best-fitting model selection. In this figure, the black circles represent the mean of the presence values (0, 1) at each grazing intensity level (i.e., the fraction of nests at each level) while the bars represent the standard deviation. The left inclined straight line is the probability estimated by the model whereas the shaded area (blue) shows the confidence interval.

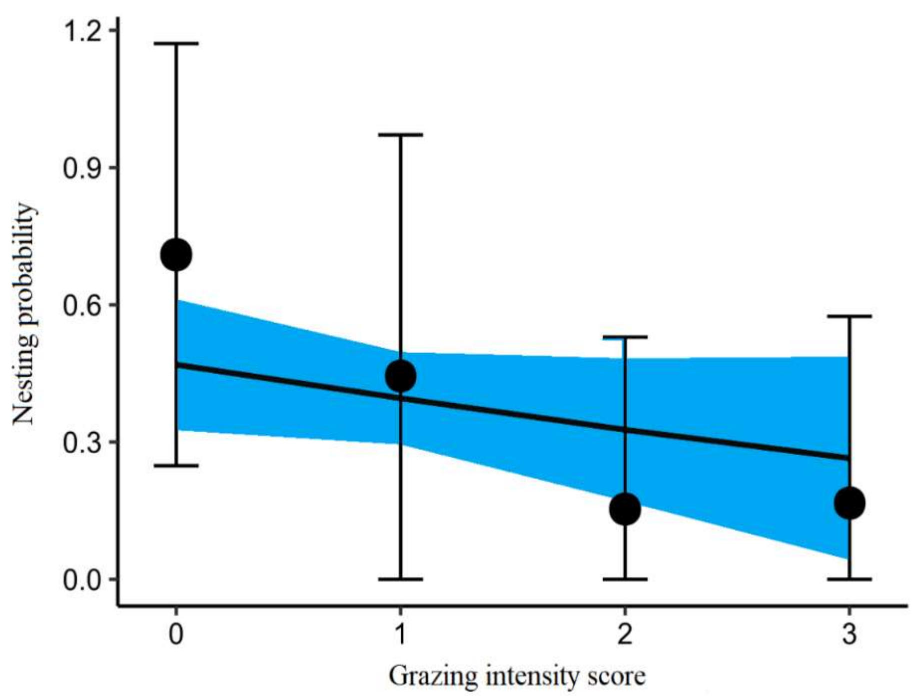

Figure 5.4: Relationship between grazing intensity and nesting probability: the probability of nesting decreases with an increase in grazing intensity.

5.4.3 Characteristics of eggs and nest of Grey Crowned Crane

Thirty-one (31) clutches with a mean of 2.23 eggs/clutch and a range of 1 to 4 eggs were described. The modal clutch size was three-egg with a total of 12 clutches and 36 eggs. There was only one occurrence of a four-eggs clutch (Figure 5.5).

Figure 5.5: A four-egg clutch and typical nest of Grey Crowned Crane in Lake Ol' Bolossat.

Nearly half (45%) of the clutches were in the northern section while the southern and middle section had almost identical proportions at 26% and 23% respectively. The rest of the clutches, 6%, were distributed in the upland wetlands (Table 5.4).

Table 5.4: **Distribution of various clutch sizes in the three sections of Lake Ol' Bolossat and the upland wetlands.**

Clutch size	Lake's Sections: north	middle	south	Upland wetlands	No. of clutches	Total eggs in each clutch
1 Egg	3	2	2	0	7	7
2 Eggs	4	5	0	2	11	22
3 Eggs	6	1	5	0	12	36
4 Eggs	1	0	0	0	1	4
Total	**14**	**8**	**7**	**2**	**31**	**69***

*This total excluded an oviduct egg from a power transmission line collision casualty.

The mean water depth around nests in each section were: north (35.76 cm), middle (59.91 cm) and south (66.93 cm), and had no significant difference among the three sections (One-Way ANOVA: $F = 2.935$, df = 2, $p > 0.05$). Mean vegetation height around the nests were north (57.79 cm), middle (27.43 cm) and south (46.64 cm), and did not differ significantly among the sections (One-Way ANOVA: $F = 2.711$, df = 2, $p > 0.05$).

Mean weight for the eggs was 143.57 g (n=69), and was not significant among the four clutch types (One-Way ANOVA: $F = 2.105$, df = 3, $p > 0.05$). Similarly, the mean lengths of the four clutch types were not significantly different (One-Way ANOVA: $F = 0.689$, df = 3, $p > 0.05$). Some of the clutches observed had freshly-laid eggs whose weight ranged from 140 g to 165 g, although there was an extreme of some eggs weighing 170 g to 215 g. Table 5.5 is a summary of egg measurements from 30 nests (lake) and 3 (upland wetlands). The weight of eggs was more variable than the other metrics because these were at different stages of embryo development i.e. ranged from freshly-laid to near-hatching eggs, the former weighing more than the latter.

Table 5.5: Descriptive statistics of Grey Crowned Crane eggs' morphometrics measured in Lake Ol' Bolossat basin.

	n	**Mean**	**Minimum**	**Maximum**	**SE**
Clutch-size	31	2.23	1	4	0.15
Mass (g)	69*	143.57	95	215	2.79
Length (mm)	70	83.53	70.4	89.7	0.45
Breadth (mm)	70	56.79	51	61.4	0.28
Volume (cm^3)	70	137.85	98.16	163.8	1.75

*A stale egg weighing 65 g was excluded in the analysis.

The mean distance between any two nests was 400±78.69 m with a minimum and maximum of 47 m 1.55 km respectively. Five pairs of cranes made a second nesting attempt during the study period but none of them used the same nest. Nevertheless, they all placed their new nests some few meters from the old nest's position thus showing some level of nest-site fidelity.

Table 5.6: Habitat variables measured at 33 nests of Grey Crowned Cranes in Lake Ol' Bolossat basin.

Parameter	**Mean**	**Minimum**	**Maximum**	**SE**
Nest length (cm)	77.48	46.00	116.00	3.56
Nest width (cm)	65.07	9.00	109.00	3.38
Nest cup depth (cm)	6.27	3.00	11.50	0.31
Nest height above water (cm)	19.16	3.00	54.00	1.63

The nesting materials used by Grey Crowned Crane in nest construction were gathered from the nest vicinity and comprised of sedges (*Schoenoplectus corymbosus* and *Cyperus exaltatus*), grasses (*Leersia hexandra*) and forbs (*Typha domingensis, Salvinia molesta, Persicaria* sp. and *Lythrum rotundifolium).* The dominant vegetation in the vicinity of nest position constituted the bulk of the nesting materials. In areas with tall vegetation, cranes made use of their bill to slash and heave the materials together to make a mound on which the nest cup to hold eggs was made. In this study, six of the 33 nests had the area around them cleared of vegetation ranging from 5 m^2 to 16 m^2. In nests with freshly-laid eggs, some of the nesting materials were still fresh while a few others were incomplete at the start of laying.

5.4.4 Duration of the breeding season

In this study, the breeding season was considered as the period between start of nest construction followed by of first clutch and fledging of the last chick. This study run through three breeding seasons (2017/18, 2018/19 and 2019/20) during which the long rains arrived as early as March and as late as July. Nest construction and egg-laying were observed only after certain water depth and vegetation cover were attained in the nesting habitats. The three breeding seasons were of different lengths (months). The shortest of the three seasons was the 2017/18 which lasted for eight months (between July 2017 and February 2018) which was followed by the longest season (2018/19) lasting for 13 months (from April 2018 to April 2019). The 2019/2020 season continued for 11 months from August 2019 until June 2020.

5.4.5 Age categories of Grey Crowned Crane

Three of the most distinct and easily distinguishable age categories observed in the field were downy chicks, juveniles (including immature birds) and adults. Sub-adults were also encountered mostly in the foraging flocks. A newly hatched young (Figure 5.6-A) is covered in buffy down feathers with a slaty grey bill, pale ivory egg tooth and a brown eye (Walkinshaw, 1964). The chicks shown in this figure hatched in synchrony and were therefore two days old (right chick) and one-day old (left chick). Respectively, their measurements were: weight (80g, 75 g), head (46.3 mm, 47.0 mm), bill (18.3mm, 17.8 mm), tarsus (34.6 mm, 34.1 mm) and middle toe (32.3 mm, 32.4 mm). The third egg (weighing 105 g) hatched on the third day but the chick could not be measured to minimise disturbance.

Juveniles (Figure 5.6-B) are described as generally greyish with a spiky golden and buffy crest, a brown iris and legs and toes in transition from pink to horny and finally black (Johnsgard, 1983). Sub-adults have full adult plumage but they will not have the throat wattle (gular sac) and the red above the white facial marking. The adult plumage is attained at c.12 months (Johnsgard, 1983), while the adult eye colour and complete development of the throat wattle and facial markings are attained at c.24 months of age (Pomeroy, 1980b). The adult Grey Crowned Crane (Figure 5.6-C) has a predominantly grey and generally loose plumage, contrasting colour pattern on the head with colourful facial markings, and a distinct black-tipped golden crown. The Adult male and female of all crane species are identical in external features, although males are usually somewhat larger (Archibald & Lewis, 1996).

Figure 5.6: Three age categories of Grey Crowned Crane.

[A] Newly-hatched chicks, egg and nest; [B] an approximately 18 weeks old juvenile; [C] Adult.

5.5 Discussion

This research has found that there are three environmental variables that appear to be quite influential in nest-site selection by the Grey Crowned Crane. These are water depth, vegetation height and offshore distance of the nest. These results provide key insights into features of the species' nesting habitat requirements i.e. it prefers wetlands with standing water of at least 50 cm deep surrounded by tall vegetation of 60 to 90 cm and at least 50 to 100 m inside the wetland from the shoreline.

A nest platform of aquatic vegetation such as reeds or floating bogs comprising of sub-merged grasses and reeds are needed in a nest-site location. It is on this platform that cranes heap a matt of vegetation to make a cup to hold the eggs for incubation. Nest-sites with emergent vegetation around the nest were mostly observed in shallow marshes of under 50 cm deep. Other nests were however located in areas without an emergent vegetation cover at all, but were inaccessible to terrestrial predators due to a water depth exceeding 1 m. In such cases, water depth could have been among the critical factors considered in choosing such locations. Water depth is not only an important predictor variable as a predator deterrent but also in invertebrates abundance that forms a larger percentage of the diet of parental adult Grey Crowned Cranes (Gichuki, 2000).

Although results indicate offshore distance as a critical factor, nests located in upland wetlands were in small marshes in farmlands surrounded by crop fields or grasslands with a high influx of humans and livestock. This could be an indication of scarcity and/or deterioration of traditional breeding sites in the lake and hence cranes are desperate of nesting opportunities.

Whereas grazing intensity was not identified as predictor variable in nest-site selection, vegetation around a crane's nest is important in concealment from terrestrial predators (Muheebwa-Muhoozi, 2001). Vegetation structure is also known to affect waterfowl in several ways such as decrease in the number of nesting pairs and broods (Harrison *et al.*, 2017). Livestock grazing has the capability to lower the quality of a cranes' reproduction habitation and contribute to unsuccessful nests (Ivey & Dugger, 2008). Gosai *et al*. (2016) observed disturbance from cattle and buffalos that led to damage of nests and loss of eggs on nesting Sarus Cranes. Grazing could also impact on vegetation succession whose composition and structure is less suitable to Grey Crowned Crane (Morrison, 2015).

The distribution of territorial pairs across the lake could be an insinuation of the distribution, abundance and availability of resources particularly food However, it could also be an indication of degradation of alternative breeding habitats in the upland wetlands and increased human disturbance that coerce cranes to congregate in a few 'safer' sites. This may result in competition for resources (Watson *et al*., 2014). Distribution patterns may also explain the different portioning of basic resources that cranes require for breeding. Where there are clusters, smaller territories are held compared to other situations where pairs are more dispersed.

It was observed that territories were only assertively safeguarded at occupation, nest-building and incubation stages. Attention of intruders befell less important ensuing hatching when the parental pairs diverted their interest concentrating on rearing the chicks and providing them with protection. There was an overlap of families in use of territories after hatching This insinuates that the size of the territory of the Grey Crowned Crane is not fixed and is only functional at certain period of the breeding season with its size shrinking with advance in the breeding season activities. When resources are clumped in their distribution, defending a territory becomes meaningless and territoriality breaks down (Urfi 2003). This reduction in size of the territory and its defence observed in the study area may therefore be as a result of diversion of attention from territory defence to feeding the chicks and surveillance for danger to increase chicks' survival.

Grey Crowned Cranes occupied territories in all sections of the lake excluding a four-kilometre long expanse on the south-western shores of the lake between Karandi and Bahati villages. The lake shoreline in this section is has no marshes (that cranes require for feeding and nesting) while the shoreline has a steep edge. The riparian section is also covered by dense *Pennisetum spacelata* tussocks reach over a 1 m tall which is inappropriate for cranes due to obstructed visibility and associated high risks from terrestrial predators such as feral dogs and humans (poachers). Some sections of the lake such as at Gatumbiro had extensive marshes but a low occupation by cranes. This site has a high traffic of fishermen in canoes and a quarry in the heavily encroached and settled riparian grassland.

Cranes are known to have a robust fidelity of the sites they use for different reasons such as breeding (Su & Zou, 2012). Pairs observed making a second nesting attempt never re-used a nest but placed their nest some short distance from the old nest. This behaviour of shifting the nest position could be as a result of deterioration of the condition of the previous nest, especially in areas with high livestock densities grazing in the marshes. As a protection mechanism against nest parasites, cranes may also be avoiding old nests that could be harbouring nest-based parasites (Bush & Clayton, 2018).

Although sligthly lower, the overall average clutch-size reported in this study was 2.23±0.15 eggs (31 nests) falls within a close range of 2.56 (41 nests) reported by Pomeroy (1980) from 41 nests in Uganda and 2.4±0.2 eggs reported by Gichuki (1993) from 89 nests in Kenya. This shows some consistency in the species and may therefore not be expected to be significantly different between regions.

Some of the one-egg clutches recorded had freshly-laid eggs and therefore may have been incomplete. Subsequent nest visits were avoided to reduce disturbance. Allan (1996) noted that some of the one-egg clutches could represent incomplete clutches and therefore befit a source of bias in analysis of clutches data. The four-egg clutch was the only observation during the study period, and no families were observed with four chicks. Three other records have been reported in Kenya too. Gichuki (1993) had two clutches in Kitale. A family with four chicks was reported from Masai Mara NR (Stratton Hatfield, *pers. comm.,* 5 March 2020) while a single clutch was observed in Mugie Wildlife Conservancy, Laikipia (*pers. obs.,* August 2018).

5.6 Conclusion

It has been established that some of the environmental variables in nest-sites are more influential than others in placement of the nest from an ecological point of view. For example, water depth would be more important (in providing security from terrestrial predators and food resources) than distance from the nearest path or road. Thus, the null hypothesis that "there are no factors influencing nest-site selection in Grey Crowned Crane in Lake Ol' Bolossat basin" is rejected. These results therefore provide critical and reliable information towards understanding some of the basic characteristics of wetlands that Grey Crowned Crane require for nesting as well as information on their nesting behaviour.

New information has also been generated on characteristics of nest, eggs and clutch sizes of Grey Crowned Crane in the study area including a rare clutch of four eggs. Observation of a modal clutch size of three eggs shows the species capability to recover its population in the absence of threats that affect the quality of breeding sites, loss of eggs and chicks. This high level of fecundity shows that such as species wouldn't require captive breeding unless efforts to encourage successful breeding in the wild have failed.

Synchronization of nesting with local weather pattern is important as it ensures that the cranes raise young at a time when environmental conditions and food abundance are at their optimum thus increasing chicks' survival and fitness of the species as a whole. Variation of local weather pattern was observed to lead to contraction or extension of the breeding season, which might consequently be associated to climate change and its impacts. Flexibility in breeding behaviour as a result of weather variability is thought to involve changes in diet choice, habitat selection and other behaviour (Dunn & Winkler, 2010). For example, cranes delayed nesting (in case of extended drought) while excess rainfall led to flooding resulting to loss of nests, eggs and desertion of a clutch, with consequences on the species' breeding performance and productivity. Although such effects could adversely affect the species at the level of the population in the long-standing, it could be alternatively viewed as a beneficial behavioural change and adaptation where breeding dates are shifted and/or delayed until when a breeding attempt could be more successful.

CHAPTER SIX

6.0 DISTRIBUTION AND ABUNDANCE OF POTENTIAL PREY OF GREY CROWNED CRANE IN LAKE OL' BOLOSSAT BASIN

6.1 Introduction

All species of cranes are omnivorous foraging in wetlands, grasslands and cultivated fields. The Grey Crowned Crane has been described as a specialist wetland-dependent waterfowl (Arinaitwe, 1998), therefore a good indicator species of the quality of a wetland ecosystem. This is because of their high dependence on wetlands as roosting, foraging, resting and nesting sites. Their life-cycle involves use of wetlands especially nesting that lasts between four and 24 weeks. The chicks of most birds are fed on a diet largely comprising of invertebrates to provide them with proteins needed for normal body growth which is a principal cause of the growth and survival of young (Park *et al*., 2001). The protein diet is supplemented with seeds of sedges and aquatic grasses, terrestrial grass seeds, and other food materials.

The marshes of Lake Ol' Bolossat are characterised by periods of flooding during the rainy season and drying in the dry season. This makes them dynamic macro-habitats as does the diversity and abundance of macro-invertebrates that thrive in them. Other than providing food to many animal species, aquatic invertebrates have been used extensively to evaluate water quality of streams (Ojija & Laizer, 2015). Macro-invertebrates species diversity and relative abundance are an indicator of the pollution of wetlands and general pointers of water quality (Mwaura, 2006). The attributes of water systems consequently affects the number and species diversity of waterbirds that rely on these ecosystems for foraging and rearing their young (Ma *et. al.*, 2010).

The composition of Grey Crowned Crane's diet is relatively known. Karanja & Gichuki (1988) examined faeces and made field observations of feeding cranes in Lake Ol' Bolossat. They observed that, in the marshes and water edges, cranes fed on plant materials such as sedge seeds and water lily tubers, insects (e.g. dragonfly larvae and earthworms) and smaller vertebrates including small fish and tadpoles. In grasslands, they foraged on grass seeds, grasshoppers, spiders, earthworms and bird eggs. They also made observations in farmlands where cranes took seeds (e.g. wheat, oat and maize), invertebrates (e.g. earthworms and beetles), as well as and vegetables. Gichuki (1993), studying the diet of non-parental, parental and juvenile cranes in Kitale, found out that cranes fed on a variety of food materials from plants (both grass and non-grass seeds) as well as animal prey (e.g. mollusca, insecta and small vertebrates).

An ecosystem's biomass is defined as "the mass or weight of living tissue" (Parresol, 2002). Biomass is usually subdivided into five fundamental trophic levels constituting the primary food chain: producers, herbivores, predators, top predators and decomposers (King, 2022). Information on the influence of food availability vs breeding activities of the Grey Crowned Crane has been lacking. Such information is important in backing of the hypothesis that "birds synchronize breeding with the time of the year when there is great abundance of most food resources" (McKinnon *et al*., 2012). This phenomenon, known as the mismatch hypothesis, predicts that "reproductive success is maximized when animals synchronize their reproduction with the food supply" (Dunn *et al*., 2011).

Sampling was hence done at two different times of the crane's life-cycle: when they are highly-dependent on wetlands (nesting; wet season), and when they are less-dependent on wetlands (dry season). In most species, the breeding season is deeply entwined to the distribution and abundance of food resources in the environment (Urfi, 2003). The two seasons were hence the optimum times of the year to relate the crane's breeding behavior with weather and environmental conditions.

6.2 Aims

The aims of this part of the study were:

i. To establish the water physico-chemical parameters of Lake Ol' Bolossat.
ii. To determine the seasonal variation in abundance of invertebrates and small vertebrates in cranes foraging habits in the study area.
iii. To identify factors influencing food abundance and availability to cranes in their foraging habitats in the study area.

6.3 Materials and Methods

6.3.1 Selection of sampling sites

Eighteen sampling sites were identified along the shoreline and in the riparian grasslands (Figure 3.4). Their distribution ensured a reasonable representation of conditions of the lake ecosystem. The sites were clustered into three sectors as north, middle and south, each having a total of six study sites (making a total of 18 sampling sites) as described below.

Northern section: Ziwani & Mairo-Inya (1), Baari (2), Githungucu (3), Kianjata (16), Githiiro (17) and Kibathi (18). The section is characterised by a narrow lake width, high density of emergent macrophytes, scattered pools of open water infested by *Salvinia molesta*, quarrying activities, water abstraction for human consumption supply, urbanisation, intensive farming including floriculture and a high human population density.

Middle section: Kanguyo (4), Ngurumo (5), Makereka (6), Fuleni (13), Gatumbiro (14) and Kanguu (15). The eastern side had tussock-dominated riparian grasslands in Githungucu and between Ngurumo and Makereka that are usually occupied by a high density of livestock.

Human population density in this section is low compared to the northern section. Grasslands, land sub-divisions and ploughing were rampant in Ngurumo and Gatumbiro. The marshes are fringed in a narrow width on both shorelines except for Gatumbiro that had floating marshes and quarrying activities. Ngurumo and Makereka had natural springs that flow over the surface for most part of the year.

Southern section: Iria-Ini (7), Gakoe (8), Kirima (9), Mugathika (10), Mukindu (11) and Bahati (12). It has the largest area and deepest sections of the lake with open water. A narrow peninsula encloses marshes in Bahati. The area between Iria-Ini and Gakoe is under intensive irrigation fed by the spring water from foothills of Satima escarpment. Kirima had an inlet from a flower farm while its heavily grazed riparian grasslands host several hundreds of livestock.

6.3.2 Samples collection

Five water parameters were determined *in-situ* using a handheld multi-parameter tester (APERA® Instruments, California, USA). These were: surface temperature of the water (taken at between 5-10 cm below the water surface), salinity, conductivity, pH and total dissolved solids. A mean from four readings at each site in each season was used.

Sampling of aquatic macro-invertebrates was carried out in the shallow water (<50 cm deep) within an average distance of 5-10 m offshore. This is the niche that adult cranes and juveniles were observed foraging. Seasonal sampling is reported as an ideal strategy that minimises seasonal limitations (Chadd, 2010). A set of two samples (giving a total of 36 samples) were consequently collected at each site, one in the wet season (October) and dry season (February) spread across the study period.

A standard Freshwater Biological Association D-frame pond net with a 1.5-meter-long handle was used (Figure 6.1). Use of this net is recommended in still waters as it generally produces qualitative or semi-quantitative datasets (Chadd, 2010). Sweeping for all the samples were done by the same person to reduce individual sampling bias. At each sampling site, four randomly selected points (set at a minimum of 10 meters apart) were chosen. To standardise the sampling effort, ten sweeps were made at each of the four points giving a total of 1,440 sweeps.

Figure 6.1: Sampling aquatic macro-invertebrates using a standard pond net in a shallow marsh in Lake Ol' Bolossat.

A sieve was used to collect the macro-invertebrates into an 800 cm^3 collecting jar while plant debris were carefully examined for adhering invertebrates before discarding on site. All the four sweeps (40 sweeps in total) were treated as one sample for that season and specific site. Some clean water was added to the jar to ensure survival of invertebrates to ease sorting. Sorted specimens were placed in vials containing 75% Ethanol for preservation. A cotton fibre label written in an indelible ink was placed inside the jar with date and name of sampling site. Samples were taken to the lab for oven-drying using a Gallenkamp™ Hotbox Oven at 70^0 C until a constant weight was attained. Readings were done using a sensitive laboratory balance.

Pitfall traps are the most commonly used sampling technique in most terrestrial biodiversity surveys and inventories. Disposable plastic cups were used to trap ground-dwelling and crawling invertebrates and small vertebrates. The cups were sunk to the ground with the rim of the open end flushing. A small amount of a mixture of water, alcohol and liquid detergent were half-filled. Five traps were laid in a line transect with a 5 m spacing between any two traps. No bait was used to lure any group of animals to the trap. These were run for 48 consecutive hours after which they were emptied. Specimens were preserved as described above (see section 7.3.2). High human traffic lead to loss of some traps in some sites and could therefore not be run for longer period to minimise data and trap losses. The sampling design and effort resulted in a total of 170 traps (85 in each season) and approximately 8,160 trap hours.

Sweep-netting was used to sample insects quickly from low-growing forbs and grasses (McGavin, 2007). A standard net (1 m long handle, 38 cm diameter) was used. To standardize sampling efforts and make results comparable between the 18 study sites that were sampled, a total of 50-sweeps were made by the same person in both seasons. The 50-sweeps were collected within five randomly placed transects ensuring no overlap. Holding the net parallel to the ground and making a 180-degree swing, each passage of the net was considered as one sweep. The end of transect was attained on reaching the 10 sweeps. All the 50 sweeps were considered as one sample for that specific site and season, and were therefore combined in an A4 size Ziploc bag. A total of 1,600 sweeps were obtained.

6.3.3 Statistical analysis

All data sets were tested for normality before subjecting them to statistical tests. One-way Analysis of Variance (ANOVA) was used to test for significance of variability in water parameters and macro-invertebrates' biomass among the sampling sites and sections of the lake. The significance of means of water parameters and animal biomass between any two sets of data, e.g. between any two sampling sites, sections of the lake or habitats, was tested using the Student *t*-test. In a few instances, Wilcoxon test, a nonparametric statistical test, was used to compare two paired groups such as abundance of macro-invertebrates between the dry and wet seasons. This is because of its capability to work with a non-normally distributed data that has a big range.

6.4 Results

6.4.1 Water physico-chemical parameters

Significant seasonal variations were observed in all the parameters measured except surface water temperature (see Table 6.1).

Table 6.1: Mean dry and wet seasonal variations of water physico-chemical parameters measured in the lake.

Parameter	Wet season (October)	Dry season (February)	Seasonal variation
pH	6.81	8.19	$t = -7.44, p < 0.05$
Conductivity (µS/cm)	293.38	928.93	$t = -6.85, p < 0.05$
Total Dissolved Solids (ppm)	221.2	657.3	$t = -6.46, p < 0.05$
Water surface temperature (^{0}C)	21.83	20.62	$t = 1.89, p > 0.05$
Salinity (ppt)	0.18	0.48	$t = -6.69, p < 0.05$

The difference in surface water temperature between the two seasons was not significant (t = 1.89, p >0.05). A significant difference was however observed in the southern section (t = 2.648, p <0.05). Figure 6.2 illustrates the minimum and maximum surface water temperatures for both seasons in each section and sampling sites. The largest differences of 5.2^0 C and 5.3^0 C were recorded in Mukindu (11) and Kianjata (17) respectively.

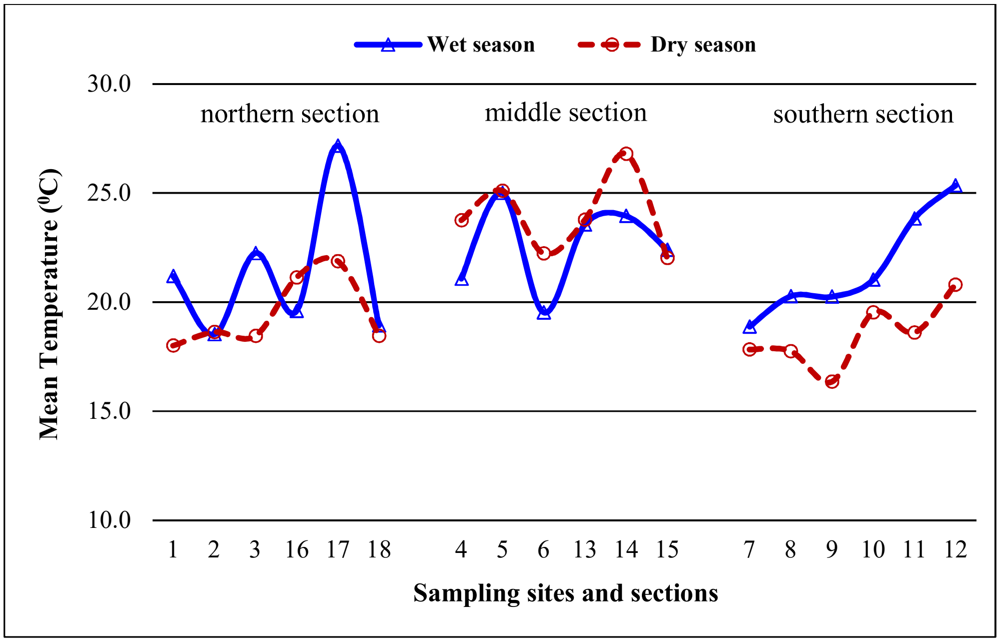

Figure 6.2: Mean surface water temperature between the wet and dry seasons at each sampling site and sections of the lake.

Figure 6.3 shows the dry and wet seasons water physico-chemical parameters for pH and TDS. The pH ranged from 5.29 to 8.28 (wet season) and 7.62 to 8.92 (dry season), the greatest variation being observed in Githiiro (18) and Iria-Ini (7). TDS oscillated between the seasons significantly (t = 4.5022, p <0.05), particularly in the middle section (t = 4.702, p <0.05).

Conductivity and salinity showed the most significant variations between the sampling sites and among sections of the lake, the middle section having the greatest variation at Fuleni and Ngurumo (Figure 6.4).

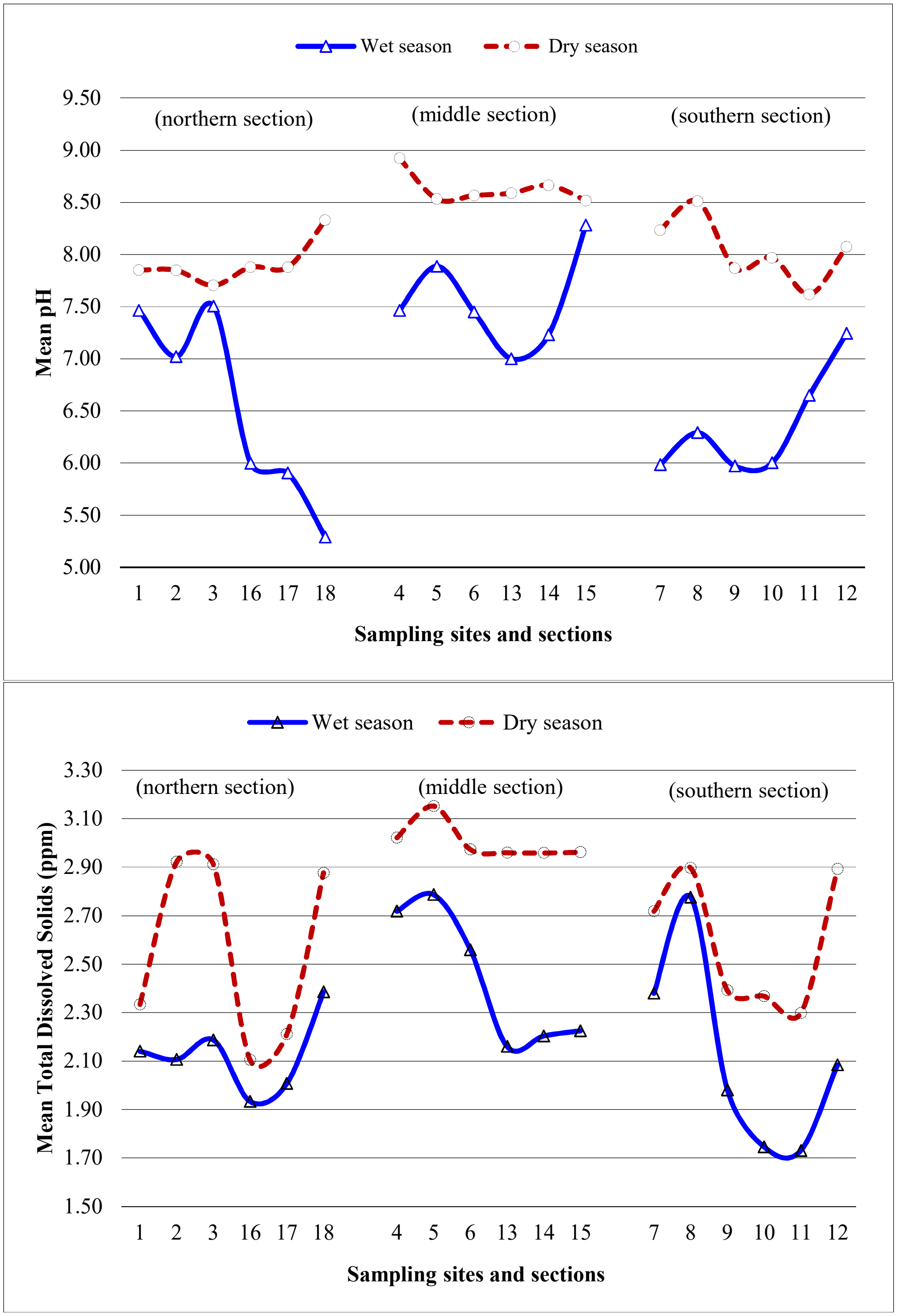

Figure 6.3: Mean dry and wet seasons values for pH (top) and Total Dissolved Solids (bottom).

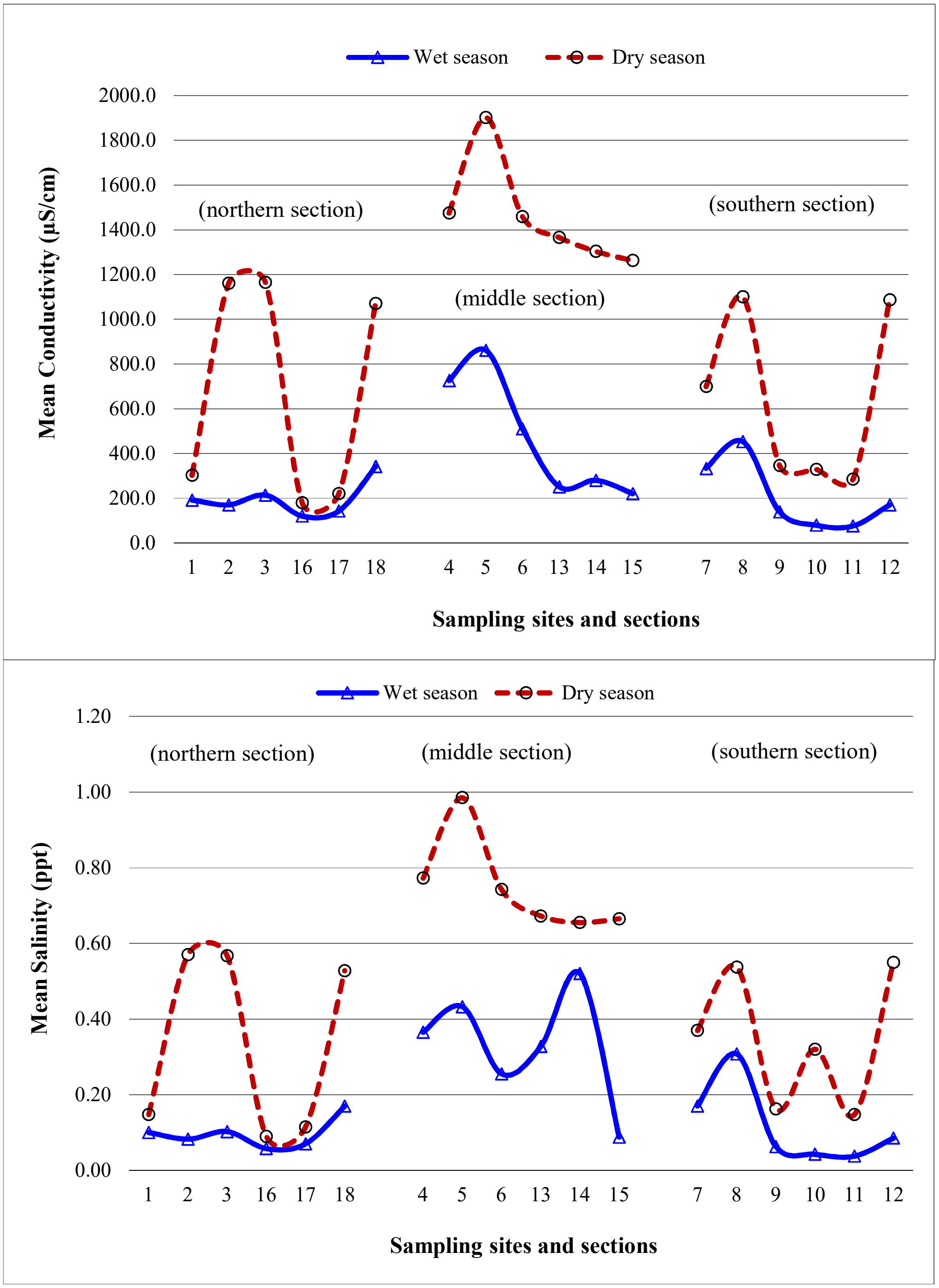

Figure 6.4: Mean dry and wet seasons value for conductivity (top) and salinity (bottom).

6.4.2 Abundance of macro-invertebrates and small vertebrates

Identification of the commonly encountered taxonomically different taxa of aquatic macro-invertebrates followed IUCN (2011) and Glime (2017). The diversity, abundance and distribution functional taxa in each section of the lake, study sites and seasons is shown in Table 6.2.

A total of 4,475 individuals were recorded. This however excluded individuals under the length of 25 mm on assumption that they could be too small for cranes to pick and would not be worth the effort to pursue. The most diverse group were hemipterans and odonata accounting for 64.7% and 10.2% respectively, with gastropods following closely at 9.5%. The wet season accounted for 60.8 % of this total while the southern section took lead with 47.3% followed by the middle section (29.8%). The most abundant sites in both seasons were Mugathika (5.6%), Bahati (4.7 %) and Kirima (3.6%) whereas during the wet season, the most abundant sites were Kirima (9.5%), Bahati (8.9%) and Iria-Ini (5.2%). These sites were in the southern section.

Excluding four sites (Baari, Gakoe, Mugathika and Kibathi) that unexpectedly had higher abundance during the dry season, all the other sites showed a remarkable increase of invertebrates during the wet season of between 4.38% (Fuleni) and 80.11% (Githungucu). Overall, a substantial difference was detected on the abundance of macro-invertebrates between the dry and wet seasons (Two-sample paired Wilcoxon test: $W = 137$, $z = 2.2434$, $p < 0.05$).

Table 6.2: Abundance and distribution of aquatic macro-invertebrates in the three sections of Lake Ol' Bolossat in both seasons.

Section	Sampling sites	Season	Gastropoda (Planorbidae)	Gastropoda (Lymnaeidae)	Gastropoda (Physidae)	Decapoda (Cambaridae)	Araneae	Ephemeroptera (Mayfly)	Trichoptera (Caddisfly)	Coleoptera	Odonata (Dragonfly)	Odonata (Damselfly)	Hemiptera (Corixidae)	Hemiptera (Notonectidae)	Hemiptera (Pentatomidae)	Hemiptera (Gerridae)	Hemiptera (others)	Diptera (Culicidae)	**Total**
Northern	Mairo-Inya (1)	Dry	2		2					9			16	1	1			7	38
		Wet	1		5					15			22	5				12	60
	Baari (2)	Dry	40		2					18			3		6			43	112
		Wet	15	2	1		2			11	3	4	14		4			5	61
	Githungucu (3)	Dry	14				2			4	1				5			10	36
		Wet	14	88			1		2	8	4	6	47	1	10				181
	Kianjata (16)	Dry				40				7		2	36				2		87
		Wet				32		10		2			95	4			1		144
	Githiiro (17)	Dry				25				8		1	6		1				41
		Wet				13				10	1	1	82		1	2	1		111
	Kibathi (18)	Dry		2		1	1	9		29	1	4	7		12			23	89
		Wet	4	1	3	1	4	3	1	18	1	3	12		9				60
		Total	90	93	13	112	10	22	3	139	11	21	340	11	49	2	4	100	**1,020**
Middle	Kanguyo (4)	Dry		1					1		10	4	17	3	1			1	38
		Wet	14						1	4	9	12	60		13			5	118
	Ngurumo (5)	Dry									5		36					2	43
		Wet									4	34	44		4			12	98
	Makereka (6)	Dry	22						1	6	20	4	52		9			4	118
		Wet								11	1	9	159	18	17	2		13	230
	Fuleni (13)	Dry	3			1				1	16	3	98		2			7	131
		Wet	1		2	1			1	6	17	2	90		7			10	137
	Gatumbiro (14)	Dry				2					16	14	27	3	2				64
		Wet			3	3	1			9	13	2	20	9	14		8	5	87
	Kanguu (15)	Dry	4	3				3		4	27		85		2				128
		Wet				13			1	12	6	7	62	19	10		7	8	145
		Total	44	4	5	20	1	3	5	53	144	91	750	52	81	2	15	67	**1,337**

Table 6.2 (continued)

Section	Sampling sites	Season	Gastropoda (Planorbidae)	Gastropoda (Lymnaeidae)	Gastropoda (Physidae)	Decapoda (Cambaridae)	Araneae	Ephemeroptera (Mayfly)	Trichoptera (Caddisfly)	Coleoptera	Odonata (Dragonfly)	Odonata (Damselfly)	Hemiptera (Corixidae)	Hemiptera (Notonectidae)	Hemiptera (Pentatomidae)	Hemiptera (Gerridae)	Hemiptera (others)	Diptera (Culicidae)	Total
South	Iria-Ini (7)	Dry								4	15	7	55		9	3			93
		Wet			14	2			3		8	14	158		14	8		13	234
	Gakoe (8)	Dry	2	1				3		2			50		1			5	64
		Wet													10				10
	Kirima (9)	Dry							3	2	11	6	139		2				163
		Wet				4			2	26	6	8	352	10	12				420
	Mugathika (10)	Dry							1	9	21	3	121	83	7			5	250
		Wet					1				5	19	43	6	1				75
	Mukindu (11)	Dry					2			4	21		12		3			3	45
		Wet				2			1	25	4	7	54	52	6			4	155
	Bahati	Dry	137		13		1	3	1	22	3		14		18				212
		Wet	3	1	3		2			2	25	6	244	84	17	2		8	397
		Total	142	2	30	8	6	6	11	96	119	70	1,242	235	100	13		38	**2,118**

6.4.3 Abundance of small vertebrates

A total of 80 individuals of small vertebrates from three taxa (amphibians, reptiles and fish) were caught at various sites (Table 6.3). The dominant group were fishes (50) followed by amphibians (29) while only one reptile was recorded. Majority (70%) of these were caught in the northern section whereas the middle section had twice the number caught in the southern section. The most diverse group in terms of species diversity were the amphibians with 5 species.

Table 6.3: Abundance and species diversity of small vertebrates captured in Lake Ol' Bolossat.

Sections of the lake	Northern Section					Middle Section					Southern Section		**Total**
Sampling sites	2	3	16	17	18	4	6	13	14	15	10	12	
Class Amphibia (Amphibians)													
Senegal Kassina (*Kassina senegalensis*)	7		2		1							4	14
Nile Ridged Frog (*Ptychadena nilotica*)					3								3
Kinangop Puddle Frog (*Phrynobarbrachlus kinangopensis*)	1	2		1	1				3				8
Peter's Reed frog (*Hyperolius glandicolor*)		2										1	3
Ridged Frog (*Ptychadena spp.*)												1	1
Class Reptilia (Reptiles)													
Variable Skink (*Trachycepis varia*)							1						1
Class Pisces (Fish)													
Pseudocranilabrus multivictoriae	4			24	6	1			3				38
Enteromius paludinosus		1	1					7		1	1	1	12
Total	12	5	3	25	11	1	1	7	6	1	1	7	**80**

6.4.4 Seasonal variation of terrestrial and aquatic biomass

The biomass of macro-invertebrates in both terrestrial (riparian grasslands) and wetland (marshes) as potential prey for the Grey Crowned Cranes during the breeding (wet) and non-breeding (dry) seasons was investigated. Its variation was compared to water physico-chemical parameters because of their potential influence on abundance of organisms thriving in the aquatic system where cranes forage. Terrestrial biomass included samples from two micro-habitats, ground-crawling and foliage dwellers. The overall difference in biomass among the three habitats (aquatic, foliage and ground) and the seasons was significantly different (One-Way ANOVA: $F = 4.161$; df = 5, 94; $p < 0.05$). The marshes (aquatic samples) had the highest biomass (hence most productive micro-habitat) during the wet season (Figure 6.5).

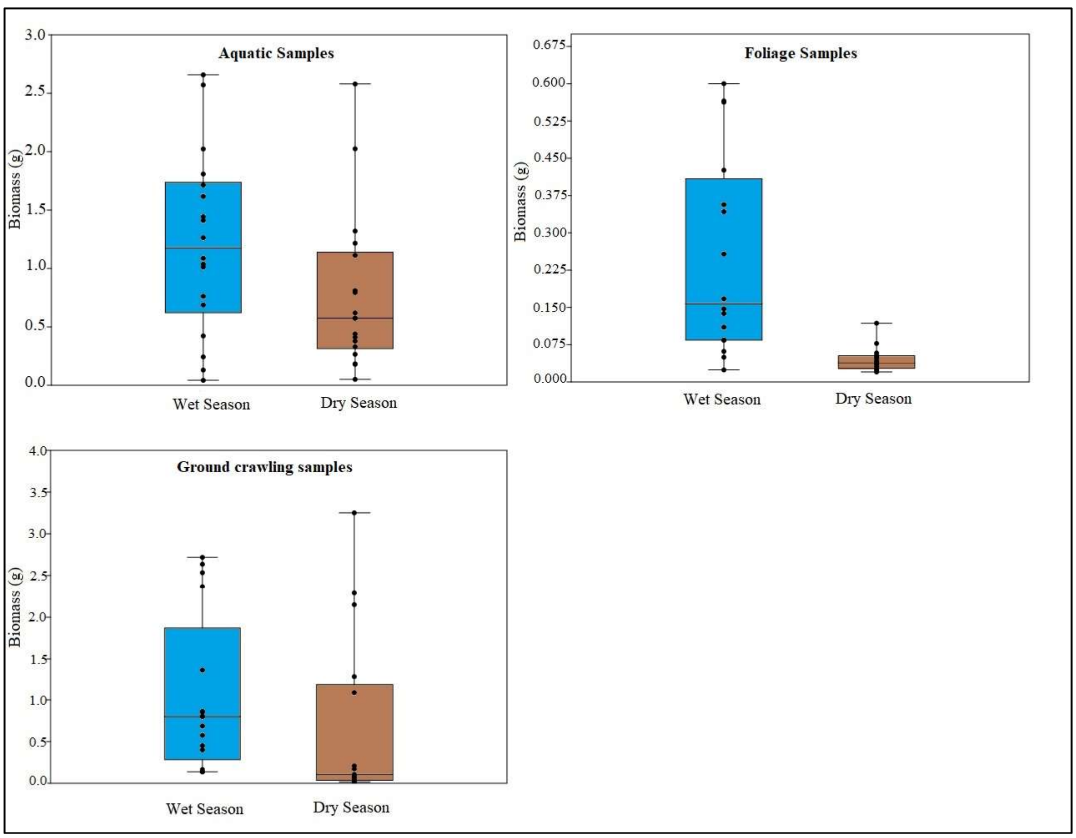

Figure 6.5: Seasonal variation of biomass between the wet and dry seasons in three micro-habitats in Lake Ol' Bolossat. Dots represent biomass values while error bars show samples variability.

The difference in biomass of aquatic macro-invertebrates in the marshes was expressively distinctive between the wet and the dry seasons (Two-sample paired *t*-test: $t = 2.9104$; $p < 0.05$). The difference was nonetheless insignificant among the two seasons in the various study sites (Repeated-measures One-Way ANOVA: $F = 1.5310$; df = 5, 30; $p > 0.05$). Biomass was lowest in Ziwani, Ngurumo, Gakoe and Mugathika during both seasons. Kirima in the southern section had the largest seasonal variation of biomass between the seasons.

6.4.5 Foliage and ground-crawler's biomass

A significant difference of biomass between the dry and wet season was observed for invertebrates that live among grass foliage (Two-sample paired *t*-test: $t = 3.9487$; $p < 0.05$), and among and within the study sites (Repeated-measures One-Way ANOVA: $F = 5.566$; df = 5, 26; $p < 0.05$). The highest invertebrates' biomass was recorded in Iria-Ini, Ngurumo and Fuleni during the wet season compared to other sites, while the lowest was in Ziwani, Kibathi, Iria-Ini and Ngurumo during the dry season.

The difference in biomass of invertebrates and small vertebrates between the two seasons was not significant (Two-sample paired *t*-test: $t = 2.0031$; $p > 0.05$). This difference was however significant between and among the two seasons and study sites (Repeated-measures One-Way ANOVA: $F = 0.6086$; df = 1, 30; $p < 0.05$). Baari and Kanguu recorded the highest biomass in both seasons.

6.4.6 Factors influencing availability of prey food

Sampling of terrestrial invertebrates and small vertebrates was carried out in areas where livestock also grazed. Some of these sites (with palatable grass species) are overgrazed by livestock which results to a poor assemblage of vegetation that could not support prey providing food for the cranes. It was expected that sites with high livestock numbers would have low abundance and biomass values. This hypothesis was however not tested as a more robust study design and approach are needed to collect such data e.g. ensuring sampling is done in areas where both cranes and livestock interact. Measurements of vegetation height and sampling over a longer period may also be required. Grazing however have the potential to affect abundance and biomass, and could be one of the cause of observations made in this study. Additional possible factors that could have influenced abundance (and hence biomass) of macro-invertebrates and small vertebrates which were observed (but not quantified) include vegetation type (species composition), leaf litter, soil characteristics, number of avian insectivore species foraging in sampling sites, and plant phenology (especially flowering).

6.5 Discussion

Animal populations are limited by their food whose availability is prescribed by weather conditions (White, 2008). There was a positive relationship between food biomass and habitat conditions, which consequently influences the behavior of animals that are dependent on such habitats. Sampling in dry and wet seasons enabled a comparison of abundance of potential prey during Grey Crowned Cranes' dependence and non-dependence on both wetland and terrestrial habitats as far as their breeding cycle is concerned.

A clear difference in water parameters was observed between the two seasons. While all parameters showed higher values during the dry season than the wet season, water surface temperature had a reverse observation. Several factors could explain this discrepancy. Readings made in the mornings would be expected to be lower than mid-day. Cloud cover, regardless of time of the day, has potential influence on water surface temperature due to its effect on solar radiation. Wind speed has capability to transfer heat from the atmosphere and mixing of water (Fondriest Environmental Inc., 2014). The average depth of c.10 cm may also have contributed to this observation since this region of the water column is more vulnerable to ambient conditions than deeper water.

The behavioural change observed in Grey Crowned Cranes where the breeding cycle is delayed and varying in length in different seasons may be partially vindicated by observations reported in this chapter. Commencement of the rains denoted the initiation of the breeding cycle for the cranes in the study area. During the rainy season, there is a general build-up and surge of insect populations (Santana *et al.,* 2015). In this study, the mean biomass of macro-invertebrates was abundant in the wet, rainy season compared to the dry season. Thus, hatching of chicks corresponded with availability of abundant food resources. This shows their ability to acclimatize to the changing environmental conditions by delaying breeding until the prevailing conditions are favourable to support an abundance insect prey as chicks' food.

Birds breeding late in the season are however likely to rear chicks during a time of food scarcity that consequently undermines the health and growth rate of chicks while the parents have to spend more time searching a scarce food resource, thus lowered chances of chick survival (Cox *et al*., 2019). Aquatic insects (and not terrestrial insect prey) are also reported to have high concentrations of highly unsaturated omega-3 fatty acids (Twining *et al*., 2018), which is an essential nutrient influencing improvement of reproduction and health performances (Sretenović *et al*., 2009). This may explain why cranes spend more time in wetlands when chicks are small besides availability of vegetation that provide them with cover.

The protein demands of waterfowl (especially breeding adults) intensifies in the breeding season due to the requirements of egg-laying (Krapu, 1979). Protein is also needed by the growing chicks for development, especially of the flight feathers (Joint Working Group on Refinement, 2001). Flight increases survival of individual juveniles and the species as a whole. Timing of the breeding season is therefore made in such a way that it coincides with the wet season when there is not only an availability of nesting materials and cover but also the availability of an abundant animal protein source required for the growth of the chick. In other similar studies, e.g. Gichuki (1993), low food biomass was recorded during egg-laying and incubation periods.

Mwaura *et al*. (2002) listed differences in the catchment environment (e.g. climate, geology, soils, vegetation and land use) as additional factors describing differences in characteristics of wetlands and present species. In this study, other factors resulting to differences in prey abundance observed include anthropogenic activities at and around the sampling sites as well as the origin of surface water. For example, a low mean biomass (low abundance) was observed in Ziwani and Mairo-Inya which are sites under the influence of urbanisation and dense human settlements compared to other sites. Ngurumo too had a low biomass which is attributable to its shallow marshes, scarce emergent macrophytes, and heavy invasion by the pernicious *Salvinia molesta* weed. Highest abundance was observed in Gatumbiro in both seasons, a site characterized by emergent macrophytes and low density of *Salvinia molesta*.

The physico-chemical properties water is important in determining its biological characteristics i.e. the abundance and diversity of macro-invertebrates in an aquatic ecosystem including the vegetation structure. Changes in these parameters have profound implications on water quality and living organisms. For example, temperature controls the appropriateness of water for various forms of aquatic life, determines solubility of oxygen in water, and affects rate of photosynthesis by algae and other aquatic plants (Kohil *et al.*, 2018). Although not measured in this study, low oxygen levels would affect the abundance and survival of potential prey food for the cranes. Low water pH can lead to the discharge of lethal substances from sediments that would be directly harmful to aquatic organisms (Dallas & Day, 2004).

6.6 Conclusion

This study has shown that season is important in determination of abundance and distribution of macro-invertebrates and small vertebrates in both aquatic and terrestrial ecosystems. The null hypothesis that "there are no seasonal variations in the abundance of potential prey food for Grey Crowned Crane in the study area" is hence rejected. The overall objective and aims have also been greatly achieved including determination of water physico-chemical parameters, and assessment of seasonal influence on abundance and biomass of potential food items for the cranes. These observations have a strong link to timing of breeding activities of the cranes that overlaps with periods of high abundance.

A seasonal variation in water parameters was also observed. This shows that these parameters have an influence on the abundance of aquatic biodiversity which is depended upon by the cranes and other waterbirds for feeding and rearing chicks. It is also thought that there is an interaction of these parameters although this was not tested in this study. The causes of observed seasonal variations in both water parameters and living organisms are numerous. These include climate change which has been projected to cause strains on water resources such as flood and drought, and subsequently affecting the aquatic invertebrate communities and populations (Chadd, 2010).

Lake Ol' Bolossat is surrounded by agricultural land where crop farming and animal husbandry are practiced. Agro-chemicals and fertilizers are used to enhance crop production. Changes in land use patterns e.g. development of flower farms and intensive agriculture that use huge volumes of agro-chemicals to boost production and control crop pests and diseases, have an impact on water systems, aquatic invertebrates and waterbird populations. When such chemicals and solid agricultural waste are transported to the lake though surface runoff, the and physical and chemical properties of the water could be adversely affected. Consequently, the aquatic life is also affected.

There are also changes that going on in the wetland's ecology such as invasion by non-native species particularly *Salvinia molesta* and the herbivore rodent *Myocastor coypus*. *Salvinia's* thick mat reduces sunlight penetration, reduces aquatic macrophytes, lowers dissolved oxygen and cause stress to aquatic organisms (Wahl *et al*., 2020). This has far-reaching effects on the entire food chains and food webs. The results from this study contributes to the understanding of the relationship between water quality and aquatic organisms as determining factors to behaviour and survival of water-dependent species like the Grey Crowned Crane.

The abundance and species diversity of aquatic organisms is not only determined by water physico-chemical parameters but also by the structure of aquatic plants. Plants provide important habitats for macro-invertebrates and small vertebrates that in turn are influence the number and distribution of food for amphibians, fish and waterbirds. Aquatic vegetation may however lower the quality of water by affecting parameters such as temperature, dissolved oxygen, and pH.

CHAPTER SEVEN

7.0 LANDSCAPE LEVEL CHANGES AND THREATS TO SUSTAINABLE CONSERVATION OF GREY CROWN CRANE IN LAKE OL' BOLOSSAT BASIN

7.1 Introduction

Biodiversity threats and loss has been deliberated at length at both local and global levels and is thus a growing concern worldwide. It has been described as one of the most pressing environmental issues of our time (Pereira *et al.*, 2012). This is because of its direct and indirect consequences to human health when ecosystem services are unable to meet the demands and needs of human social needs (WHO, 2020). Specific causes of decline of biodiversity and consequences that follow can be either natural or human-induced factors.

Even though the majority of species face similar threats, most threats facing birds worldwide are of anthropogenic origin, such as habitat loss and degradation and overexploitation and invasive species (BirdLife International, 2018). However, habitat loss is often cited as the significant threat affecting 85% of the world's Endangered species alongside overexploitation, pollution and invasive species (Venter *et al.*, 2006). These processes are accelerated at sites without formal protection or those with formal protection status but without any authority overseeing their day-to-day running and management, such as Lake Ol' Bolossat in Kenya.

Gruidae are is amongst the highly threatened bird families in the world (Meine & Archibald, 1996), alongside Old World vultures (Accipitridae), parrots (Psittacidae) and bustards (Otididae) (BirdLife International, 2018). Cranes population declines are caused by factors such as land use changes leading to habitat loss and fragmentation, land degradation, disturbance around nesting sites, power-line collisions and electrocution, unlawful harvesting of birds and collection of eggs from the wild for food, utilisation of parts in cultural rituals, domestication and international illegal trade (Archibald & Meine, 2019), all of which are linked to poor integration of environmental protection (Harris & Mirande, 2013; Morrison, 2015).

Various analytical techniques are available to study and interpret Land Cover and Land Use (LCLU) changes e.g. Remote Sensing and Geographic Information System. The LCLU changes in the study area were determined by downloading and interpreting the image differencing between any two images e.g. 1989-2000. There are various sources of images such as United States Geological Survey (USGS) that provide Landsat images free of charge. Landsat is a series of Earth observation satellites jointly managed by the US federal government's National Aeronautics and Space Administration (NASA) and the USGS (earthexplorer.usgs.gov). The Landsat program's continuous archive (1972 to present) provides essential land change data.

Land use generally refers to how land has been utilised by humans, the main driver being the need to provide basic needs such food and housing). Hasty enlargement and amplification of agriculture is leading to uncompromising damage of grassland and wetland habitats for cranes worldwide (Austin *et al.*, 2018b). The study area has realised an exponential human population growth and immigration (MEMR, 2012), majority of them being in urban areas of Nyahururu, Ol' Kalou and Mairo-Inya (Government of Kenya, 2020). Kenya National Burea of Statistics (2019) reported a total of 64,899 persons (mean density 443 persons/km^2) in all the 15 sub-locations around the lake. Influx of humans in the basin has resulted to land sub-divisions and fragmentation of native grassland habitats that has adversely affected grassland-dependent wildlife species. Parcels are often fenced to mark boundaries, control animal and humans' movement, and protect crops from wildlife damage.

Threats facing biodiversity are mostly at the local level and therefore, local communities bordering conservation areas and unprotected biodiversity hotspots have an imperative role to play in their conservation (Berkes, 2007). This study evaluated land use changes over three decades (1989-2020) and investigated the role of local community in conservation of Grey Crowned Cranes through the activities of Cranes Conservation Volunteers, a local conservation action group. The understanding of the local people's knowledge, attitude and practices is cited as an important undertaking in conservation (Gemeda *et al.*, 2016). Perceptions of this community on threats facing the cranes was evaluated to understand the severity of threats around the lake.

7.2 Aims

The aims of this part the study aim were:

i. To determine land use and land cover changes in three decades (1989-2020) and their potential impacts on the cranes in the study area.
ii. To identify the various types of threats, their severity and impacts on cranes and their habitats in the study area.
iii. To evaluate local community's conservation initiatives and impacts on the cranes population in the study area.

7.3 Materials and Methods

7.3.1 Land Use and Land Cover changes

Satellite images were obtained from the USGS (http://glovis.usgs.gov). The specific timelines of the images needed for analysis were 1990, 2000, 2010 and 2020. During this period, a lot of human activities took place e.g. immigrations and settlements in the riparian land after the 1992 and 2008 tribal crushes in the Rift Valley. In order to get images with least interference such as cloud cover, images were searched for the whole year from which the most suitable one was picked. In 1990 however, available images had heavy cloud interferences and therefore an image from 1989 was used. The acquired images of 1989 (1^{st} March) were collected by

Landsats 1-5 which had the Multispectral scanner on board. The 2000 (25^{th} October) image was collected by Landsat 4-5 with the Thematic Mapper. The 2010 (30^{th} January) image was collected by Landsat 7 while the 2020 (27^{th} December) image was collected from Landsat 8 with the enhanced Thematic Mapper. The best images were then selected and downloaded for further analysis.

Classification was done using the open source Geographic Information System (Quantum GIS - QGIS) where images of the four years were added on the QGIS platform. The images were then pre-processed using the semi-automatic plug-in. Pre-processing included clipping the images to acquire the precise area of concentration and acquiring the reflectance of the images. This enabled the viewing of the various features on the images using the spectral bands. With various band combinations, it was easier to identify the features and classify them. The images were then classified by creating regions of interest and setting classes of various land features. This was followed by running a classification to show the features on the image with the various classes of interest. An image with the description of the land cover features was extracted and saved as a Joint Photographic Exchange Graphic image and later converted to Bitmap to improve clarity on production.

7.3.2 Evaluation and classification of threats

Expert opinion is a tool that has been used in studies aiming to obtain expert knowledge on a given topic (Chamberlain *et al*., 2016). Data on perceptions of the purposively selected members of the local community on 16 pre-determined and categorized threats facing the cranes and their habitats was collected using a questionnaire. Purposive sampling design was not only used to select the respondents but also the enumerators. The selection process was influenced by prior knowledge of the target population. Kigen *et al.* (2014) employed a similar approach while conducting a study on ethno-medicinal plants usage in Elgeyo-Marakwet County, Kenya.

The minimum specific criteria for eligibility for the enumerators and respondents were residency in the study area, demonstrated interest and knowledge in local conservation affairs and membership to a local conservation group. To ensure responses' independence, 10 enumerators simultaneously run the questionnaire in a single morning between 8.30-11.30 am. Selected respondents were approached to rank the 16 threats by assigning each a score of either 1 (mild, very low impact or effects; uncommon), 2 (moderate effects, few incidences), or 3 (high/severe, common, widespread) depending on their perceptions, knowledge and experience.

Field observations on threats were also made during the study period. An additional secondary data was obtained from records kept and maintained by CCV since April 2016. Through a centralized mobile phone, members report incidences directly to the office as and when these happen or received from the wider community. Data recorded include date, time, locality, observer's name, nature of incidence (e.g. electrocution, poisoning, carcass found etc.) action taken, and sometimes a photograph of the incidence. Recovered snares and other forms of traps with their accompanying data are catalogued and stored in CCV's office.

7.3.3 Community conservation initiatives

Local community's initiatives and their impacts on Grey Crowned Crane conservation efforts were assessed through one-on-one interactions with the leadership of CCV during their field activities, village meetings, school visits, seminars and workshops and on-site visits. Secondary data e.g. number of fledged chicks for each breeding season prior to this study was made available. Monitoring fledged chicks is a simple tool of measuring the impacts of conservation initiatives.

7.3.4 Statistical analysis

To understand the relative magnitude of the 16 confirmed threats affecting the cranes and their habitats in the study area, a one-on-one survey was conducted to quantify expert opinion. To determine the category of threats with the greatest impacts, an average of each threat score and an overall average for each of the three categories as either of low, medium or high impact were computed. SPSS Statistical software was used to compute Cronbach's alpha (to measure the coefficient of reliability or internal consistency of the threats ratings) and Fleiss' Kappa (*k*) (to assess the reliability of agreement or the extent to which the raters agree on rating each threat) (Equations 1 and 2).

Equation 1: Cronbach's coefficient (α)

$\alpha = \frac{N \cdot \bar{c}}{\bar{v} + (N-1) \cdot \bar{c}}$, where *N* represents the number of scale items (respondents), $\bar{c}$ is the average covariance between item-pairs, and $\bar{\boldsymbol{v}}$ is the average variance.

Equation 2: Fleiss's Kappa (*k*)

$k = \frac{p_0 - pe}{1 - pe}$, where *p*o refers to the observed agreement and *p*e represents the expected agreement.

A correlation was conducted to examine whether there was a relationship between relative importance of a threat and its distribution around the lake. Four Land Use and Land Cover images (1989, 2000, 2010 and 2020) from USGS were used to interpret and quantify changes.

Land use categories were confirmed from County Government of Nyandarua (2018) and knowledge and experienced gained from the ground prior to and during the study period.

7.4 Results

7.4.1 Land Use and Land Cover changes

Seven land use and land cover types were obtained from the four classified Landsat images and Nyandarua County Integrated Development Plan. These were: open water, marshes, forests (natural and plantations), grasslands, cultivated lands, bare soils/lands, and the built environment. Each of these category occupied different area of land during the three decades (Figures 7.1).

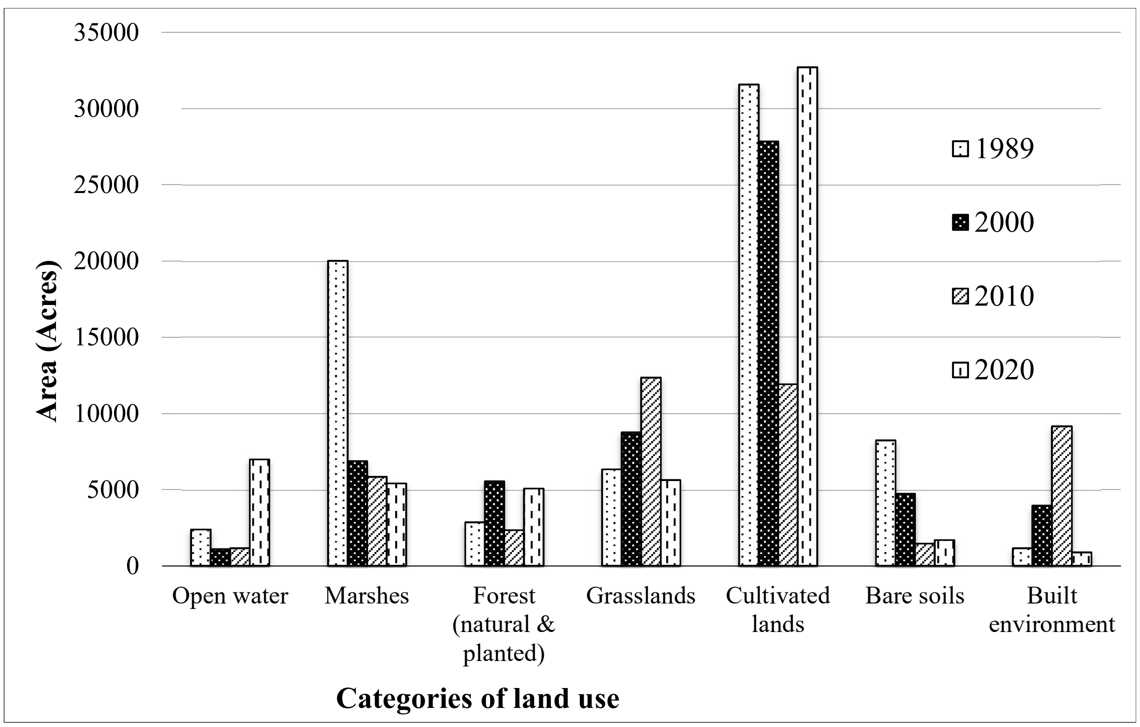

Figure 7.1: Land Use and Land Cover distribution around Lake Ol' Bolossat between 1989 and 2020.

Some of the typical LULC types around the lake are shown in Figure 7.3 which is a view of the basin from Sattima escarpment on the south-eastern side. These are open water, cultivated land under intensive irrigation, built up areas (homesteads), farm woodlots and grasslands. Bare ground is visible on unplanted fields and shoreline.

Figure 7.2: A view from Sattima escarpment of LULC types in the southern section of Lake Ol' Bolossat.

There has been significant LULC changes in Lake Ol' Bolossat basin in the three decades under consideration (1989-2020; Figure 7.3). Open water coverage in the lake reduced by 54% between 1989 and 2000 with no major changes in the next decade (2000-2010). However, it had a tremendous increase of 83% between 2010 and 2020. In 1989, the marshes covered most of the wetland area but has had significant decreases over the period. Tree cover including both natural and plantations (comprising of exotic species such as Eucalyptus and Cypress), experienced an overall decline between 1989 and 2010 but had a 54% increase between 2010 and 2020.

In 1989, the grasslands covered c.11% of the area under consideration, and increased to 15% and 21% between 2000 and 2010 respectively. This increase might have been as a result of increase in wheat fields, sown pastures (e.g. oat and Rhode’s grass), or abandonment of waterlogged fields previously under cultivation. However, a >50% decrease was observed.

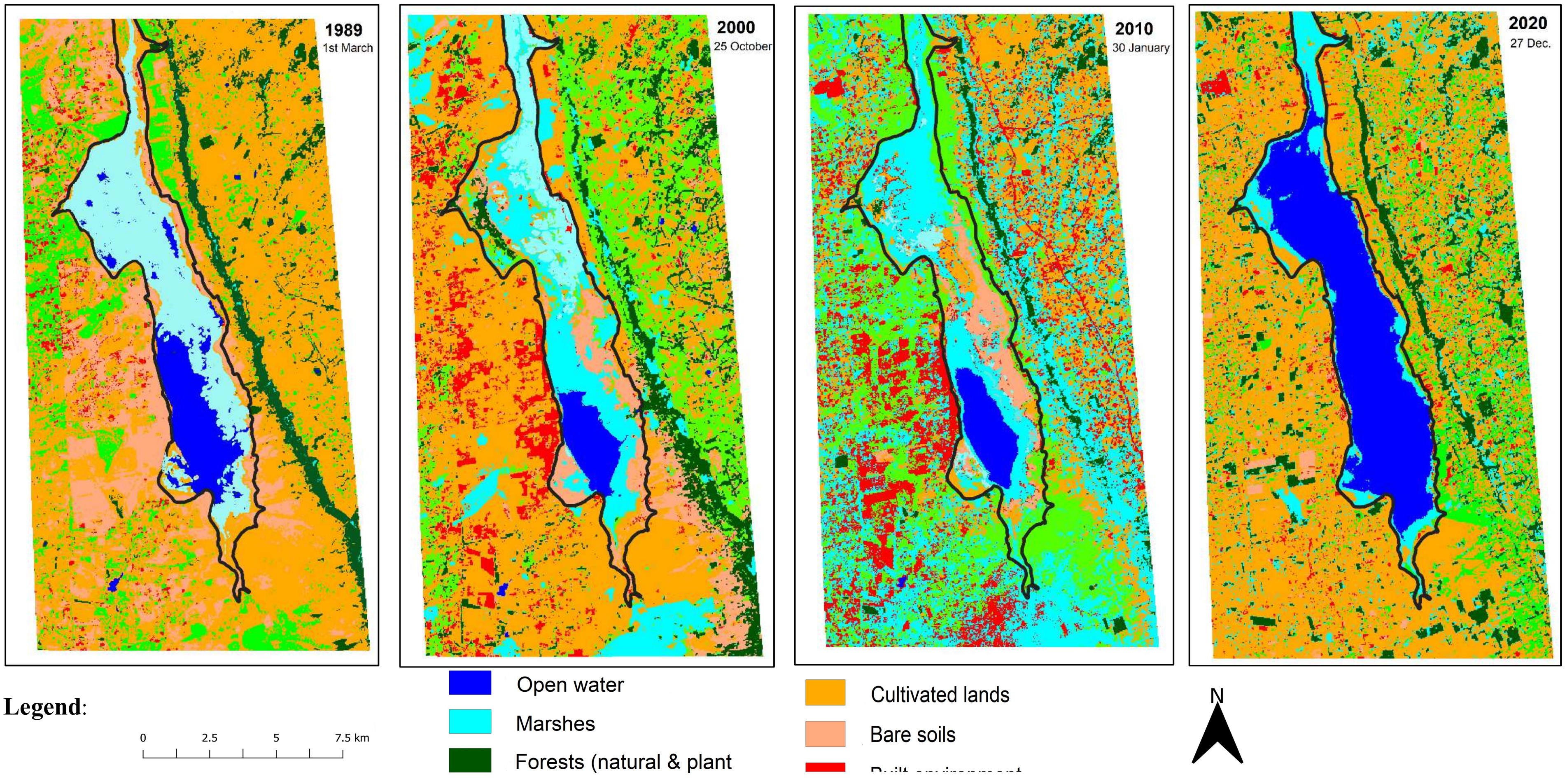

Figure 7.3: Landsat images of the middle and southern sections around Lake Ol' Bolossat over three decades (1989-2020) reflecting major changes in Land Cover and Land Use. (Source: USGS).

between 2010 and 2020, during which time the cultivated lands had an increase of 64%. Except in 2010 when the marshes occupied the largest proportion of land at 34%, cultivated lands has been the dominant form of land use throughout the three decades with an average of 45% coverage. Its greatest increase (64%) was observed between 2010 and 2020. The largest proportion (14%) of bare ground reported in 1989 which were observed both in the wetland and buffer zones especially in 2000 and 2010. In 2010 for instance, 590 ha of land (2.5%) were bare most of which were within the lake's shoreline perhaps due to drought where the lake level receded.

There was a general increase of 71% of land classified as built environment over the three decades (1989 and 2000), its largest of 15.7% being in 2010. Despite a reported increase in human population in the study area, the results show a decline of the built environment between 2010 and 2020. This decline may be ascribed to several reasons such as: i) human population increase may not necessarily correspond to a substantial growth in the quantity of houses, ii) area under forestry experienced a 54% increase, some of which are trees around homesteads that would cover/block houses from satellite camera, iii) there has been unforced relocation of people in temporary occupation of privately-owned land (e.g. Githungucu village in early 2021), and iv) removal of homesteads in waterlogged parts of the basin that are inhabitable during the wet seasons.

7.4.2 Categorization of threats

A total of 102 respondents (raters) from 13 of the lake's 16 villages participated in a survey aimed at rating the threats in terms of their occurrence and impacts on cranes around the lake. Their demographics and socioeconomic characteristics is provided in Appendix II. A Cronbach's alpha (a coefficient of reliability) index of 0.909 indicated good level of consistency in the ratings, meaning that the respondents have a virtuous understanding of the nature and extent of threats affecting the cranes in the study area. Fleiss' Kappa (*k*) (a coefficient of assessing the reliability of agreement) index of 0.042 however, indicated a poor agreement, strongly suggesting that the threats are quite varied and their magnitude differ from one part of the lake to the other. These differences may be due to differences in Land Use types, size of human population, number and types of livestock, seasonal distribution of foraging fields, and abundance and accessibility of food. In Table 7.1, the relative importance of each threat is a mean score from 102 respondent ratings on a scale of either 1, 2 or 3.

Table 7.1: Relative importance, impact and spatial coverage of threats affecting Grey Crowned Cranes in Lake Ol' Bolossat basin.

Description of Threat	Relative importance (mean score)	Impact level	Spatial distribution (% shoreline affected)
Climate change (drought)	1.7864	High	100
Climate change (flooding)	1.7087	High	80
Electrocution & Collision	1.3592	Low	25
Encroachment	1.8155	High	100
Fire (marshes & grasslands)	1.4272	Low	10
Fishermen/Boat activities	1.5340	Moderate	60
Invasive/Introduced species	1.4854	Low	85
Land use changes	1.6505	Moderate	100
Livestock (overgrazing)	2.1359	High	100
Livestock (trampling)	1.8835	High	90
Macrophyte harvesting	1.3592	Low	35
Poaching (eggs, chicks)	1.8932	High	70
Poaching (snaring, trapping)	1.5728	Moderate	65
Poisoning & Persecution	1.5631	Moderate	25
Predation (feral dogs)	1.6602	Moderate	60
Quarrying & Erosion	1.3786	Low	25

In the table, the impact level of each threat is based on the value of the mean score where a scale of three descriptions was used: low (<1.49 mean score), moderate (1.5-1.69 mean score) and high (>1.70 mean score). Spatial coverage (%) is an approximation of number of villages or parts of the shoreline from which the threat is known to occur or frequently reported. The importance of an individual threat (i.e. its relative mean score) was positively correlated to its spatial coverage (i.e. estimated % spatial distribution) (Pearson's r = 0.755; $df_{(n-2)}$ = 14, p <0.05). This means that the higher mean scores values of threats go with high % of distribution around the lake. Therefore, the wider the spread of a threat is, the greater is its impacts on Grey Crowned Cranes and their habitats.

The threats were sorted out into three major categories aligned to Grey Crowned Cranes' life history cycle starting in their breeding sites (wetlands) through the riparian land into foraging fields. The three threat categories (illustrated in Figure 7.4 with details in Table 7.2) were determined as follows.

i) *High impact threats*: reduces the quality of the nest-site, leading to loss of eggs and reduced survival of chicks.

ii) *Medium impact threats*: affects wetland habitats where Grey Crowned Cranes select a nest-site forage, rest and roost.

iii) *Low impact threats*: affects Grey Crowned Cranes in grasslands and crop fields where cranes forage and rest during the day.

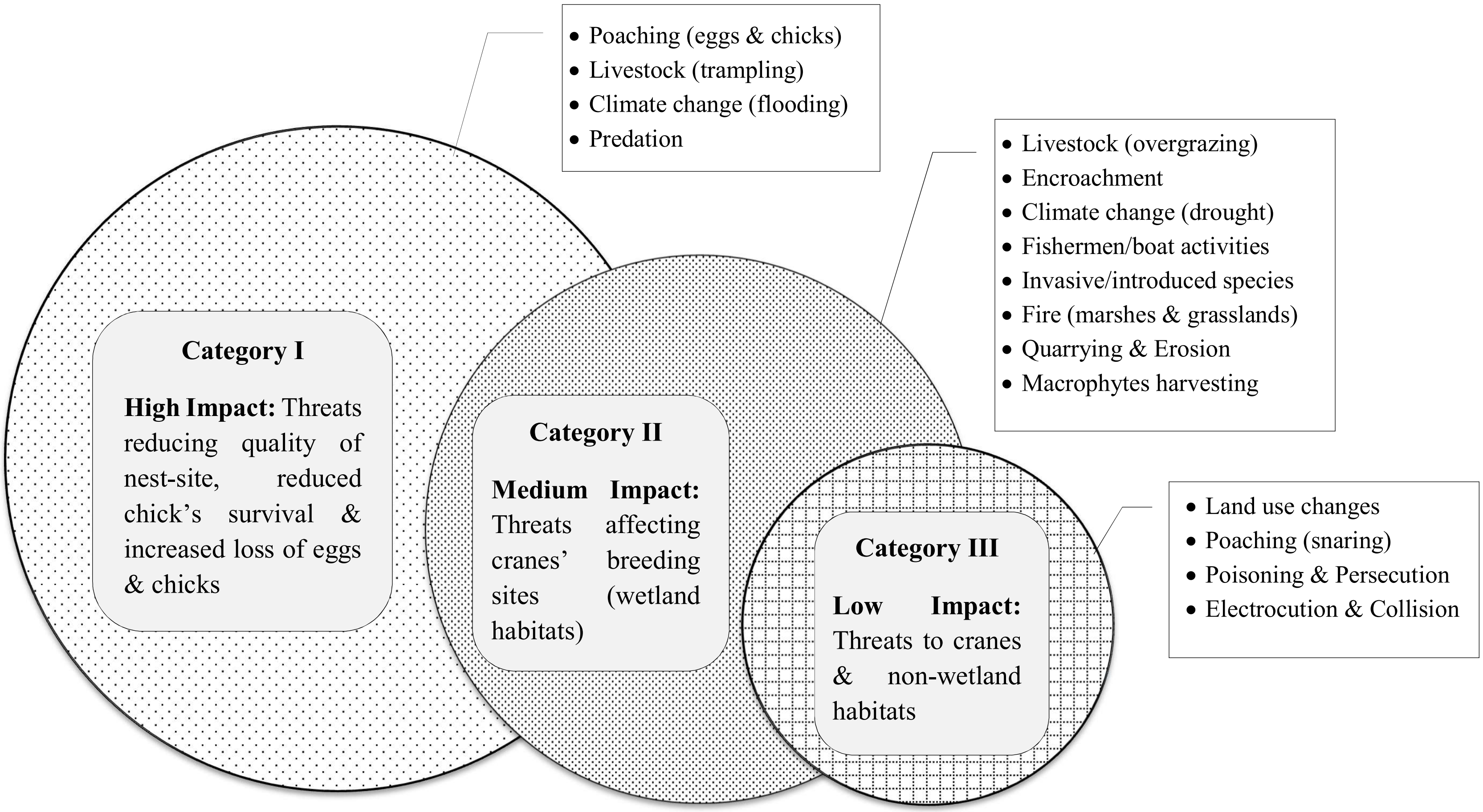

Figure 7.4: Categories of threats affecting the Grey Crowned Crane's population in Lake Ol' Bolossat. *The callout lists types of threats in each category (in decreasing order of importance) while the size of the circle implies overall severity.*

Table 7.2: Details of threats affecting Grey Crowed Cranes and their habitats in Lake Ol' Bolossat basin as observed during the study period.

Category I: High impact threats	
Description: This category comprises threats that result to insecure nest and loss of eggs and chicks. They are the most severe threats impacting negatively on the Grey Crowned Crane population of Lake Ol' Bolossat.	
Livestock (trampling):	Creates disturbance, increases loss of clutches, destruction of nests and reduced breeding success.
Predation:	Changes in vegetation structure exposes chicks to predators such as feral dogs, African Fish Eagle and African Marsh Harrier.
Poaching:	Disappearance of unfledged chicks in the study area is highly attributed to illegal removal than predation. Egg collection is for provision of protein at the local level; bush meat market is thought to be active; local domestication is uncommon; adult cranes trapping common.
Climate change:	Local changes in weather patterns delays, and sometimes shortens, nesting cycle; excess rainfall (flooding) causes loss of nests, clutches and probably drowning of chicks.
Category II: Medium impact threats	
Description: Threats in this category are of medium impacts affecting cranes' breeding sites (i.e. wetland habitats)	
Fire:	Destroys breeding and foraging habitats in the marshes and riparian grasslands.
Macrophytes harvesting:	Mostly affects *Papyrus* and *Cyperus* sedges; Papyrus is commercially harvested for the art and craft market; causes habitat loss, removes cover, creates disturbance and exposes nesting pairs and chicks
Livestock (overgrazing):	Reduces vegetation height in riparian grasslands and in the marshes important for foraging and chicks cover; affects prey abundance
Invasive species:	*Myocastor coypus*, *Procambarus clarkii, Azolla pinnata* and *Salvinia molesta;* affects native species and ecological integrity of the aquatic ecosystems. (Figure 7.5)

Encroachment:	Leading to deterioration and degradation of marshes and riparian grasslands through loss of native vegetation, removal of vegetation cover and erosion.
Quarrying & soil erosion:	The immediate location of quarrying sites on the lakeshore is a source of disturbance. Siltation and associated pollutants affect wetlands in various ways.
Fishermen & boat operators:	Previously associated with egg collection; creates disturbance to breeding, resting or foraging cranes and other waterbirds; fishing nets waste pollute water.
Effects of climate change (drought):	Drought may cause starvation and death of chicks; leads to considerable fluctuation in water levels.
Category III: Low impact threats	
Description: These are threats affecting adult (or fledged) Grey Crowned Cranes and their non-wetland habitats in the entire landscape. They are however considered of low impact at least for now.	
Poaching:	Trapping recorded mostly in foraging fields; escapees observed with snares on legs; others with injured or broken legs or amputated feet (Figure 7.6); endured pain and permanent disability cause divert attention from social behaviour and breeding activities.
Electrocution & collision with power lines:	Eight cranes perished as a result of electrocution while one collided with a power line; incidences may increase in the future due to rural electrification (Figure 7.7).
Poisoning & persecution:	Medium to high potential threat; 18 individuals died from suspected poisoning in Githungucu village in post-data collection period (G. Ndung'u, *pers. comm.*, 12 April 2021; Figure 7.8); use of agro-chemicals causing indirect poisoning through invertebrates prey.
Land sub-divisions & fences:	A juvenile crane perished from entanglement in barbed wire that had been heaped together and overgrown with grass; fenced fields unsecure to cranes
Other factors:	The Kenyan school calendar holidays fall in April, August and December thus coinciding with peaks of clutches in August and chicks in December; children often take chicks to play with or take home as pets.

Figure 7.5: Alien invasive species in Lake Ol' Bolossat. [A] *Myocastor coypus* and [B] *Salvinia molesta*.

Figure 7.6: An adult Grey Crowned Crane with amputated leg as a result of snaring. (©Werner Schröder).

Figure 7.7: **An adult female Grey Crowned Crane casualty from collision with a power transmission line at Kanjogu, Lake Ol' Bolossat.** [A] Carcass of the crane under the power line, 22 October 2019 (Source: GN Muigai); [B] An egg from this female's oviduct.

Figure 7.8: Seven of the 18 Grey Crowned Crane carcasses who died from suspected poisoning in a sown wheat field in Githungucu village. (©GN Muigai, 21-Apr-2021).

7.4.3 Impacts of community-led interventions

A mid-2015 pilot study around the lake disclosed that human activities had far-reaching, negative impacts on Grey Crowned Crane (Muigai, 2016). Raising awareness on implications of threats directly affecting cranes population (e.g. eggs collecting and poaching, their habitats etc.) among the local communities was started in mid-2016. It targeted individuals who were known or thought to be collecting eggs, removing chicks and trapping adults. Strategies used included one-on-one informal meetings (with fishermen, herdsmen and boat riders), distribution of information brochures and posters written in local vernacular and Swahili, and an explanation of what the Wildlife Law says about crimes involving Endangered species in Kenya. Additional strategies were offering opportunities for selected members to attend seminars and workshops, a visit to a national park to appreciate active members, and cash payment towards nests and chicks monitoring.

The number of fledged chicks in each breeding season (regardless of the number of breeding pairs, impacts of predation and disease nor the length of the breeding season) was adopted as a measure of awareness campaign. These campaigns are bearing fruits as demonstrated in Figure 7.9 where there has been a significant improvement in number of fledging chicks, starting with a zero in the 2015/2016 breeding season to 94 in 2018/2019. The enhanced breeding success is credited to Cranes Conservation Volunteers and the wider resident’s membership.

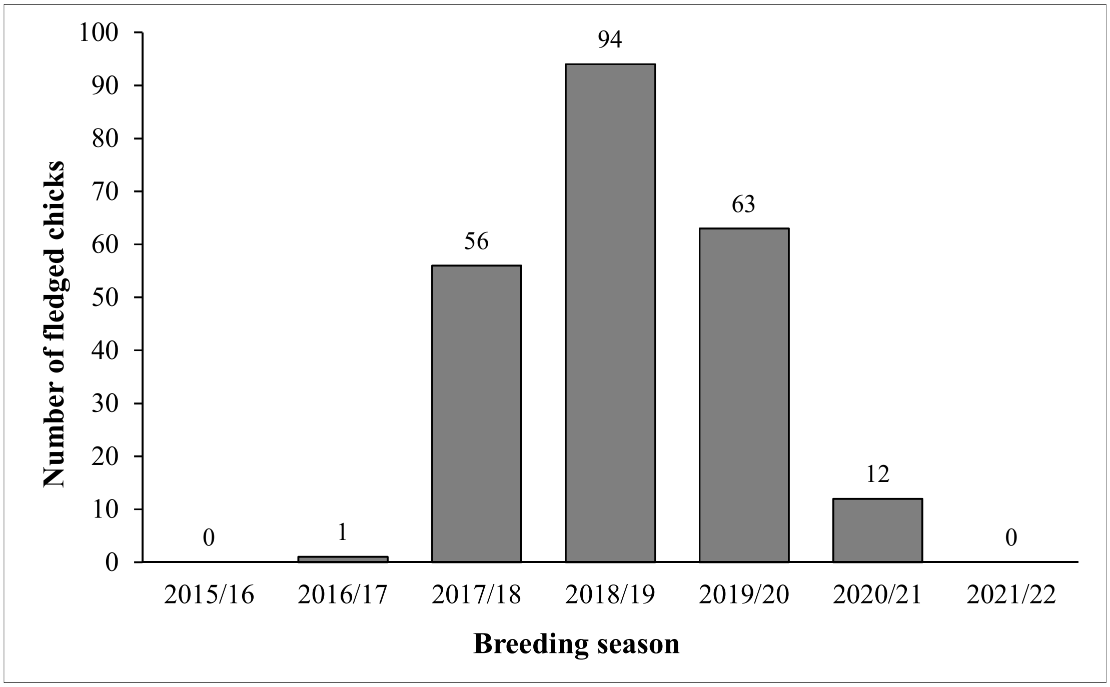

Figure 7.9: Number of fledged Grey Crowned Crane chicks in Lake Ol' Bolossat in seven consecutive breeding seasons. (*Source*: Cranes Conservation Volunteers, Kenya)**.**

A reduction on the number of fledged chicks is however observed in Figure 7.9 from 2019/2020 breeding season. This was as a result of an influx in the number of individuals of Nutria (which is thought to prefer the reeds roots for food) giving way to open waters that were heavily invaded by *Salvinia molesta* leading to an overall loss of crane's breeding habitat. During the same period, there was delay in the onset and amount of rainfall compared to the previous seasons (G. Ndung'u, *pers. comm.*, 10 August 2021). The number of chicks was even lower (12) during 2020/21 breeding season as a result of continued habitat loss from invasive weeds and was made worse by the impacts of changes in local weather patterns (lack of rainfall). In the current year (2021/2022) (corresponding to finalisation of this thesis), there were no breeding activities (zero chicks) within the breadth of the nearly dry lake bed (Figure 7.10) with no marshes and the only remaining water being in the southern tip where the lake is deepest.

Figure 7.10: Shortage of rains in Lake Ol' Bolossat basin in 2021 and 2022 has resulted to its drastic receding and loss of cranes' breeding habitat (marshes). Date: 18 March 2022.

7.5 Discussion

The present study adds to previous studies on Land Use and Land Cover modifications in Lake Ol' Bolossat basin, particularly on how this is affecting the distribution of Grey Crowned Crane's breeding and foraging habitats. This study has found that there have been enormous changes in land cover which is coherent with earlier studies. Muriithi *et al*., (2013) reported significant changes in different types of land use over a 20-years interval (1989-2010) where farmlands and build-up area increased by 31% and 33% respectively, while forest cover and floodplains reduced by 30% and 26% respectively, the main cause of these drastic changes being an increase in human population. A topical report by Terer *et al.* (2019) indicated that most of the land within a 4 km buffer around the lake is dominated by agricultural fields and grasslands. In this study, forest cover decreased between and 1989 and 2020 including along the Satima escarpment. Its increase after 2010 is attributed to an increase in planting mainly of Eucalyptus and cypress in farms and small-scale plantations in the water-logged grasslands in the lake basin.

Considerable land use changes around the lake have resulted into significant land subdivisions and fragmentation of riparian grasslands were reported to have occurred after 1993 when the National Settlement Trustee Fund demarcated and settled people in the lake's buffer zone (Thenya *et al.*, 2011; Government of Kenya, 2020). Some of the possible reasons for the observed increase in human settlements in the area is Kenya's political disturbance of 2007-2008 (Thenya *et al*., 2011). As human population increases in the study area, more land use and land cover changes such as transition of grasslands to cultivated land is expected.

It has also been confirmed in this study that consequences of climate change are affecting reproduction and behaviour of Grey Crowned Crane. Extreme dry weather conditions have in the past led to considerable fluctuation of water levels. Gichuki & Gichuki (1998) reported that the lake dried up completely in 1929, 1940, 1954 and 1959, and that only scattered pools of water remained in 1965, 1975, 1980, 1987 and 1992. A 31 January 1973 satellite image of Lake Ol' Bolossat presented by MEMR (2012) show an extended coverage of the open water very similar to the image of 27 December 2020 (this study). This is evidence that the lake's area under marshes and open water fluctuates over time with major changes taking place in a cycle of approximately 50 years.

During extreme dry seasons when area under bare soils (e.g. image of 30 January 2010) increases tremendously with the lake nearly drying and emerging again after the rains. Fluctuations in coverage of marshes would be impacting on territorial behaviour of Grey Crowned Cranes and consequently will impact on their reproduction and recruitment potential. Land Cover and Land Use have actually been reported as important factors influencing the ecology and behaviour of animals. For example, Bialas *et al.*, (2021) found out that distance to landfills as anthropogenic sources of food had an imperative consequence on the likelihood of nest occupation in White Stork *Ciconia ciconia* in Poland.

IUCN (2020) has provided a criteria along with a scoring system for assessing a taxon for the purpose of listing on the IUCN Red List of Threatened Species. This classification was not followed in this study because the aim was to evaluate the severity of each threat at the local site level as perceived by the local community who have experienced them first-hand due to their residency status. However, the threats as identified and evaluated at present form a basis for future species assessment at a higher level and are similar to what has been reported elsewhere for the species, e.g. Shanugu & Phiri (2015), Morrison (2015), BirdLife International (2016) and Wamiti *et al.* (2017).

Most of the threats identified are of anthropogenic origin including those from livestock. Each threat affects Grey Crowned Crane in different ways. For example, livestock trampling rates have been shown to increase with livestock density (Sabatier *et al*., 2015). Human-induced fires on the lake's marshes and riparian grasslands were set for various reasons such as stimulating growth of tender, nutritious pasture (Wade & Lewis, 1987) and to control parasites such as ticks (Victoria *et al*., 2013). Fire also causes adverse effects in the environment including death of animals such as amphibians, reptiles and invertebrates, and massive damage and loss of vegetation cover (Martin *et al.*, 2016). Increased death of chicks during birds' nesting season may result from fires as a result of destruction of nests and eggs and killing of pre-fledged chicks (Austin, 2018). Moreover, fires upset cranes' food (both animal and plant materials) in the marshes, crop fields and grasslands.

Infrastructure development is emerging as a serious threat to birds globally. In the study area, a corridor of two parallel high voltage transmission lines from Loiyangalani (400 kV) and the Eastern Africa Interconnector (Ethiopia–Kenya, 400 MW). Respectively, the lines are 2 and 3.7 km from the southern tip of the lake and have so far caused mortality of an adult female crane as a result of collision. Sub-division and fencing of land results in trivial patches affect large foraging birds like cranes because they have to intensify time spent looking for food (leading to energy loss) by flying from one patch to another (Wu *et al*., 2009).

In Kenya, the Grey Crowned Crane is listed as a protected species in the Sixth Schedule of The Wildlife Conservation and Management Act of 2016. The Act, besides emphasising protection of all endangered species and their habitats, specify the penalty for committing such a crime i.e. a fine not surpassing Kenya Shillings one hundred million or life imprisonment. While such Laws are meant to be punitive and to deter offenders and their accomplices, they can only save a species when crimes are promptly reported and expeditiously investigated to facilitate successful prosecution and judgement. Those mandated by law to arrest, prosecute and deliver judgement must understand the status of Kenya's threatened species.

The Grey Crowned Crane has been regarded and repeatedly reported as a crop pest by farmers around the lake, with some of them threatening to poison them due to extensive crop damage. Most complaints are from those growing peas (*Pisum sativum*), beans (*Phaseolus vulgaris*), Wheat (*Triticum aestivum*), maize (*Zea mays*) and potato (*Solanum tuberosum*). The cranes pose a threat to these crops at different growth stages, for example, peas and beans are fed upon at flowering and seed ripening stages while only uncovered potato tubers are pecked. Cranes forage in harvested and newly planted fields of wheat, oat and barley picking the fallen and exposed seeds until the young crops are c.15-20 cm high, and were never observed feeding on a standing, mature crop. Conflict with farmers makes cranes candidates for poisoning and direct persecution. This challenge must be addressed to reduce the potential risk of poisoning e.g. through seed dressing with a deterrent agrochemical.

7.5 Conclusion

This study hypothesised that: i) there were no major Land Use and Land Cover changes affecting cranes, ii) there were threats affecting cranes, and iii) there were no activities by the local community towards safeguarding cranes and their habitations in the study area. The results of this part of the study have however rejected all the three null hypotheses.

Analysis of Land Use and Land Cover satellite images have shown that there were significant changes on crane's two key habitats i.e. marshes and grasslands, which have resulted to cranes adopting to forage in cultivated fields. The continuous loss and recovery of marshes in the lake affects cranes foraging and breeding habits. In extremely dry periods when the lake level recedes to the deeper southern section, breeding activities are completely suspended until habitat recovers after adequate rains. Although the lake basin has two rivers draining in the northern section, recent (2021/2022 drought) have revealed that these rivers do not flow towards the southern end of the lake. The lake therefore largely depends on surface runoff and seepage from the surrounding land, and spring water from the Sattima escarpment. It is therefore important that conservation efforts also focus on rehabilitation of the springs to ensure a continuous flow of water to the lake to avid drying up and loss of marshes habitat.

An increase in human population in the study area has resulted to a demand for land for settlement and cultivation. Besides sub-divisions, the riparian land has been most vulnerable which has resulted to loss of native grasslands which are not only depended upon by cranes and other birds but also by hippopotamus. This has over the years led to increasing incidences of human-wildlife conflicts affecting both humans and wildlife. Loss of cranes foraging habitats has seen them increase utilisation of cultivated land making them prone to poisoning and persecution. A balance must therefore be struck between human and wildlife needs in the landscape. Although some of the impacts in land cover changes are natural phenomena, total implementation of the gazette notice declaring an area of 147 km^2 around the lake as a Protected Wetland Area and implementation of the 2020-2030 Integrated Management Plan may help address some of the conservation challenges. These should be given priority through financing and sincere stakeholders involvement. This will help in securing the riparian zone and curb further degradation of the marshes and catchment areas.

Development of a successful conservation approach necessitates having information about which species are at risk and what factors threaten their survival (Venter *et al.*, 2006). This study has identified a total of 16 threats affecting cranes and their habitats in the study area. These were put into three categories depending on their level of impact on the cranes. The most critical category were threats affecting cranes and their breeding habits (wetlands) i.e. threats reducing quality of nest-site, reduced chick's survival & increased loss of eggs & chicks. Noting that these may change over time, these threats were collection of eggs and removal of chicks, livestock trampling, climate change (flooding) and predation by feral domestic dogs. To reverse the global trend in decline of this species' population, priority should be given to address this category of threats. The aforementioned implementation of the gazette notice followed by a further gazettement of the wetland as a national reserve could help address these threats and many others. Committed law enforcement is imperative in curtailing some threats.

This study has also established that local communities living in, and adjacent to, areas where threatened wildlife species occur has a major part to perform in their conservation. The fact that information is power is shown by the results of strategies, and vibrancy thereof, employed by Cranes Conservation Volunteers (CCV) who have committed themselves to educate the communities on the predicament of the species among the villages surrounding the lake and upland wetlands, and legal consequences of deliberate and/or undeliberate human activities affecting an endangered species such as the Grey Crowned Crane. The increase in number of fledged chicks is a simple, inexpensive yet robust monitoring tool that could be adopted elsewhere to evaluate the effectiveness of conservation efforts.

Support is needed to initiate projects reaching a majority of the local population. These could include infrastructure development, and health and nutrition. This way, the community would develop a positive culture of living and tolerating the cranes and will help reduce threats targeted to them such as persecution and poisoning. Given that over 85% of this species' population occurs outside protected areas (Wamiti *et al.*, 2020), involvement of local communities is a key component for the specie's population recovery. This will eliminate the need for captive breeding and reintroduction programmes which would be expensive. The species has the potential to recover its population in the wild but will require that threats are mitigated at the local levels. Therefore, the approach taken and lessons learnt by CCV need to be published for others to borrow a leaf.

CHAPTER EIGHT

8.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

8.1 General Discussion

The aim of this study was to generate science-based knowledge and information to help in identification of priority measures for management and conservation of Grey Crowned Crane population and habitats in Lake Ol' Bolossat basin. Specifically, the study focused on determining the population characteristics and social organisation, establishing factors that influence nest-site selection and nesting habits, evaluating the diet and its seasonal variations, as well evaluating the existing threats affecting the species and community-led conservation activities in the basin. This was the first time an ecological study of that magnitude was being conducted on this population, the only other such study in Kenya being Gichuki's (1993) who studied the Kitale area population.

This study has established that Lake Ol' Bolossat basin holds 5% of the global and 14% of the Kenyan population of this species. This population, reaching a maximum of nearly 1,200 individuals during the dry season, is comprised of an estimated inhabitant population of between 250 and 350 cranes. The lower limit of this estimate were pairs taking up breeding territories across the 30 km stretch of the lake and others are scattered in the upland wetlands. The proportion of breeding birds was estimated at 22% of the maximum population in this study, favourably comparing with 25% reported by Gichuki & Gichuki (1989). Review of previous work on this population, e.g. Ndithia *et al.* (2009) and Madindou *et al*. (2019), supports the findings that Lake Ol' Bolossat is a chief place for the Grey Crowned Crane. These findings therefore put the study area on the global map as one of the key sites in the species range, particularly because of two major reasons: the number of territorial pairs (proportion of breeding population) and population size.

This study recorded a maximum flock size of 332 cranes, much higher than previous records. Although Muigai (2016) reported a flock of 413 cranes, the recent observations indicates that the local population have increased over the years or that the available foraging fields locally and/or in the neighbouring areas are much less or deteriorated such that cranes are now flocking in a fewer sites. All the large flocks in this study were observed in human-modified habitats in the agricultural fields especially those under wheat and maize cultivation. Use of crop fields have increased crane-human conflicts that exposes cranes to poisoning and persecution from intolerant farmers. A review of Land Use and Land Cover changes revealed that there was a decrease in area occupied by grasslands and an increase in cultivated land which could explain these observations.

Land use changes in the study area, whether natural or human-induced, have an impact and influence on social behaviour and spatial-temporal distribution on local cranes population. One of the natural drivers of these changes has been climate change leading to changes in local weather patterns. An extensive area under marshes was observed in the 1989 image that have considerably decreased. This is affecting the local population in terms of available nesting opportunities which may lead to increased breeding pair densities and intense competition for territories and resources. Consequently, such changes in breeding habitat size and conditions could result to a slowed population growth.

Changes in weather such as delayed precipitation was seen to be a major cause of delay in initiation of breeding activities. Weather patterns and hence seasons, had a great impact on aquatic and terrestrial food abundance and availability. This is an important factor in breeding cycle plasticity that gives cranes an opportunity to ensure any efforts to nest coincided with a time of availability of suitable food sources for the dietary requirements especially for the breeding female adults and to rear the chicks. Suitability of a nesting habitat was apparently influenced by environmental factors namely water depth, vegetation height and offshore distance to the nest. Most water physico-chemical parameters also varied significantly between the seasons and habitat conditions in the lake. These are also crucial factors that have a direct influence on the aquatic conditions and associated fauna that comprise diet of cranes. There is therefore an array of inter-linked factors that are required for a successful breeding attempt.

The current study also addressed knowledge gaps in terms of threats and challenges facing the Grey Crowned Crane population in the study area. The most widespread and persistent threats to cranes in the lake and its watershed were landscape transformations through cumulative Land Use and Land Cover changes, local weather pattern variability, and threats of anthropogenic origin. The local community, through the activities of Cranes Conservation Volunteers, have realized that they have an essential part to act in addressing some of these threats especially those that contribute to poor breeding performance and survival of chicks and adults. Despite financial and deviance from non-cooperating members of the community, their initiatives gives hope that the species can recover from the declining population on its own in the absence of threats. Support in form of finance to diversify projects and activities that develops their capacity and improve socio-economic development and in addressing some of the threats through law enforcement are needed.

8.2 General Conclusions

This study has determined the characteristics of Grey Crowned Crane population, its spatial-temporal distribution, nesting behaviour and the environmental factors and human dimensions influencing it in different ways and magnitudes. The following are conclusions drawn from this study and their implications on Grey Crowned Crane.

- Lake Ol' Bolossat basin supports highly variable Grey Crowned Crane population ranging in size from 521 to 1,115, with the resident population estimated at 250-350.

Representing 15% and 5% of the species' national and global population sizes respectively and an 11.65% young to adult ratio underlines the basin as a critical site for the species. Both terrestrial and wetland habitat substrates were utilised in almost equal proportions, with wheat fields and grasslands being the most preferred foraging habitats. Landscape management options should take into consideration the adaptation of this species in occupation of human-modified habitats.

- Three factors (water depth, vegetation height and distance of nest from the shoreline) were observed to have a greater influence in selection of a nest-site. Cranes thus placed their nests in water more than 50 cm deep, vegetation 60-90 cm high, and preferably 100 m offshore. A minimum of territorial pairs, both breeding and non-breeding, and a further 20 pairs in upland wetlands were recorded. The basin is hence a critical breeding site for the species and thus has an important input to reverse the declining specie's population.

- Food plays a critical role in a species breeding success and survival. Assessment of potential terrestrial and aquatic prey items for the Grey Crowned Crane revealed that season was an important factor influencing its abundance and availability. It was also determined that water quality also varied seasonally. There is therefore a possibility that the conditions of the aquatic environment have a strong influence on the aquatic life. The marshes were more productive than terrestrial habitats. This helps to explain the extended use of these habitats by nesting pairs whose chicks require protein for normal and fast growth. These observations correspond to crane's timing of breeding activity that coincides with the wet season when food is abundant.

- Land use and land cover changes assessment showed that major changes took place during the period under consideration (1989-2020). Significant changes took place between 2010 and 2020 where there was an increase of 83% of open water and a significant decrease of 73% of the marshes. Native grasslands cover also decreased by >50% probably due to an increase of 64% in area under cultivation. Loss of marshes have potential to negatively impacts on Grey Crowned Crane's population due to shrinking of foraging and nesting habitats. Grasslands reduction not only affect cranes but also other grassland-dependent species.

- A total of 16 threats were identified. These were put in three categories depending on their impacts on Grey Crowned Crane's population and habitats. These were: i) high impact threats that lessen the desired attributes of the nest-site, leading to loss of eggs and reduced survival of chicks. (e.g. livestock trampling and poaching), ii) medium impact threats affecting wetland habitats where crane select a nest-site, forage, rest and roost (e.g. encroachment and invasive species) and iii) low impact threats that affect cranes outside the wetlands and their foraging habitats (e.g. land use changes and electrocution and collision with power lines). Addressing these threats, with an aim of reduced loss of eggs and chicks, reduced chicks and adult mortality and improved quality of nest-sites, requires vigorous involvement of the local community, law enforcement and appropriate legislation.

- The findings of this study presents essential information on the Grey Crowned Crane's population size and its spatial-temporal distribution in the study area, characteristics of nesting habitats, types of threats and their impacts on the species and habitats, the role of local community in its conservation and survival, and emphasized the need of integrating these findings in landscape-level decision-making.

8.3 Recommendations

8.3.1 Management of Lake Ol' Bolossat

Noting that the Grey Crowned Crane has no flexibility in habitat choice for nesting, Gichuki & Gichuki (1989) recommended management of populations to provide an 'enabling environment' for the species to reproduce and survive. As highlighted in this study, identification and addressing habitat needs and threats affecting cranes and their habitats (especially breeding sites) should be at the site level. The minimum and critical actions to provide an 'enabling environment' at Lake Ol' Bolossat are reduction or elimination of threats affecting nesting sites such as collection of eggs and chicks, livestock trampling and overgrazing that depletes vegetation. This may be achieved through zonation and deliberate removal of livestock during breeding seasons. Some level of increased conservation education and monitoring is required as upheld by Collier *et al.* (2016). The distribution and density of mated cranes across the lake shows areas that are important in the species' breeding activities. These parts of the lake could be ear-marked for zonation so that they are excluded from any form of utilisation that could affect the site's quality and/or the distribution of the breeding pairs.

Given its outstanding regional and global significance as a key breeding site for Grey Crowned Crane alongside the presence of other globally-threatened bird species, a full implementation of the gazette notice declaring Lake Ol' Bolossat as a Protected Wetland Area and the Integrated Management Plan 2020-2030 (Government of Kenya, 2020) should ensure that the wetland is managed for the good of local communities and biodiversity. The County Integrated

Development Plan (CIDP) should consider allocating funds to the lake's conservation and sustainable utilisation. The 2018-2022 CIDP recognizes the lake as an ecologically sensitive area and highlighted it's potential in economic development, and proposed activities such as catchment areas rehabilitation, survey of riparian land for creation of a conservation area, and fishery resource development (County Government of Nyandarua, 2018). Options to re-gazette the wetland as a National Reserve should be hastened to ensure the wetland is protected for posterity. The lake also deserves evaluation and consequential listing as a wetland of global standing under the Ramsar Convention as well as a UNESCO World Heritage Site (perhaps annexing it to the Aberdare Mountains Ecosystem).

A careful management of the wetland, including exclusion of livestock during the breeding season, would definitely reduce human and livestock disturbances to nesting cranes and other waterbirds. Law enforcement should also be stepped up to control activities that impact negatively on cranes' breeding performance, such as trapping and collection of eggs and chicks, and to halt further encroachment on the riparian land. Enactment of a 'Wetlands Act' at the national level, including the management and control of invasive alien species, will go a long way towards wetlands conservation in Kenya. Some of the actions needed to address the conservation needs of Grey Crowned Crane is habitat management. Currently, the population of *Myocastor coypus* is sharply rising while area under *Azolla pinnata* and *Salvinia molesta* coverage is increasing tremendously. These species are causing unknown impacts on native species, including nesting waterbirds such as loss of nesting and foraging niches.

8.3.2 Management of Kenyan population of Grey Crowned Crane

This study sheds light on understanding various ecological and conservation aspects of Grey Crowned Crane population in Lake Ol' Bolossat basin. The site has a significant role in the species' population recovery and perpetuity. While confined breeding and reintroduction programmes have been recommended for several threatened species, this study does not make this recommendation for the Grey Crowned Crane. This is because, its population in Kenya may not have reached critical levels warranting such a programme. Their clutch mode of three eggs as well as a high hatching success are two factors that favour a natural population recovery. Efforts to enhance this should focus on elimination and reduction of threats especially at the nesting-sites and the general breeding habitats (wetlands and adjacent grasslands). This will ensure successful nest construction, egg laying and incubation, feeding and fledging of chicks. An annual monitoring of this population is recommended to monitor changes in numbers and measure the impacts of conservation efforts.

There is a growing concern for the Grey Crowned Crane's future in Kenya owing to the ongoing rapid alterations of landscapes and the ever rising threats to wetland and grassland habitats. Thus, identification of key sites that hold substantial populations of this species, especially wetlands and grasslands that are registered as public utilities and accord them some formal protection, is crucial for the species' survival. Land under private ownership is also playing a key role in survival of wild populations of wildlife including cranes. Currently, some of the large-scale landowners (e.g. Kakuzi PLC and conservancies across Laikipia County) are supporting conservation efforts of the species. This should be embraced and technical assistance offered to those who may need habitat manipulations in favour of the species.

The improved knowledge on emerging key sites for the species in Kenya supported by a growing interest to conduct research on the species requires all forms of support. Investing in building and sustaining a cranes conservation and study human resource capital is fundamental in addressing knowledge gaps and conservation needs of the species. The increasing participation and support from international organisations such as International Crane Foundation, Nature and Biodiversity Conservation Union, Cranes Conservation Germany and

African Bird Club in support of Grey Crowned Crane research and conservation activities at Lake Ol' Bolossat is very encouraging.

There is an existing International Single Species Action Plan (ISSAP) for the Conservation of Grey Crowned Crane (Morrison, 2015). Formation of an International Working Group in Entebbe, Uganda in July 2019 stimulated the formation of a core team to spearhead the domestication of the ISSAP in Kenya. The membership is comprised of Kenya Wildlife Service, International Crane Foundation/Endangered Wildlife Trust Partnership, National Museums of Kenya, and National Environment Management Authority. This plan is expected to highlight actions required to address the plight of the Grey Crowned Crane in Kenya.

8.3.3 Proposed Research

1. Roost sites have an important influence in the behaviour and habits of cranes. Information is therefore needed on distribution and characteristics of roost sites, number of cranes at each roost, dispersal patterns to and from foraging sites, vegetation profile, water depth, offshore distance and roosting associates.
2. An investigation into causes of mortality of juveniles and adult cranes is needed. This include mapping of key power lines and crane's crossing points, number of casualties involved and installation of preventive devices to reduce collisions and electrocution of flying cranes.
3. A key threat affecting Grey Crowned Cranes' breeding performance is caused by livestock especially trampling and overgrazing by cattle and predation of eggs and chicks by feral dogs. There is a need also to quantify the effects of high livestock densities in wetlands and grasslands used by cranes in various parts of the country including western Kenya holding large populations, such as Kitale and Lake Victoria basin. A comparative study in protected areas on the impacts of wild herbivores and predators is also recommended.

4. Comparison of hatching and breeding success in families/pairs raising a single, two, three and (rarely) four chicks as well as determination of probabilities of each chick's sex for each family scenario. This could also go along with as study on the effect of egg size on chick's survival.
5. An understand how farming practices, including choice of crops and use of seed dressing and pesticides in control of pests as a potential risk of cranes poisoning.
6. An investigation to understand the market chains of wild-caught cranes and determination of the size and status of the captive Grey Crowned Crane population with a comprehensive review and overhaul of regulations governing acquisition, management and disposal of captive wild animals in Kenya.
7. A study is also recommended on ecological implications of invasive species on native species and wetland habitations in the study area since these are likely be impacting variously on the overall health of the lake and the diverse biodiversity it supports.
8. Ongoing movements studies on this population (Nowald *et al., In prep*.) reveals a wide range of an area with core sites in constant or seasonal use. This points to the need for genetic mapping to identify different populations of the species across the country.

8.4.3 Policy Interventions

Policy- and regulations-led actions are urgently required in the management of wetland ecosystems in Kenya. This include management of invasive alien plants such as *Salvinia molesta* in Lake Ol' Bolossat. It is necessary that the wetlands policy guidelines in delineation of a 'riparian land' are adhered to and implemented at Lake Ol' Bolossat to ensure existence of a diurnal grazing zone for hippopotamus and other wildlife species. The continuing encroachment on the riparian land is a major causes of human-wildlife conflict around the lake that is presently involving hippopotamus and cranes. There is also a need to regulate procurement, supply, sale and use of pesticides and fungicides as some of these are lethal to wildlife and environment.

There is also a need to review and/or develop new policies on licensing and monitoring of captive keeping of wildlife populations in Kenya, as well regulations governing wildlife trade. The current status of affairs seems to have loopholes that licensed individuals and criminals are taking advantage of in sourcing, sell or smuggling out wild-caught wildlife species. For instance, there is a need to address the increasing and unknown population of cranes in captive facilities, homes and hotels across Kenya, and chains involved in meeting the demands of a growing market for crane chicks. It is believed that these facilities are a market for wild-caught cranes, especially the chicks. As a control measure, population of cranes in licensed facilities, including captive breeders if any, should be permanently marked and closely monitored. The active participation of Kenya Wildlife Service leading other government arms (Customs, Kenya Police and The Judiciary) is desirable. Establishment of a Crane Rescue Centre next to a suitable habitat like Lake Ol' Bolossat is urgently needed so that rescued cranes and those in conditions that are unsuitable for direct release can be treated and given a soft-released into the natural environment.

REFERENCES

Allan, D. G. (1996). A review of the biology and conservation of Cranes. In R. D. Beilfuss, W. R. Tarboton, & N. N. Gichuki (Eds.), *Proceedings of the African Crane and Wetland Training Workshop* (pp. 13–29). International Crane Foundation.

Amulike, B. B., Fuller, T.K., Houlihan, P.W. & Griffin, C.R. (2020). Seasonal variation in grey crowned crane (*Balearica regulorum*) abundance in the Ngorongoro Crater, Tanzania. *African Journal of Ecology*, *April*, 1–7. https://doi.org/10.1111/aje.12738

Angelier, F., Tonra, C.M., Holberton, R. L., & Marra, P.P. (2011). Short-term changes in body condition in relation to habitat and rainfall abundance in American redstarts Setophaga ruticilla during the non-breeding season. *Journal of Avian Biology*, *42*(4), 335–341. https://doi.org/10.1111/j.1600-048X.2011.05369.x

Archibald, G.W. & Lewis, J.C. (1996). Crane Biology. In D. H. Ellis, G.F. Gee, & C.M. Mirande (Eds.), *Cranes: Their Biology, Husbandry and Conservation* (pp. 1–29). National Biological Service/International Crane Foundation.

Archibald, G.W. & Meine, C.D. (1996). Family Gruidae (Cranes). In J. del Hoyo, A. Elliott, & S. J. (Eds.), *Handbook of the Birds of the World. Volume 3. Hoatzin to Auks.* (pp. 60–89). Lynx Edicions.

Archibald, G.W. & Meine, C.D. (2019). Introduction. In J.T. Harris & C.M. Mirande (Eds.), *A global overview of cranes: status, threats and conservation priorities* (pp. 9–16). International Crane Foundation.

Arinaitwe, J. (1998). Wetlands and Waterbird Conservation in East Africa. In A. Beintema & J. van Vassem (Eds.), *Strategies for Conserving Migratory Waterbirds: Proceedings of Workshop 2 of the 2nd International Conference on Wetlands and Development held in Dakar, Senegal, 8–14 November 1998* (pp. 46–46). Wetlands International.

Austin, J.E. (2018). Threats to Cranes Related to Agriculture. In J.E. Austin, K.L. Morrison, & J. T. Harris (Eds.), *Cranes and Agriculture: A Global Guide for Sharing the Landscape* (pp. 83–116). International Crane Foundation.

Austin, J.E., & Buhl, D.A. (2008). Responses of Nesting Sandhill Cranes to Research Activities and Effects on Nest Survival. In M.J. Folk & S.A. Nesbitt (Eds.), *Proceedings of the Tenth North American Crane Workshop, Feb. 7-10, 2006, Zacatecas City, Zacatecas, Mexico* (pp. 98–106). North American Crane Working Group.

Austin, J.E., Morrison, K.L. & Harris, J.T. (Eds.). (2018a). *Cranes and Agriculture: A global* *guide for sharing the landscape*. International Crane Foundation.

Austin, J.E., Morrison, K.L. & Harris, J.T. (2018b). *Cranes and Agriculture: A Global Guide for Sharing the Landscape*. International Crane Foundation. Baraboo, Wisconsin , USA.

Baden, A. L. (2018). A description of nesting behaviors, including factors impacting nest site selection, in black-and-white ruffed lemurs (Varecia variegata). *Ecology and Evolution*, *9*, 1010–1028. https://doi.org/10.1002/ece3.4735

Baumgärtner, D., Mörtl, M. & Rothhaupt, K.O. (2008). Effects of water-depth and water-level fluctuations on the macroinvertebrate community structure in the littoral zone of lake constance. *Developments in Hydrobiology*, *204*, 97–107.

Beilfuss, R.D., Dodman, T. & Urban, E.K. (2007). The status of cranes in Africa in 2005. *Ostrich*, *78*(2), 175–184. https://doi.org/10.2989/OSTRICH.2007.78.2.11.91

Bennun, L., & Njoroge, P. (2001). Kenya. In L. F. Evans (Ed.), *Important Bird Areas in Africa and associated Islands: Priority sites for conservation* (pp. 411–464). Pisces Publications & BirdLife International.

Berkes, F. (2007). Community-based conservation in a globalized world. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15188–15193. https://doi.org/10.1073/pnas.0702098104

Bernadou, A., Espadaler, X., Le Goff, A. & Fourcassié, V. (2015). Ant community organization along elevational gradients in a temperate ecosystem. *Insectes Sociaux*, *62*(1), 59–71. https://doi.org/10.1007/s00040-014-0374-2

Bialas, J.T., Dylewski, Ł., Dylik, A., Janiszewski, T., Kaługa, I., Królak, T., Kruszyk, R., Pawlukojć, K., Pestka, Z., Polakowski, M., Zbyryt, A. & Tobolka, M. (2021). Impact of land cover and landfills on the breeding effect and nest occupancy of the white stork in Poland. *Scientific Reports*, 1–14. https://doi.org/10.1038/s41598-021-86529-z

Bird Committee. (2009). *Checklist of the Birds of Kenya* (2nd ed.). East African Natural History Society. Nairobi, Kenya.

BirdLife International. (2018). *State of the world's birds: taking the pulse of the planet* (p. 40). BirdLife International.

BirdLife International. (2020a). *IUCN Red List for Birds: Cranes*. http://www.birdlife.org

BirdLife International. (2020b). *Species factsheet: Balearica regulorum*. http://www.birdlife.org

BirdLife International. (2021). *Country profile: Kenya*. http://www.birdlife.org/datazone/country/kenya

Bradter, U., Gombobaatar, S., Uuganbayar, C., Grazia, T. E. & Exo, K.-M. (2005).

Reproductive performance and nest-site selection of White-naped Cranes *Grus vipio* in the Ulz river valley, north-eastern Mongolia. *Bird Conservation International*, *15*, 313–326.

Burke, V. E. M. (1965). A count of Crowned Cranes (*Balearica regulorum* (Bennet)) in Kisii district, Kenya. *Journal of East African Natural History*, *2*(111), 162–163.

Burnham, K.P., & Anderson, D.R. (2002). *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach* (2nd ed.). Springer.

Bush, S.E., & Clayton, D.H. (2018). Anti-parasite behaviour of birds. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1751), 0–3. https://doi.org/10.1098/rstb.2017.0196

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., MacE, G.M., Tilman, D., Wardle, D. A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D.S. & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*(7401), 59–67. https://doi.org/10.1038/nature11148

Catlin, D., Gibson, D., Friedrich, M.J., Hunt, K.L., Karpanty, S. M. & Fraser, J.D. (2019). Habitat selection and potential fitness consequences of two early-successional species with differing life-history strategies. *Ecology and Evolution*, *9*(24), 13966–13978.

Chabot, D., Craik, S.R. & Bird, D.M. (2015). Population census of a large common tern colony with a small unmanned aircraft. *PLoS ONE*, *10*(4), 1–14. https://doi.org/10.1371/journal.pone.0122588

Chadd, R. (2010). Assessment of Aquatic Invertebrates. In C. Hurford, M. Schneider, & I. Cowx (Eds.), *Conservation Monitoring in Freshwater Habitats: A Practical Guide and Case Studies*. Springer. https://doi.org/10.1007/978-1-4020-9278-7

Chamberlain, D.E., Pedrini, P., Brambilla, M., Rolando, A. & Girardello, M. (2016). Identifying key conservation threats to Alpine birds through expert knowledge. *PeerJ*, *4:e1723*.

Chandan, P., Ahmed, T. & Khan, A. (2019). Breeding behaviour and productivity of Black-necked crane (*Grus nigricolis*) in Ladakh, Indian Trans-Himalaya. *BioRxiv*. https://www.biorxiv.org/content/10.1101/809095v1

Chandan, P., Gautam, P. & Chatterjee, A. (2006). Nesting sites and breeding success of Black-necked Crane *Grus nigricollis* in Ladakh, India. *Waterbirds around the World*, 311–314.

Christie, K.S., Gilbert, S.L., Brown, C.L., Hatfield, M. & Hanson, L. (2016). Unmanned aircraft systems in wildlife research: Current and future applications of a transformative technology. *Frontiers in Ecology and the Environment*, *14*(5), 241–251.

https://doi.org/10.1002/fee.1281

Chung, Y., Rabe-Hesketh, S., Dorie, V., Gelman, A. & Liu, J. (2013). A non-degenerate penalized likelihood estimator for variance parameters in multilevel models. *Psychometrika*, *78*(4), 685–709.

CITES. (2020). *Convention on International Trade in Endangered Species of Wild Fauna and Flora*. http://www.cites.org

Collier, K.J., Probert, P.K. & Jeffries, M. (2016). Conservation of aquatic invertebrates: concerns , challenges and conundrums. *Aquatic Ecosystems: Marine and Freshwater Ecosystems*, *26*, 817–837. https://doi.org/10.1002/aqc.2710

Convention on Biological Diversity. (2020). *Kenya: Main Details*. https://www.cbd.int/countries/profile/?country=ke

County Government of Nyandarua. (2018). *Nyandarua County Integrated County Development Plan (CIDP-2): 2018-2022* (2nd ed.). County Government of Nyandarua. https://repository.kippra.or.ke/handle/123456789/663

Cox, A.R., Robertson, R.J., Lendvai, A.Z., Everitt, K. & Bonier, F. (2019). Rainy springs linked to poor nestling growth in a declining avian aerial insectivore (Tachycineta bicolor). *Proceedings of the Royal Society B: Biological Sciences*, *286*(1898). https://doi.org/10.1098/rspb.2019.0018

Dallas, H.F. & Day, J.A. (2004). The Effect of Water Quality Variables on Aquatic Ecosystems : A review. In *Water Research Commission*. University of Cape Town, South Africa.

Dalley, K.L., Taylor, P.D. & Shutler, D. (2008). Nest-site characteristics and breeding success of three species of boreal songbirds in western Newfoundland, Canada. *Canadian Journal of Zoology*, *86*(10), 1203–1211.

Daoud, J. I. (2018). Multicollinearity and Regression Analysis. *Journal of Physics: Conference Series*, *949*(1). https://doi.org/10.1088/1742-6596/949/1/012009

Daut, E.F. (1994). *Trapping Crowned Cranes (*Balearica regulorum*) using Alpha-Chloralose at Saiwa Swamp National Park, Kenya*. Field Report. College of Veterinary Medicine, Cornell University, USA.

de Loock, D. Van. (2019). *Life-history strategies of a facultative cooperative breeder in a fragmented Afrotropical cloud forest*. Ghent & Antwerp.

del Hoyo, J., Elliott, A., & Sargatal, J. (Eds.). (1996). *Handbook of the Birds of the World: Hoatzin to Auks.* (Volume 3). Lynx Edicions.

Donazar, J., Hiraldo, F. & Bustamante, J. (1993). Factors influencing nest site selection, breeding density and breeding success in the Bearded Vulture (*Gypaetus barbatus*). *Journal of Applied Ecology*, *30*(3), 504–514.

Drayer, A. & Richter, S.C. (2016). Physical wetland characteristics influence amphibian community composition differently in constructed wetlands and natural wetlands. *Ecological Engineering*, *93*, 166–174. https://doi.org/https://doi.org/10.1016/j.ecoleng.2016.05.028.

Drewien, R.C., Brown, W.M. & Clegg, K.R. (2010). Longevity records of rocky moountain Greater Sandhill Cranes banded during 1969-1987 in Idaho, Montana, Utah, and Wyoming. *North AMerican Crane Workshop Proceedings*.

Dunn, P.O. & Winkler, D.W. (2010). Effects of climate change on timing of breeding and reproductive success in birds. In A.P. Møller, W. Fiedler, & P. Berthold (Eds.), *Effects of Climate Change of Birds* (1st ed., pp. 113–128). Oxford University Press. https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1474-919X.1996.tb04771.x

Dunn, P.O., Winkler, D.W., Whittingham, L.A., Hannon, S.J. & Robertson, R.J. (2011). A test of the mismatch hypothesis: How is timing of reproduction related to food abundance in an aerial insectivore? *Ecology*, *92*(2), 450–461. https://doi.org/10.1890/10-0478.1

Fakarayi, T., Mashapa, C., Gandiwa, E. & Kativu, S. (2016). Varying land-use has an influence on Wattled and Grey Crowned Cranes' abundance and distribution in Driefontein grasslands Important Bird Area, Zimbabwe. *PLoS ONE*, *11*(11), 1–14. https://doi.org/10.1371/journal.pone.0166209

Fondriest Environmental Inc. (2014). *Fundamentals of Environmental Measurements*. https://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/

Gaston, K.J. (2010). Biodiversity. In N. S. Sodhi & P. R. Ehrlich (Eds.), *Conservation Biology for All* (pp. 27–44). Oxford University Press.

Ge, C., Li, Z., Li, J., & Huang, C. (2011). The effects on birds of human encroachment on the Qinghai–Tibet Plateau. *Transportation Research Part D: Transport and Environment*, *16*, 604–606.

Gemeda, D.O., Minstro, A.A., Feyessa, D.H., Sima, A.D. & Gutema, T.M. (2016). Community knowledge, attitude and practice towards Black Crowned Crane (*Balearica pavonina* L.) conservation in Chora Boter district of Jimma Zone, Ethiopia. *Journal of Ecology and The Natural Environment*, *8*(4), 40–48. https://doi.org/10.5897/JENE2015.0549

Gichuki, C.M. (1996). Biodiversity and catchment area on its way out. In R. D. Beilfuss, W. R. Tarboton, & N.N. Gichuki (Eds.), *Proceedings of 1993 African Crane and Wetland*

Training Workshop, 8-5 August 1993, Wildlife Training Institute, Maun, Botswana (pp. 195–197). International Crane Foundation.

Gichuki, C.M. (2002). *The reproductive and foraging behaviour of the African Snipe (*Gallinago nigripennis*) (Bonaparte 1839) in central Kenya*. Kenyatta University.

Gichuki, N. (2000). Influence of breeding on foraging behaviour and diet of Crowned Cranes. *Ostrich*, *71*(1–2), 74–79. https://doi.org/10.1080/00306525.2000.9639873

Gichuki, N.N. (1993). *Factors affecting the reproductive success of the Grey Crowned Crane*. PhD Thesis. University of Cambridge.

Gichuki, N.N. (1996). Factors affecting reproductive success in crowned cranes. In R. Beilfuss, W. Tarboton, & N.N. Gichuki (Eds.), *Proceedings 1993 African Crane and Wetland Training Workshop,* (pp. 175–181). International Crane Foundation.

Gichuki, N.N. & Gakuo, L. (1998). *The checklist of birds of Lake Ol' Bolossat and its environs*. Unpublished Report.

Gichuki, N.N., & Gichuki, C.M. (1989). *Recent Research and Conservation activities of Cranes in East Africa*. National Museums of Kenya.

Gichuki, N.N. & Gichuki, C.M. (1991). Relationship between habitat selection and flock characteristics in foraging Grey Crowned Cranes *Balearica regulorum* in Kenya. In J. Harris (Ed.), *Proceedings of the 1987 International Crane Workshop, 1-10 May 1987, Qiqihar, Heilongjiang Province, People's Republic of China.* (pp. 357–361). International Crane Foundation.

Girma, Z., Mamo, Y., Mengesha, G., Verma, A. & Asfaw, T. (2017). Seasonal abundance and habitat use of bird species in and around Wondo Genet Forest, south-central Ethiopia. *Ecology and Evolution*, *7*(10), 3397–3405. https://doi.org/10.1002/ece3.2926

Gitahi, P. (1996). Cranes counting in Kenya. In R. . Beilfuss, W. Tarboton, & N.N. Gichuki (Eds.), *Proceedings of 1993 African Crane and Wetland Training Workshop* (p. 191). International Crane Foundation. Baraboo, USA.

Glime, J.M. (2017). Aquatic Insects: Biology. In J. M. Glime (Ed.), *Bryophyte Ecology* (Vol. 2, pp. 1–40). chigan Technological University, International Association of Bryologists. http://digitalcommons.mtu.edu/bryophyte-ecology2/

Gosai, K.R., Shrestha, T.K., Hill, S.D., Shrestha, S. M., Gyawali, B., Gautum, D.N. & Achyut, A. (2016). Population structure, behavior, and current threats to the sarus crane (Grus antigone antigone) in Nepal. *Journal of Asia-Pacific Biodiversity*, 6–10. https://doi.org/10.1016/j.japb.2016.06.008

Goss-Custard, J.D., Triplet, P., Sueur, F. & West, A.D. (2006). Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation*, *127*(1), 88–97.

Gould, J.L. (2008). Cognition and Behavioural Ecology. In S.E. Jørgensen & B.D. Fath (Eds.), *Encyclopedia of Ecology* (pp. 668–672). Elsevier B.V.

Government of Kenya. (2020). *Lake Ol' Bolossat Integrated Management Plan, 2020-2030* (p. 116). NEMA.

Gregory, R.D., Gibbons, D.W. & Donald, P.F. (2004). Bird Census and Survey Techniques. In W. J. Sutherland, I. Newton, & R. Green (Eds.), *Bird Ecology and Conservation: A Handbook of Techniques* (pp. 17–55). Oxford University Press.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. (2001). PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica*, *4*(1), 9.

Hanya, G. & Chapman, C.A. (2013). *Linking feeding ecology and population abundance : a review of food resource limitation on primates*. *Ecological Research, 28,* 183–190. https://doi.org/10.1007/s11284-012-1012-y

Harris, J. & Mirande, C. (2013). A global overview of cranes: Status, threats and conservation priorities. *Chinese Birds*, *4*(3), 189–209.

Harrison, R.B., Jones, W.M., Clark, D., Heise, B.A. & Fraser, L.H. (2017). Livestock grazing in intermountain depressional wetlands: effects on breeding waterfowl. *Wetlands Ecology and Management*, *25*, 471–484. https://doi.org/10.1007/s11273-017-9529-z

Hobbs, R.J. (2003). Ecological management and restoration: Assessment, setting goals and measuring success. *Ecological Management and Restoration*, *4*(Supplementary), 2–3.

Hoffman, H. & Bouwman, R. (2009). The effects of fire on grassland bird communities of Barberspan, North West Province, South Africa. *Ostrich*, *78*(3), 591–608. https://doi.org/10.2989/OSTRICH.2007.78.3.6.317

Hoyt, D. (1979). Practical Methods of Estimating Volume and Fresh Weight of Bird Eggs. *The Auk*, *96*(1), 73–77. https://doi.org/10.1093/auk/96.1.73

Huchard, E. & Cowlishaw, G. (2011). Female-female aggression around mating: an extra cost of sociality in a multimale primate society. *Behavioral Ecology*, *22*, 1003–1011. https://doi.org/10.1093/beheco/arr083

Infonet Biovision. (2020). *AEZs: Kenya System*. https://infonet-biovision.org/EnvironmentalHealth/AEZs-Kenya-System

IUCN. (2011). The diversity of life in African freshwaters: underwater, under threat. In W. R. T. Darwall, K.G. Smith, D.J. Allen, R. . Holland, I.J. Harrison, & E.G. Brooks (Eds.), *The diversity of life in African freshwaters: Underwater, under threat. An analysis of the status* *and distribution of freshwater species throughout mainland Africa*. Cambridge Publishers. https://portals.iucn.org/library/efiles/documents/rl-6-001.pdf

IUCN. (2020). *Threats Classification Scheme (Version 3.2)*. https://www.iucnredlist.org/resources/threat-classification-scheme

Ivey, G.L. & Dugger, B.D. (2008). Factors influencing nest success of Greater Sandhill Cranes at Malheur National Wildlife Refuge, Oregon. *Waterbirds*, *31*(1), 52–61.

Jarrett, N., Mason, V. & Levassor, V. (2003). Using egg density and egg mass techniques for incubation stage assessment to predict hatch dates of G reater Flamingo Phoenicopterus ruber roseus eggs. *Wildfowl*, *54*, 131–142.

Jedlikowski, J., Brambilla, M. & Suska-Malawska, M. (2014). Finescale selection of nesting habitat in Little Crake Porzana parva and Water Rail Rallus aquaticus in small ponds. *Bird Study*, *61*(2), 171–181.

Johnsgard, P.A. (1983). *Cranes of the World*. Indiana University Press.

Joint Working Group on Refinement. (2001). Breeding or rearing birds from hatch. *Laboratory Animals*, *35*(Suppl. 1), 24–27. https://doi.org/10.1258/0023677011911985

Jones, J.A., Harris, M.R. & Siefferman, L. (2014). Physical habitat quality and interspecific competition interact to influence territory settlement and reproductive success in a cavity nesting bird. *Frontiers in Ecology and Evolution*, *2*(OCT), 1–8. https://doi.org/10.3389/fevo.2014.00071

Karanja, M.W. & Gichuki, N. (1988). *Summary of the diet of Grey Crowned Cranes in different habitats in Lake Ol' Bolossat. Unpublished Report.*

Kenya Forest Service. (2010). *Aberdare Forest Reserve Management Plan: 2010 - 2019* (p. 94). Kenya Forest Service. Nairobi, Kenya.

Kenya Law Reforms Commission. (2010). *The Constitution of Kenya 2010*. National Council for Law Reporting. http://kenyalaw.org/kl/index.php?id=398

Kenya National Burea of Statistics. (2019). *2019 Kenya Population and Housing Census: Distribution of Population by Administrative Units*. http://www.knbs.or.ke

Kiama, C.W., Njire, M.M., Kambura, A.K., Mugweru, J.N., Matiru, V.N. & Wafula, E.N. (2021). Isolation and Characterization of Bacteria from Lakes Olbolosat and Oloiden, Kenya. *African Journal of Microbiology Research*, *15*(1), 1–19. https://doi.org/10.5897/AJMR2020.9451

Kigen, G., Some, F., Kibosia, J., Rono, H., Kiprop, E., Wanjohi, B., Kigen, P. & Kipkore, W. (2014). Ethnomedicinal Plants Traditionally Used by the Keiyo Community in Elgeyo Marakwet County, Kenya. *Journal of Biodiversity, Bioprospecting and Development*, *1*(3), 1–11.

Kimani, D., Njoroge, P., Muriithi, J., Mungai, P., Bett, A., Mathenge, J., Muteti, D., Andai, E., Andieng'e, A. & Imboma, T. (2015). *Waterbird Monitoring Programme in Kenya: January 2015 Census Report*. National Museums of Kenya. Nairobi, Kenya.

King, D. (2022). *What are the Trophic Levels in our Ecosystem?* Sciencing.Com. https://sciencing.com/trophic-levels-ecosystem-8205653.html

Kirika, P. & Mbale, M. (2019). *Rapid Biodiversity Assessment of Lake Ol' Bolossat: Plants* (T. Terer, D.O. Onyango, P. Kirika, M. Mbale, R. Yego, P.K. Malonza, V. Muchai, J. Kochey, J. Gathua, G. Koskei, M.N. Muchane, K.M. Waithaka, W. Wamiti & P. Njoroge (Eds.)). National Museums of Kenya, BirdLife International.

Kohil, R.K., Garg, V.K. & Dhawan, A. (2018). *Physical, Chemical and Biological Characteristics of Water* (p. 16). Central University of Punjab.

Krapu, G.L. (1979). Nutrition of female dabbling ducks during reproduction. In T.A. Bookhout (Ed.), *Waterfowl and Wetlands: An Integrated Review. Proceedings of a Symposium Held at the 39th Midwest Fish and Wildlife Conference, Madison, Wisconsin, 5 December 1977* (pp. 59–70). The Wildlife Society.

Krhoda, G.O. (1992). The hydrology and functions of wetlands. In S.A. Rafter, S.G. Njuguna, & G.W. Howard (Eds.), *Wetlands of Kenya: Proceedings of the KWWG seminar on wetlands of Kenya, NMK, Nairobi, Kenya, 3-5 July 1991* (pp. 13–22). IUCN.

Lewis, A. & Pomeroy, D. (1989). *A Bird Atlas of Kenya*. A.A. Balkema.

Lister, B.C. & Garcia, A. (2018). Climate-driven declines in arthropod abundance restructure a rainforest food web. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(44), DOI: 10.1073/pnas.1722477115

Lomáscolo, S.B., Monmany, A.C., Malizia, A. & Martin, T.E. (2010). Flexibility in Nest-Site Choice and Nesting Success of Turdus rufiventris (Turdidae) in a Montane Forest in Northwestern Argentina. *The Wilson Journal of Ornithology*, *122*(4), 674–680.

Luo, J., Wang, Y., Yang, F. & Liu, Z. (2012). Effects of human disturbance on the Hooded Crane (*Grus monacha*) at stopover sites in northeastern China. *Chinese Birds*, *3*(3), 206–216.

Ma, Z., Cai, Y., Li, B. & Chen, J. (2010). Managing wetland habitats for waterbirds: An international perspective. *Wetlands*, *30*, 15–27.

Macharia, G.M. (2011). *Land use and its effect on biodiversity in the Lake Ol' Bolossat basin, Nyandarua, Kenya*. Kenyatta University.

Madindou, I., Gichohi, E., Bett, A., N'gweno, F., Chesire, D., Ikime, T. & Gacheru, P. (2019).

Waterbird Count Results in the Rift Valley and Central Kenya for July-August 2019. *Centre for Biodiversity Research Reports: Ornithology* (86). National Museums of Kenya. Nairobi, Kenya.

Martin, D., Tomida, M. & Meacham, B. (2016). Environmental Impact of Fire. *Fire Science Reviews*, *5*(5), 21.

Maxson, S.J., Fieberg, J.R. & Riggs, M.R. (2008). Sandhill Crane nest habitat selection and factors affecting nest success in northwestern Minnesota. In M. J. Folk & N. A. Nesbitt (Eds.), *Proceedings of the Tenth North American Crane Workshop, Feb. 7-10, 2006, Zacatecas City, Zacatecas, Mexico* (pp. 90–97). North American Crane Working Group.

McGavin, G.C. (2007). *Expedition Field Techniques: Insects and other terrestrial arthropods*. Geography Outdoors.

McGlynn, T. (2010). How does social behavior evolve? *Nature Education Knowledge*, *3*(10), 69. https://www.nature.com/scitable/knowledge/library/how-does-social-behavior-evolve-13260245/

McKinnon, L., Picotin, M., Bolduc, E., Juillet, C. & Bêty, J. (2012). Timing of breeding, peak food availability, and effects of mismatch on chick growth in birds nesting in the High Arctic. *Canadian Journal of Zoology*, *90*(8), 961–971. https://doi.org/10.1139/Z2012-064

Meine, C. (2010). Conservation Biology: Past and Present. In N.S. Sodhi & P.R. Ehrlich (Eds.), *Conservation Biology for All* (pp. 7–26). Oxford University Press.

Meine, C.D. & Archibald, G.W. (1996). Introduction. In C. D. Meine & G. W. Archibald (Eds.), pp. 9-16. *The Cranes: Status Survey and Conservation Action Plan*. International Crane Foundation. Baraboo, Wisconsin, USA.

MEMR. (2012). *Kenya Wetlands Atlas*. Progress Press Co. Malta.

Mergeay, J., Declerck, S., Verschuren, D. & Meester, L. De. (2006). Daphnia community analysis in shallow Kenyan lakes and ponds using dormant eggs in surface sediments. *Freshwater Biology*, *51*(3), 399–411.

MEWNR. (2015). *Kenya Biodiversity Atlas*. Ministry of Environment Natural Resources and Regional Development Authorities. Nairobi, Kenya.

Mirande, C.M. & Harris, J.T. (2019). *Crane Conservation Strategy*. International Crane Foundation. Baraboo, Wisconsin, USA.

Morrison, K. (2015). *International Single Species Action Plan for the Conservation of the Grey Crowned-crane.* (AEWA Technical Report No. 59).

Morrison, K., Beall, F., Friedmann, Y., Gichuki, C., Gichuki, N., Jordan, M., Kaita, M., Ndang'ang'a, P. & Muheebwa, J. (2007). *African Crane Trade Project: Trade Mitigation*

Planning Workshop. Workshop Report. Conservation Breeding Specialist Group (SSC / IUCN) / CBSG Southern Africa. International Crane Foundation / Endangered Wildlife Trust Partnership, Johannesburg.

Morrison, K. & Bothma, J. (1998). Wetland nesting sites of Grey Crowned Cranes on the Steenkampsberg Plateau, South Africa. *South African Journal of Wildlife Research*, *28*(4), 110–120.

Mosher, B.-A.C. (1986). Factors influencing reproductive success and nesting strategies in Black Terns. PhD Thesis. Simon Fraser University.

Muchane, M.N., Waithaka, K.M. & Terer, T. (2021). *Macro-fungi Community of Lake Ol Bolossat Basin and Associated Riparian Ecosystems in Central , Kenya*. *6*(1), 6–15. https://doi.org/10.11648/j.ijnrem.20210601.13

Muheebwa-Muhoozi, J. (2001). The status of the Grey Crowned Crane *Balearica regulorum* in Uganda, with special reference to breeding. *Ostrich Supplement*, *15*(122–125).

Muhumuza, M. & Balkwill, K. (2013). Factors Affecting the Success of Conserving Biodiversity in National Parks: A Review of Case Studies from Africa. *International Journal of Biodiversity*, (*2013*), 1–20.

Muigai, G. (2016). *Grey Crowned Crane monitoring report at Ol' Bolossat* (Issue Jan-Sept.).

Muriithi, Z., Ako, E., Kiplagat, J., Maingi, S. & Olang, L. O. (2013). Assessment of land cover changes in Lake Olbolosat region of the central Kenyan highlands using Landsat satellite imagery aided by indigenous knowledge. *Journal of Biodiversity Management & Forestry*, *2*(2), 1-5.

Musila, S., Wambugu, M. & Wamiti, W. (2007). *Waterbird Monitoring Programme in Kenya: July 2006 and January 2007*. Research Reports of the National Museums of Kenya. Nairobi, Kenya.

Mwaura, F. (2006). Some Aspects of Water Quality Characteristics in Small Shallow Tropical Man-Made Reservoirs in Kenya. *African Journal of Science and Technology; Science and Engineering*, *7*(1), 82–96.

Mwaura, F., Mavuti, K.M. & Wamicha, W.N. (2002). Biodiversity characteristics of small high- altitude tropical man-made reservoirs in the. *Lakes & Reservoirs: Research & Management*, *7*(1), 1–12.

Nasirwa, O., Mungai, P., Ng'weno, F., Kirao, L., Chesire, D., Ikime, T. & Barasa, F. (2018). *January 2018 Waterbird Count Results in the Rift Valley, Nairobi, Central, Coast, Amboseli and Yala Swamp*. Research Reports of the National Museums of Kenya (No. 83). Nairobi, Kenya.

Nasirwa, O. & Owino, A.O. (2000). *Monitoring of waterbirds in Kenya: July 1999 and January 2000*. Research Reports of the National Museums of Kenya (No. 37). Nairobi, Kenya.

National Council for Law Reporting. (2018). *Declaration of Protected Area: Lake Ol' Bolossat*. Government Press. http://kenyalaw.org/kl/fileadmin/pdfdownloads/LegalNotices/2018/LN179_2018.pdf

Ndede, R.O. (1988). Report of the Grey Crown Crane (*Balearica regulorum)* conducted on May 14th 1988 (p. 6). Wildlife Clubs of Kenya. Nairobi, Kenya.

Ndithia, H., Njeri, R. & Njeri, N. (2009). *Waterbird Monitoring Programme in Kenya: January 2009 Census Report*. Research Report of the National Museums of Kenya. Nairobi, Kenya.

Ndung'u, G., Wamiti, W. & Schröder, W. (2018). Promising efforts to conserve Grey Crowned Cranes in Kenya. *Swara*, 54–57.

NEMA & UNDP. (2009). *Fourth National Report to the Conference of Parties of the Convention on Biological Diversity*. National Environment Management Authority and United Nations Development Programme. Nairobi, Kenya.

Nowald, G., Fanke, J. & Hansbauer, M.M. (2018). Linking crane life history and feeding ecology with natural habitats and agricultural lands. In J. E. Austin, K. L. Morrison, & J. T. Harris (Eds.), *Cranes and Agriculture: A guide to sharing the landscape* (pp. 18–34). International Crane Foundation. Baraboo, Wisconsin, USA.

Nsengimana, O., Becker, M., Ruhagazi, D. & Ferus, J. (2019). Minimum population size and distribution of Grey Crowned Cranes *Balearica regulorum* in Rwanda : an aerial and ground survey. *Ostrich*, *90*(1), 79–83.

Ojija, F. & Laizer, H. (2015). Macro invertebrates as biondicators of water quality in Nzovwe Stream in Mbeya Tanzania. *International Journal of Scientific & Technology Research, 5*(6), 211–222.

Olupot, W. (2016). Grey Crowned Crane threat assessment around the wetlands of eastern Uganda. *Ostrich*, *87*(3), 263–270.

Oyugi, J.O. & Owino, A.O. (1998). *Monitoring of waterbirds in Kenya: July 1997 and January 1998*. Research Reports of the National Museums of Kenya. Nairobi, Kenya.

Oyugi, J.O. & Owino, A.O. (1999). *Monitoring Waterbirds in Kenya: July 1998 and January 1999* (p. 33). Research Reports of the National Museums of Kenya. Nairobi, Kenya.

Park, K., Robertson, P., Campbell, S., Foster, R., Russell, Z., Newborn, D. & Hudson, P. (2001). The role of invertebrates in the diet, growth and survival of red grouse (*Lagopus lagopus scotica*) chicks. *Journal of Zoology*, *254*(2), 137–145.

https://doi.org/10.1017/S0952836901000644

Parresol, B.R. (2002). Biomass. In A. H. El-Shaarawi & W. W. Piegorsch (Eds.), *Encyclopedia of Environmetrics* (Vol. 1, pp. 196–198). John Wiley & Sons Ltd. http://en.wikipedia.org/wiki/Biomass

Pereira, H.M., Navarro, L.M. & Martins, I.S. (2012). Global Biodiversity Change: The Bad, the Good, and the Unknown. *Annual Review of Environment and Resources*, *37*(1), 25–50. https://doi.org/10.1146/annurev-environ-042911-093511

Pomeroy, D. (1980). Aspects of the ecology of crowned cranes *Balearica regulorum* in Uganda. *Scopus*, *4*, 29–35.

Pomeroy, D.E. (1980). Growth and plumage changes of the Grey Crowned Crane *Balearica regulorum gibbericeps*. *Bulletin BTO*, 100: 219–223.

Pomeroy, D.E. (1987). The ecology and status of crowned cranes in East Africa. In R. D. Beilfuss, W. R. Tarboton, & N.N. Gichuki (Eds.), *Proceedings 1993 African Crane and Wetland Training Workshop,* (pp. 323–330). International Crane Foundation.

Pomeroy, D., Platz, E., Platz, K., Lack, P. & Gottschalk, T.K. (2018). The problems of recording bird numbers in the breeding season as pairs. *Ornithological Science*, *17*(1), 69–78.

R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.r-project.org/

Ramsar Convention Secretariat. (2013). *The Ramsar Convention Manual* (6th ed., Vol. 6). Ramsar Convention Secretariat. https://doi.org/10.1007/978-94-007-0551-7

Rémy, A., Odden, M., Richard, M., Stene, M. T., Le Galliard, J. F., & Andreassen, H. P. (2013). Food distribution influences social organization and population growth in a small rodent. *Behavioral Ecology*, *24*(4), 832–841. https://doi.org/10.1093/beheco/art029

Robb, G. N., McDonald, R. A., Chamberlain, D. E., & Bearhop, S. (2008). Food for thought: Supplementary feeding is a driver of ecological change in avian populations. *Frontiers in Ecology and the Environment*, *6*(9), 476–484.

Robinson, N.M., Leonard, S.W.J., Bennett, A.F. & Clarke, M. F. (2014). Refuges for birds in fire-prone landscapes: The influence of fire severity and fire history on the distribution of forest birds. *Forest Ecology and Management*, *318*, 110–121. https://doi.org/10.1016/j.foreco.2014.01.008

Rodrigues, A. (2008). Islam and Symbolism. *Military Review*, *May-June*, 106–114. https://doi.org/10.1142/9789814740456_0001

Ruxton, G. D. (2006). The unequal variance t-test is an underused alternative to Student's t-test and the Mann-Whitney U test. *Behavioral Ecology*, *17*(4), 688–690. https://doi.org/10.1093/beheco/ark016

Sabatier, R., Durant, D., Ferchichi, S., Haranne, K., Léger, F. & Tichit, M. (2015). Effect of cattle trampling on ground nesting birds on pastures: An experiment with artificial nests. *European Journal of Ecology*, *1*(2), 5–11.

Sandbrook, C. (2015). What is Conservation? *Oryx*, *49*(4), 565–566. https://doi.org/10.1017/S0030605315000952

Santana, H. S., Silva, L. C., Pereira, C. L., Simião-Ferreira, J. & Angelini, R. (2015). The rainy season increases the abundance and richness of the aquatic insect community in a Neotropical reservoir. *Brazilian Journal of Biology = Revista Brasleira de BBologia, 75*(1), 144–151. https://doi.org/10.1590/1519-6984.09213

Smith, P. A. (2003). *Factors affecting nest site selection and reproductive success of tundra nesting shorebirds*. University of British Columbia.

Sorato, E., Gullett, P. R., Griffith, S. C., & Russell, A. F. (2012). Effects of predation risk on foraging behaviour and group size: adaptations in a social cooperative species. *Animal Behaviour*, *84*, 823–834. https://doi.org/10.1016/j.anbehav.2012.07.003

Sretenović, L., Pantelić, V., & Novaković, Ž. (2009). Importance of utilization of omega-3 fatty acids in human and animal nutrition. *Biotechnology in Animal Husbandry*, *25*(5-6–1), 439–449. https://doi.org/10.2298/bah0906439s

Stewart, R. E. (2020). *Technical Aspects of Wetlands Wetlands as Bird Habitat*. http://water.usgs.gov/nwsum/WSP2425/birdhabitat.html

Su, L. & Zou, H. (2012). Status, threats and conservation needs for the continental population of the Red-crowned Crane. *Chinese Birds*, *3*(3), 147–164.

Sundar, K. S. G. (2009). Are rice paddies suboptimal breeding habitat for Sarus Cranes in Uttar Pradesh, India? *The Condor*, *111*(4), 611–623.

Swaisgood, R. R., Nordstrom, L. A., Schuetz, J. G., Boylan, J. T., Fournier, J. J. & Shemai, B. (2018). A management experiment evaluating nest-site selection by beach-nesting birds. *Journal of Wildlife Management*, *82*(1), 192–201.

Symonds, M. R. E. & Moussalli, A. (2011). A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. *Behavioral Ecology and Sociobiology*, *65*(1), 13–21. https://doi.org/10.1007/s00265-010-1037-6

Terer, T., Odeny, D., Kirika, P., Mbale, M., Wamiti, W., Njoroge, P. & Malonza, K. (2019). *Rapid Biodiversity Assessment of Lake Ol' Bolossat: Habitat characterisation, water* *quality, fungi, plants, birds, mammals, invertebrates, fish, amphibians and reptiles*. National Museums of Kenya.

Thenya, T. (2001). Challenges of conservation of dryland shallow waters, Ewaso Narok swamp, Laikipia District, Kenya. *Hydrobiologia*, *458*, 107–119. https://doi.org/https://doi.org/10.1023/A:1013196500456

Thenya, T., Kiteme, B., Ouko, C., Njunguna, E., Karanja, F., Ojwang', D., Wambugu, G. & Kahiu, N. (2011). Assessment of Ecological Status and Socio-economic Dynamics of Upper Ewaso Ng'iro Basin Wetlands. Centre for Training and Integrated Research for ASAL Development (CETRAD). Nanyuki, Kenya.

Tolvanen, J., Seppänen, J., Mönkkönen, M., Thomson, R. L., Ylönen, H. & Forsman, J. T. (2018). Interspecific information on predation risk affects nest site choice in a passerine bird. *BMC Evolutionary Ecology*, *18*(181), 1–8.

Twining, C. W., Jeremy, R. S. & Winkler, D. W. (2018). Aquatic insects rich in omega-3 fatty acids drive breeding success in a widespread bird. *Ecology Letters*, *21*(1812–1820). https://doi.org/doi: 10.1111/ele.13156

United Nations. (1992). *Convention on Biological Diversity* (p. 28). https://doi.org/10.1146/annurev.ento.48.091801.112645

Urban, E. K. (1988). Status of cranes in Africa. In G. C. Backhurst (Ed.), *Proceedings of the Sixth Pan-African Ornithological Congress* (pp. 315–329).

Urban, E. K., Fry, C. H., & Keith, S. (1986). *The Birds of Africa* (Vol. 2). Academic Press. London.

Urfi, A. J. (2003). Breeding ecology of birds: why do some species nest singly while others are colonial? *Resonance*, *July*, 22–32.

Venter, O., Brodeur, N. N., Nemiroff, L., Belland, B., Dolinsek, I. J. & Grant, J. W. A. (2006). Threats to endangered species in Canada. *BioScience*, *56*(11), 903–910.

Victoria, J. P., Baum, K. A., Payton, M. E., Little, S. E., Fuhlendorf, S. D. & Reichard, M. V. (2013). Tick abundance and levels of infestation on cattle in response to patch burning. *Rangeland Ecology and Management*, *66*(5), 545–552.

Wade, D. D. & Lewis, C. E. (1987). Managing Southern Grazing Ecosystems with Fire. *Rangelands*, *9*(3), 115–119.

Wahl, C. F., Diaz, R. & Ortiz-Zayas, J. (2020). Assessing *Salvinia Molesta* impact on environmental conditions in an urban lake: Case study of lago las curias, Puerto Rico. *Aquatic Invasions*, *15*(4), 562–577. https://doi.org/10.3391/ai.2020.15.4.02

Walkinshaw, L. H. (1964). The African Crowned Cranes. *The Wilson Bulletin*, *76*(4), 355–377.

Wambugu, M., Musila, S. & Wamiti, W. (2007). *Waterbird Monitoring in Kenya: July 2007 Census*. National Musuems of Kenya. Nairobi, Kenya.

Wamiti, W., Malaki, P.A. & Mwangi, A. W. (2009). Birds of Conservation Concern Upgrades Lake Ol' Bolossat Status to Kenya's 61st Important Bird Area. In D. M. Harebottle, A. J. F. K. Craig, M. D. Anderson, H. Rakotomanana, & M. Muchai (Eds.), *Proceedings of the 12th Pan-African Ornithological Congress, Cape Town, South Africa, Goudini Spa, 7-12 September 2008*. Animal Demographic Unit, University of Cape Town.

Wamiti, W., Mwangi, J., Fox, D., Bakari, N., Schröder, W., Nowald, G., Walter, B., Ndung'u, G., Bii, E., Wanjala, M., Nekesa, V., Waiguchu, G. & Kimani, D. (2020). Kenya's first countrywide census of Grey Crowned Crane: February-March 2019. *Bulletin African Bird Club*, *27*(2), 210–218.

Wamiti, W. & Njoroge, P. (2019). *Rapid Biodiversity Assessment of Lake Ol' Bolossat: Birds*. National Museums of Kenya and BirdLife International. Nairobi, Kenya.

Wang, Z., Zhongqiu, L., Beauchamp, G. & Jiang, Z. (2011). Flock size and human disturbance affect vigilance of endangered red-crowned cranes (Grus japonensis). *Biological Conservation*, *144*(1), 101–105.

Ward, P. & Zahavi, A. (1973). The importance of certain assemblages of birds as "Information-Centres" for food-finding. *Ibis*, *115*(4), 517–534. https://doi.org/10.1111/j.1474-919X.1973.tb01990.x

Watson, H., Bolton, M. & Monaghan, P. (2014). Out of sight but not out of harm's way: Human disturbance reduces reproductive success of a cavity-nesting seabird. *Biological Conservation*, *174*(100), 127–133.

Western, D., Waithaka, J. & Kamanga, J. (2015). Finding space for wildlife beyond national parks and reducing conflict through community based conservation: the Kenya experience. *Parks*, *21*(1), 51–62.

Wetlands International. (2005). *AEWA Conservation Guidelines on the preparation of National Single Species Action Plans for migratory waterbirds*.

Wetlands International. (2010). Guidance on waterbird monitoring methodology: Field Protocol for waterbird counting. *Wetlands International*, *March*, 1–15.

White, T. C. R. (2008). The role of food, weather and climate in limiting the abundance of animals. *Biological Reviews*, *83*(3), 227–248. https://doi.org/10.1111/j.1469-185X.2008.00041.x

WHO. (2020). Climate change and human health: Ecosystem goods and services for health. https://www.who.int/globalchange/ecosystems/biodiversity/en/.

Wilcove, D. S., Rothstein, D., Dubow, J., Phillips, A. & Losos, E. (1998). Quantifying threats to imperiled species in the United States. *BioScience*, *48*(8), 607–615.

Wu, H., Zha, K., Zhang, M. & Yang, X. (2009). Nest site selection by Black-necked Crane *Grus nigricollis* in the Ruoergai Wetland, China. *Bird Conservation International*, *19*(3), 277–286.

WWF. (2004). *Counting Wildlife Manual*. https://wwfeu.awsassets.panda.org/downloads/counting_wildlife_mozambiqe_english.pdf

Yang, L., Zhou, L. & Song, Y. (2015). The effects of food abundance and disturbance on foraging flock patterns of the wintering Hooded Crane (*Grus monacha*). *Avian Research*, *6*(1), 1–8.

Yugong, G. (2001). *Cranes and people in China: culture, science, and conservation*. Texas Scholar Works. https://repositories.lib.utexas.edu/handle/2152/10474

Zahn, A., Englmaier, I. & Drobny, M. (2010). Food availability for insectivores in grasslands – arthropod abundance in pastures, meadows and fallow land. *Applied Ecology and Environmental Research*, *8*(2), 87–100.

Zelelew, S.A., Nowald, G., Archibald, G., Aticho, A., Morrison, K. & Mekonnen, T. (2020). *Distribution and population estimates of four crane species in Ethiopia : a global crane hotspot facing increasing threats*. *Scopus*, 40(2), 1–17.

APPENDICES

Appendix I: List of waterbirds recorded in Lake Ol' Bolossat and surrounding upland wetlands during the study period (2017-2020).

Taxonomy follows Bird Committee (2009). Breeding status includes only observations of a complete nest (NE), Eggs (EG), Incubation (IN) or dependent chick(s) (DC). IUCN Red List Status (2022): LC = Least Concern; VU = Vulnerable; NT = Near-Threatened; EN = Endangered; Migration Status: PM = Palaearctic migrant; AM = Afrotropical migrant; am/pm = migrants of that category occur alongside resident or non-migratory individuals.

Family & Common Names		Scientific Names	IUCN Red List Status	Migration Status	Breeding record
Anatidae: ducks and geese					
1	White-faced Whistling Duck	*Dendrocygna viduata*	LC		
2	Fulvous Whistling Duck	*Dendrocygna bicolor*	LC	AM	
3	White-backed Duck	*Thalassornis leuconotus*	LC		
4	Spur-winged Goose	*Plectropterus gambensis*	LC		NE, EG, IN
5	Knob-billed Duck	*Sarkidiornis melanotos*	LC	am	
6	Egyptian Goose	*Alopochen aegyptiaca*	LC		NE, IN, DC
7	Cape Teal	*Anas capensis*	LC		
8	African Black Duck	*Anas sparsa*	LC		
9	Yellow-billed Duck	*Anas undulata*	LC	am	
10	Northern Shoveler	*Anas clypeata*	LC	PM	
11	Red-billed Teal	*Anas erythrorhyncha*	LC		
12	Northern Pintail	*Anas acuta*	LC	PM	
13	Garganey	*Anas querquedula*	LC	PM	
14	Eurasian Teal	*Anas crecca*	LC	PM	
15	Hottentot Teal	*Anas hottentota*	LC		
16	Southern Pochard	*Netta erythrophthalma*	LC	am	
Podicipedidae: grebes					
17	Little Grebe	*Tachybaptus ruficollis*	LC		NE, IN, DC
18	Great Crested Grebe	*Podiceps cristatus*	LC		
19	Black-necked Grebe	*Podiceps nigricollis*	LC		
Phoenicopteridae: flamingos					
20	Greater Flamingo	*Phoenicopterus roseus*	LC	am, pm	
21	Lesser Flamingo	*Phoeniconaias minor*	NT	am	
Ciconiidae: storks					
22	Yellow-billed Stork	*Mycteria ibis*	LC	am	
23	African Open-billed Stork	*Anastomus lamelligerus*	LC	am	
24	Black Stork	*Ciconia nigra*	LC	PM	

Family & Common Names		Scientific Names	IUCN Red List Status	Migration Status	Breeding record
25	Abdim's Stork	*Ciconia abdimii*	LC	AM	
26	White Stork	*Ciconia ciconia*	LC	PM	
27	Saddle-billed Stork	*Ephippiorhynchus senegalensis*	LC		
28	Marabou Stork	*Leptoptilos crumeniferus*	LC		
Threskiornithidae: ibises and spoonbills					
29	Sacred Ibis	*Threskiornis aethiopicus*	LC		
30	Hadada Ibis	*Bostrychia hagedash*	LC		NE, IN, DC
31	Glossy Ibis	*Plegadis falcinellus*	LC	am, pm	
32	African Spoonbill	*Platalea alba*	LC		NE, IN
Ardeidae: herons, egrets and bitterns					
33	Little Bittern	*Ixobrychus minutus*	LC	am, pm	
34	Black-crowned Night Heron	*Nycticorax nycticorax*	LC	am, pm	
35	Striated Heron	*Butorides striata*	LC		
36	Squacco Heron	*Ardeola ralloides*	LC	am, pm	
37	Cattle Egret	*Bubulcus ibis*	LC	am	
38	Grey Heron	*Ardea cinerea*	LC	am, pm	
39	Black-headed Heron	*Ardea melanocephala*	LC		NE, IN, DC
40	Goliath Heron	*Ardea goliath*	LC		
41	Purple Heron	*Ardea purpurea*	LC	pm	
42	Great White Egret	*Ardea alba*	LC		
43	Yellow-billed Egret	*Egretta intermedia*	LC		
44	Black Heron	*Egretta ardesiaca*	LC		
45	Little Egret	*Egretta garzetta*	LC		
Scopidae: Hamerkop					
46	Hamerkop	*Scopus umbretta*	LC		NE
Pelecanidae: pelicans					
47	Great White Pelican	*Pelecanus onocrotalus*	LC		
48	Pink-backed Pelican	*Pelecanus rufescens*	LC		
Phalacrocoracidae: cormorants					
49	Reed Cormorant	*Phalacrocorax africanus*	LC		
50	Great Cormorant	*Phalacrocorax carbo*	LC		
Anhingidae: darters					
51	African Darter	*Anhinga rufa*	LC		
Accipitridae: diurnal birds of prey other than falcons					
52	Osprey	*Pandion haliaetus*	LC	PM	
53	African Fish Eagle	*Haliaeetus vocifer*	LC		
54	Western Marsh Harrier	*Circus aeruginosus*	LC	PM	

Family & Common Names		Scientific Names	IUCN Red List Status	Migration Status	Breeding record
55	African Marsh Harrier	*Circus ranivorus*	LC		
56	Pallid Harrier	*Circus macrourus*	NT	PM	
57	Montagu's Harrier	*Circus pygargus*	LC	PM	
Rallidae: rails and relatives					
58	Black Crake	*Amaurornis flavirostra*	LC		DC
59	Purple Swamphen	*Porphyrio porphyrio*	LC		DC
60	Common Moorhen	*Gallinula chloropus*	LC		DC
61	Lesser Moorhen	*Gallinula angulata*	LC	AM	
62	Red-knobbed Coot	*Fulica cristata*	LC	am	NE, IN, DC
Gruidae: cranes					
63	Grey Crowned Crane	*Balearica regulorum*	EN		NE, EG, IN, DC
Recurvirostridae: stilts and avocets					
64	Black-winged Stilt	*Himantopus himantopus*	LC	am	
Charadriidae: plovers					
65	Long-toed Plover	*Vanellus crassirostris*	LC		
66	Blacksmith Plover	*Vanellus armatus*	LC		NE, EG, IN, DC
67	Spur-winged Plover	*Vanellus spinosus*	LC		DC
68	Black-winged Plover	*Vanellus melanopterus*	LC		
69	Crowned Plover	*Vanellus coronatus*	LC		DC
70	Kittlitz's Plover	*Charadrius pecuarius*	LC	am	DC
71	Three-banded Plover	*Charadrius tricollaris*	LC		
Jacanidae: jacanas					
72	Lesser Jacana	*Microparra capensis*	LC		
73	African Jacana	*Actophilornis africanus*	LC		NE, IN, DC
Scolopacidae: sandpipers and relatives					
74	African Snipe	*Gallinago nigripennis*	LC	am	NE
75	Common Snipe	*Gallinago gallinago*	LC	PM	
76	Black-tailed Godwit	*Limosa limosa*	NT	PM	
77	Bar-tailed Godwit	*Limosa lapponica*	NT	PM	
78	Spotted Redshank	*Tringa erythropus*	LC	PM	
79	Marsh Sandpiper	*Tringa stagnatilis*	LC	PM	
80	Common Greenshank	*Tringa nebularia*	LC	PM	
81	Green Sandpiper	*Tringa ochropus*	LC	PM	
82	Wood Sandpiper	*Tringa glareola*	LC	PM	
83	Common Sandpiper	*Actitis hypoleucos*	LC	PM	
84	Little Stint	*Calidris minuta*	LC	PM	
85	Curlew Sandpiper	*Calidris ferruginea*	NT	PM	

Family & Common Names		Scientific Names	IUCN Red List Status	Migration Status	Breeding record
86	Ruff	*Philomachus pugnax*	LC	PM	
Glareolidae: Egyptian Plover, coursers and pratincoles					
87	Collared Pratincole	*Glareola pratincola*	LC	am	
Laridae: gulls, terns and skimmers					
88	Grey-headed Gull	*Chroicocephaus cirrocephalus*	LC		
89	Black-headed Gull	*Chroicocephalus ridibundus*	LC	PM	
90	Little Tern	*Sternula albifrons*	LC	PM	
91	Whiskered Tern	*Chlidonias hybrida*	LC		
Alcedinidae: kingfishers					
92	Malachite Kingfisher	*Alcedo cristata*	LC		
93	Giant Kingfisher	*Megaceryle maxima*	LC		
94	Pied Kingfisher	*Ceryle rudis*	LC		

Appendix II: Questionnaire used in assessment of the severity and impacts of threats affecting the Grey Crowned Crane around Lake Ol' Bolossat.

Seeking expert opinion on ranking of predetermined threats affecting Grey Crowned Crane population in Lake Ol' Bolossat basin

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Name: (Optional) ________________________________

Date: ________________________ Gender: ☐ Male ☐ Female ☐ Transgender

Age category: ☐ <20 yrs ☐ 21-40 yrs ☐ > 41 yrs; Village: ____________________

How long have you lived here (yrs)? ___________ Occupation: _________________

Distance of home to lakeshore: ☐ <250 m ☐ 251-500 m ☐ > 501 m

Threat Ranks: Based on your experience and perceptions, rate the threats as either: 1 (mild, very low, almost non-existence), 2 (Moderate, few instances), 3 (severe, frequent, widely spread)

Threat Category I	**List of threats**	**Rank (Relevance)**		
Threats reducing quality of nest-site, reduced chicks' survival & increased loss of eggs & chicks.	1a. Livestock (trampling)	☐ 1	☐ 2	☐ 3
	1b. Predation	☐ 1	☐ 2	☐ 3
	1c. Poaching (eggs, chicks)	☐ 1	☐ 2	☐ 3
	1d. Climate change	☐ 1	☐ 2	☐ 3
Threat Category II	**List of threats**	**Rank (Relevance)**		
Threats affecting cranes' breeding sites (i.e. wetland habitats).	2a. Fire	☐ 1	☐ 2	☐ 3
	2b. Reeds harvesting	☐ 1	☐ 2	☐ 3
	2c. Livestock overgrazing	☐ 1	☐ 2	☐ 3
	2d. Encroachment	☐ 1	☐ 2	☐ 3
	2e. Quarrying & Erosion	☐ 1	☐ 2	☐ 3
	2f. Fishermen/boat activities	☐ 1	☐ 2	☐ 3
	2g. Climate change (drought)	☐ 1	☐ 2	☐ 3
	2h. Invasive/introduced species	☐ 1	☐ 2	☐ 3
Threat Category III	**List of threats**	**Rank (Relevance)**		
Threats affecting cranes in their habitats including grasslands and wetlands.	3a. Poisoning & Persecution	☐ 1	☐ 2	☐ 3
	3b. Poaching (snaring)	☐ 1	☐ 2	☐ 3
	3c. Electrocution & Collision	☐ 1	☐ 2	☐ 3
	3d. Land use changes	☐ 1	☐ 2	☐ 3
	3e. Other (list__________________)	☐ 1	☐ 2	☐ 3

Appendix III: Demographic characteristics of respondents interviewed on rating of threats affecting Grey Crowned Crane around Lake Ol' Bolossat basin (*n* = 102).

	Characteristic	Frequency	Proportion (%)
Gender	Male	65	64
	Female	37	36
Age (years)	<20	10	9.80
	21-40	52	50.98
	>41	40	39.22
Home distance to shoreline (meters)	<250	31	30.39
	251-500	35	34.31
	>500	36	35.29
Occupation	Farmers	77	75.49
	Fishermen	7	6.86
	Herdsmen	3	2.94
	Teachers	2	1.96
	Students	6	5.88
	Quarrying	2	1.96
	Business	2	1.96
	Field Assistants	2	1.96
	Watchman	1	0.98
Duration of Residency) (Years)	1-10	25	24.51
	11-20	30	29.41
	21-30	26	25.49
	31-40	19	18.63
	41-50	1	0.98
	51-60	1	0.98
Residency Village	Bahati	9	8.82
	Fuleni	2	1.96
	Gatumbiro & Kanguu	12	11.76
	Githungucu & Baari	8	7.84
	Iria-Ini	4	3.92
	Kianjata	11	10.78
	Kirima & Kanjogu	10	9.80
	Makereka	13	12.75
	Mukindu & Mugathika	14	13.73
	Ngurumo	15	14.71
	Non-lake villages	4	3.92

Appendix IV: A 43 km long elevation profile between Bahati and Ndaragwa through Dundori Ridge, Lake Ol' Bolossat basin and Satima escarpment. (Developed and improved from Google Earth**).**