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MASTER'S DISSERTATION

MOVEMENT PATTERNS OF GREY CROWNED CRANES *BALEARICA REGUROLUM* ACROSS RWANDAN BORDERS

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Submitted to the department of Biology in partial fulfilment of the requirements for the degree of Master of Sciences in Biodiversity Conservation and Natural Resources Management

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Kigali, May 2023

DECLARATION

I, Jean Ferus Niyomwungeri declare that this postgraduate thesis "**Movement patterns of Grey Crowned Cranes *Balearica regurolum* across Rwandan borders**" is my own work and has not been submitted to any other University for the same degree or examination. All sources that I have used or quoted have been indicated and acknowledged in the references.

Date: 31/05/2023

Jean Ferus NIYOMWUNGERI

CERTIFICATION

This is to certify that the work contained in the thesis entitled thesis "**Movement patterns of Grey Crowned Cranes *Balearica regurolum* across Rwandan borders**" by Jean Ferus NIYOMWUNGERI in partial fulfillment of the requirements for the award of a master's degree in Biodiversity Conservation and Natural Resource Management at the University of Rwanda, College of Science and Technology has been submitted or published elsewhere for a degree.

Date: 31/05/2023

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Prof. Beth A. Kaplin

Supervisor

ABSTRACT

Grey Crowned Crane (*Balearica regulorum*), a resident of East and southern African regions, is of global conservation concern as it is classified as an endangered species according to IUCN Red List of threatened species with a decreasing population. Cranes undertake seasonal movements, while their cross-boundary movements are less studied. This study assessed the movement patterns of Grey Crowned Cranes across Rwandan borders and the environmental patterns that may influence their movement. At three sites in Rwanda (Nyagatare, Akagera National Park and Akanyaru), ten Grey Crowned Cranes were tagged with GPS-GSM by the Rwanda Wildlife Conservation Association (RWCA) to record individual GPS coordinates and other environmental factors. Home range estimated with the 95% kernel density estimation (KDE) method was 3048km^2 in the short dry season; 3017 km^2 in the long rainy season; 2241 km^2 in the long dry season and 2707 km^2 in the short rainy season. Cropland, wetland and temperature were the main environmental factors influencing the cross-border movement of Grey Crowned Cranes. Wetlands were used in the rainy season for breeding and feeding while cropland was used by Grey Crowned cranes during the dry season. This study provides the first estimates of home range size and cross-border movement parameters for Grey Crowned Cranes from Rwanda to Burundi, Tanzania and Uganda and documents their habitat suitability and seasonal variations. These results are valuable for supporting trans-boundary collaboration in protection and restoration of the habitats for these endangered bird species.

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LIST OF ACRONYMS AND ABBREVIATIONS

RWCA: Rwanda Wildlife Conservation Association

IUCN: International Union Conservation of Nature

AICcWt: Akaike's Information Criterion Weight

GPS-GSM: Global Positioning System- Global System for Mobile communication

KDE: Kennel Density Estimate

WCN: Wildlife Conservation Network

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DEDICATION

This dissertation is dedicated to my beloved wife, supervisors and whoever contributed in my studies in one way or another.

May almighty God bless you all!

CHAPTER 1. INTRODUCTION

1.1. Background information

The Grey Crowned Crane (*Balearica regulorum*), a resident of East and southern-African regions, is of global conservation concern. Populations of this species have experienced a global decline due to their incredible beauty which drives trade in this species for the pet trade (Harris & Mirande, 2013). In the past three generations (45 years), human induced activities have been considered the main contributing factors to the Grey Crowned Crane population decline mainly due to habitat loss, illegal removal of eggs and live birds from the wild as well as local and international market trade (IUCN, 2016). This led to the current global population estimate of 85,000-95,000 Grey Crowned Cranes (Meine & Archibald, 1996).

The Grey Crowned Cranes live from East Africa to South Africa, but are most abundant in Uganda, Kenya, and Tanzania. This bird is a non-migratory species despite their seasonal and local movements (Meine & Archibald, 1996). Grey Crowned Cranes move locally and seasonally in order to find suitable breeding areas for their young and find resources (IUCN, 2016), they are strongly influenced by seasons and their movements, where the duration of the rainy season determines their breeding (Meine & Archibald, 1996).

The mixture of wetlands and grasslands are preferred habitats for grey crowned cranes, as these provide suitable habitat for feeding, nesting, and roosting (Meine & Archibald, 1996). In ecosystems, this species plays an important role where they are considered as wetland quality indicators (Kanyamibwa, 1996). Wetland conversion has been driven by national and international agricultural policies and push commercialization of agriculture. These put pressure on wetlands for agriculture as an alternative way to increase the economies and satisfy human needs (Liu et al., 2013, Kanyamibwa, 1996).

Wildlife animals are mostly found in ecosystems in which they can find shelter, breeding space, dispersal and food (Kideghesho et al. 2006), and this defines and influences their annual movement patterns throughout their life (Armbruster, 1990). The species' movements influence the changes in the cranes' population size which helps to identify conservation issues at stopover sites and the establishment of species conservation strategies (Allworth etal., 2015; Higuchi et al., 1995). Species' movements also depend on connectivity which influences their home range area

(Allworth et al., 2015). Grey crowned crane are mainly found in developing countries where there is generally high human pressure on natural habitats as well as agricultural intensification policies that include wetland conversions, which collectively are critical problems to crane survival (Liu et al., 2013, Mendenhall et al., 2012). This problem has been influenced by poverty, low conservation education and lack of proper and well-defined conservation strategies that involve local communities (Kanyamibwa, 1998).

Human induced activities significantly affect crane populations and their living conditions (Meine & Archibald, 1996). In Uganda, the population of Grey crowned crane has declined 10-30% in the early 1970s due to the wetlands conversion for agriculture purposes (Olupot et al., 2009). Those human disturbances may deeply affect the movement of grey crowned cranes from one place to another looking for favorable environment.

East Africa, which has populations of Grey crowned cranes, has experienced a number of biodiversity losses due to intensive land use and land cover change (Nsabagasani et al., 2008).Different economic activities and poor environmental protection greatly contributed to the loss and degradation of wetlands (Nsabagasani et al., 2008) which put pressure on provision of environment services (Nsharwasi, 2012) and associated with the capture of cranes for trade and pet (Beilfuss et al., 2009). The communities living close to crane habitats have contributed to the decline of crane population by catching the eggs, chicks or adults from their range for the purpose of eating them (Nsengimana et al., 2017).

The Grey crowned crane is the only crane species found in Rwanda, which is in East Africa. In 2017, Nsengimana et al. found that the population of this bird species is highly affected and the main aspects threatening this bird includes poverty, livelihood disadvantages, and lack of conservation awareness among communities living near crane habitat. According to the 2019 crane census in Rwanda, regions in close proximity to Uganda, Burundi and Tanzania showed the greatest variation in crane abundance (Nsengimana & Becker, 2019). However, the government of Rwanda in collaboration with conservation NGOs put a lot of efforts in protecting the Grey Crowned cranes, e.g. the work done by Rwanda wildlife Conservation Association and the law N° 064/2021 of 14/10/2021 governing biological diversity (Official Gazette nº Special of 11/11/2021) just to mention a few (Rwanda Official Gazette nº Special of 11/11/2021, 2021).

This study provides information to help to understand the reasons leading to crane population fluctuations at the key cranes areas which are along Rwandan borders. The specific objectives of the study were to: identify the cross border home range of grey crowned crane; determine the influence of changes in seasons on the movement of the Grey crowned cranes across Rwandan borders; determine if there is a correlation between habitat use and the movements of Grey crowned cranes across the borders and to determine the environmental factors (variables) influencing the movements of Grey crowned crane across Rwandan borders.

1.2. Problem statement

Grey crowned crane is one of the most wetland and grassland-dependent species that ranges from East Africa to Southern Africa regions where human population growth continues to increase (Wamiti, 2022). It is classified as endangered species according to the IUCN Red List of threatened species with a decreasing population (IUCN,2016). Moreover, the international and national agriculture policies have enforced to increase economy and agriculture productivity which in turn put pressure on wetlands and these resulted in the loss and degradation of grey crowned crane's habitats.

In Rwanda, most of crane observations are in cropland and most crane populations have been identified along the border with neighboring countries (Nsengimana et al., 2017). The survey data on crane counts conducted during the national crane census in 2017 (Nsengimana et al., 2017) with the national crane census done in 2018 and 2019 (Nsengimana & Becker, 2019) revealed that regions that are close to Rwandan borders like Nyagatare (Matimba and Musheli) bordering Uganda; Akanyaru wetland bordering Burundi and Akagera National Park bordering Tanzania are experiencing the most fluctuations in crane populations (Nsengimana & Becker, 2019). However, there has been less work done to understand the reason why the crane populations fluctuate, especially near the neighboring countries of Uganda, Tanzania and Burundi. It is for this reason that, the focus of this work is on the movement patterns of Grey Crowned Crane across Rwandan borders.

1.3. Research objectives

1.3.1. General objective

The main objective of this study is to identify the Grey Crowned Cranes movement patterns across Rwandan borders.

1.3.2. Specific objectives

1. To identify the cross border home range of Grey Crowned Cranes.
2. To determine the influence of changes in seasons on the movement of the Grey crowned cranes across Rwandan borders.
3. To determine the correlation between habitat use and the movements of Grey crowned cranes across the borders.
4. To determine the environmental factors (variables) that influence the movements of Grey Crowned Cranes across Rwandan borders.

1.3.3. Research questions

1. What is the cross-border home range of Grey crowned cranes?
2. Do changes in seasons influence the movement of the Grey crowned cranes across Rwandan borders?
3. Is there a correlation between habitat use and the movements of Grey Crowned Cranes across the borders?
4. What environmental factors influence Grey Crowned Cranes movement patterns across Rwandan borders

1.4. Significance of the study

The knowledge of the movement patterns of Grey Crowned Cranes across Rwandan borders will be used in trans-boundary decision-making to protect Grey Crowned Cranes and their habitats. Particularly, this study is useful to different stakeholders including planners, administrators and non-governmental organizations and other private institutions responsible for the wildlife conservation and environmental management. Additionally this study will serve as a further reference point by academic institutions and other interested individuals and governmental and non-governmental organizations for further relevant research or implementation of different interventions that are important in the field of conservation.

CHAPTER 2. LITERATURE REVIEW

2.1. Factors influencing Grey Crowned Crane movements

The movement of organisms is defined as the change in spatial location of the individual or population in time (Nathan et al., 2009). In ecosystems, animal movements are an important component to maintain the resilience of ecosystem processes like trophic and species interactions (Lundberg & Moberg, 2003). Movement provides links between ecosystems which can be grouped as resource, genetic and process links (Lundberg & Moberg, 2003).

It is very important to understand the movement patterns of wild animals and the causes which may include environmental factors, availability of food, seasons of year, mating and suitable microhabitat or predators avoidance which improves the species' survival and reproductive conditions (Allen & Singh, 2016) and those animal movements support essential ecosystem functions in both habitats and contribute to ecosystem resilience (Holling, 1973). Moreover, to understand animal movement is crucial which is a component of animals' behavioral ecology, as well as life history which are important to know in order to effectively protect the species (Rubenstein & Hobson, 2004).

To identify the movement patterns of wild animals requires to mark and seasonally or annually track the individual or population (Rubenstein & Hobson, 2004). This information can help to enhance conservation management actions based on the present policies (Allen & Singh, 2016). There is a strong connection between animal movements and habitat use Some bird species migrate from long distance while others disperse short distance (Taylor 2010, Harris & Reed, 2002) but there are still gaps in knowledge on how, when and reasons for wild animal movements from one place to another (Allen & Singh, 2016). Grey crowned cranes are non-migratory bird species that have some seasonal movements influenced by food availability, suitability of habitat or breeding (Attenberger, 2021). It has been clearly shown that the precipitation has a great influence on the occurrence of Grey crowned cranes (Attenberger, 2021).

The movement of Grey Crowned Cranes can be defined by the number of cranes that move from one place to another with different influences. And the most important factors which may be involved in this movement may be environmental such as food availability, seasonal alteration and quality of breeding habitat (Rolando, 2002).

2. 2. Distribution and habitat suitability for Grey Crowned Cranes

The Grey Crowned Crane is one of six crane species occurring in Africa where it is considered as flagship species of wetland and grass land habitats (Beilfuss et al., 2007). This species habitats range from Eastern Uganda and Kenya to South Africa and mostly abundant in Uganda, Kenya and Tanzania. Cranes live in both wetland and grass land habitats and their distribution influenced by environmental factors such as food availability, the quality of breeding habitats, weather conditions and predators (Nachuha et al., 2015).

Seasons significantly affect crane distribution where in rainy season, cranes are mostly found in wetlands while in dry season cropland is a favorable habitat for cranes (Attenberger, 2021). Grey Crowned Crane typically breed in rainy season which means the cranes occur in smaller feeding groups and the paired breeding groups isolate in nesting areas (Amulike et al., 2020). However, in dry season cranes flock up and are more likely to be find in cropland foraging as it is in the period of harvesting (Attenberger, 2021).

Due to rapid population growth, Rwanda is suffering from land scarcity with more than 700 people per km^2 of population density in rural areas , Manzi et al., 2014) Countries like Rwanda with high human population density often experience problems of food insecurity which makes very difficult to maintain sustainable use of natural resources. The majority of people are poor farmers and due to small agriculture farmers provide insufficient food and the increase in soil erosion lead to loss of fertile top soil which consequently reduce the productivity (Nsharwasi, 2012). To increase the production, the Rwandan government has considered the wetlands as potential areas to improvement agricultural production and increasing rural economy and reducing poverty (Bidogeza et al., 2009). In the process of sustaining their livelihoods, humans put pressure on natural resources, resulting in degradation and loss of those natural resources (Bidogeza et al., 2009). Even though cranes require typically mixed wetland and grassland habitats, their general feeding strategy allowed them to adapt to human modified landscapes such as agricultural croplands (Meine & Archibald, 1996). Hence, nowadays most crane populations can be found in human modified environments, as the preferred wetland habitats are transformed to agricultural cropland (Meine & Archibald, 1996). Nsengimana et al. (2019) already showed that nearly half of the cranes were observed on agricultural land with the main crops being rice, maize, soya, wheat and beans. In short Grey Crowned Cranes can undertake some seasonal movement due to different environmental factors to assess different habitats for food and suitable breeding sites.

CHAPTER 3. METHODS

3.1. Study area

This study was conducted in three regions of Rwanda: north-eastern, eastern and southern that are all located near the borders of Rwanda and due to the large number of cranes in these areas, they are considered to be key crane areas (Figure1). The study areas have been selected based on the cranes occurrence data obtained from surveys done between 2018 and 2020 by Rwanda Wildlife Conservation Association's (RWCA) conservation champions (Figure 1). Conservation champions serve as a group of community members engaged by RWCA in the key crane areas so that the presence or absence of cranes and land used can be recorded using a free app called cyber tracker (Attenberger, 2021).

The first region of this study area is located in the north-eastern region of Rwanda (Nyagatare) and it will focus on the flock of crane population which is located in Matimba and Musheli sectors close to Uganda along the Umuvumba River. This area is dominated by cropland agriculture which includes maize, beans, tomatoes and soybean.

Another part of this area of study was in Akagera National Park (1.64469^{o}S, 30.70864^{o} E), which is a protected area located in eastern Rwanda along the Tanzanian border. The majority of its habitats consist of savannah habitats and wetlands (Bantlin & Drew, 2021). Akanyaru wetland is the third study area and an unprotected wetland located at 02^{o}'30' S 29^{o}55'E in southern Rwanda. It forms part of the international border of Rwanda and Burundi. A variety of marshy and papyrus habitats dominate the vegetation of Akanyaru wetland and 54 bird species have been recorded.

Rwanda rainfall is characterized by four main climatic seasons which include two rainy seasons (March-May (long rain) and September-December (short rain), and two dry seasons (June-August and January-February) (Ntwali et al., 2016; Jonah et al., 2021). Rwanda is located at a high altitude which allows to experience a tropical temperate climate where temperatures range between 16°C and 20°C year-round without significant variation, the rainfall is abundant but there are some irregularities depending on the region (Mikova et al., 2015). In Rwanda, topography varies from the mountainous west to the semi-arid eastern lowlands, which results in a wide range of climatic and ecological conditions (Ntwali et al., 2016; Jonah et al., 2021). In the high altitude region, average temperatures ranges between 15°C and 17°C and the rainfall is abundant. Some parts of the volcanic region have temperatures as low as 0°C while average temperatures in intermediate altitudes range between 19°C and 21°C and rainfall averages around 1000 mm/year (Mikova et al., 2015).

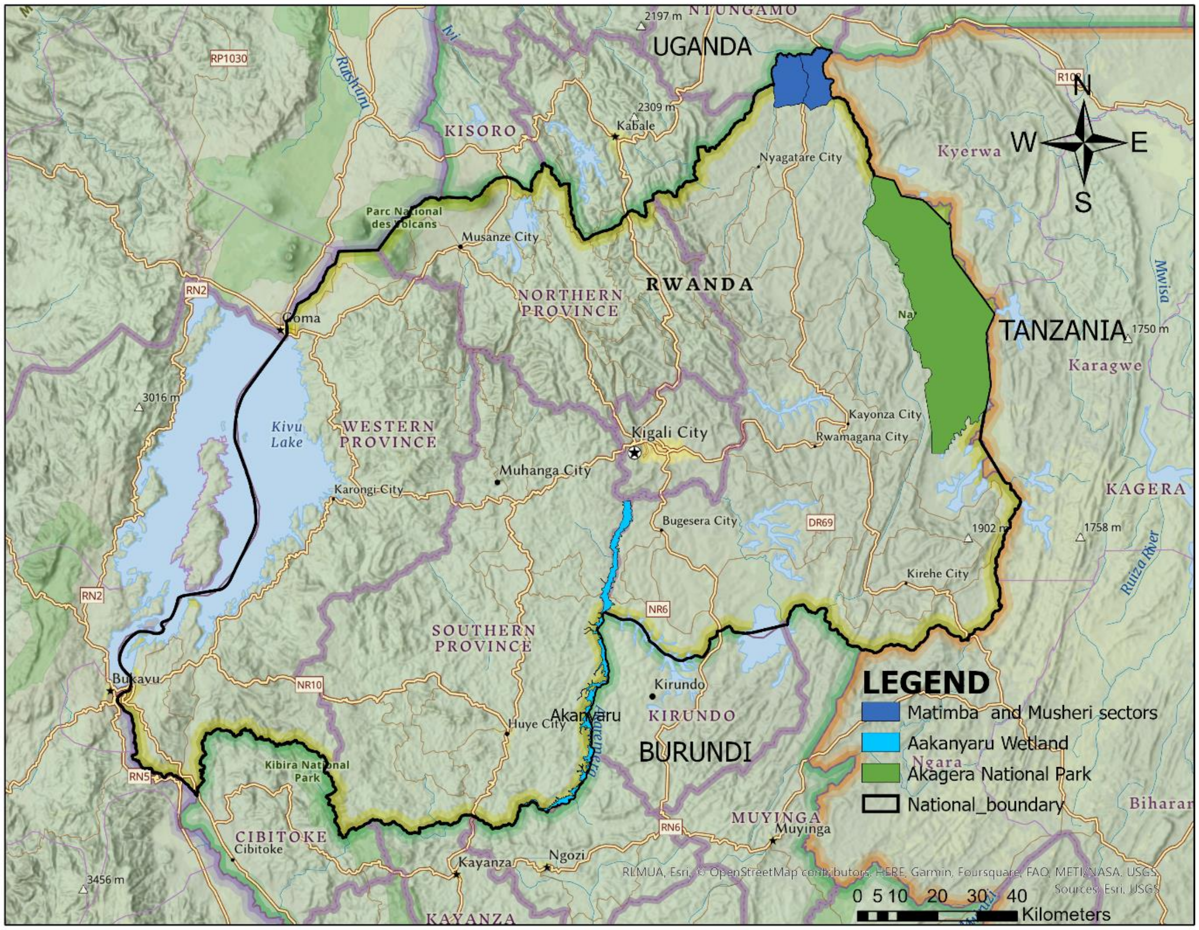

Figure 1.The study areas in Rwanda

3.2. Research design and Data collection

According to data collected in the 2019 national crane census, regions located close to Rwanda's borders, such as Nyagatare, which borders Uganda, and Akanyaru, which borders Burundi, and Akagera National park which is bordering Tanzania have seen the largest fluctuations in crane populations (Nsengimana & Becker, 2019). To understand the reason for this fluctuation, RWCA has fitted ten cranes with GPS-GSM loggers to track the movement patterns of those cranes across Rwanda’s borders (Table 1).

Table 1. Grey crowned cranes fitted with GPS-GSM since June 2019 to May 2021

No.	Crane ID (leg band number)	Transmitter ID	Tagging date	Location
1	247	48536475213 CRAG 01	4-17-19	Akagera National Park
2	211	48536904221 CRAG 05	4-17-19	Akagera National Park
3	261	48536464787 CRAG 07	4-17-19	Akagera National Park
4	248	48535704486 CRAG 09	5-09-19	Akagera National Park
5	006 yellow band	48576256437 CRAG 12	6-23-2020	Nyagatare
6	008 yellow band	48575140289 CRAG 13	6-23-2020	Nyagatare
7	004 yellow band	48575254578 CRAG 15	6-23-2020	Nyagatare
8	No leg band	48575178409 CRAG 16	6-04-2020	Akanyaru
9	009 yellow band	48575263799 CRAG 17	6-23-2020	Nyagatare
10	No leg band	48576271080 CRAG 10	6-5-2021	Akanyaru

3.2.1. The process of capturing and fitting GPS-GSM on Grey Crowned Cranes

Toe-snare technique has been used to catch and fit GPS tags on upper right leg of the individual cranes. This is non-selective technique appropriate for adult cranes especially those which are capable for flying and difficult to run after and capture as it should be done for the young cranes that cannot fly in distance. In order to avoid detection by cranes, the toe-snares are green in colored and made in monofilament and are tightly attached to hard sticks, and are placed in the areas that cranes like to feed, rest, or drink water so that the cranes are able to get in (RWCA, Unpublished data).

At crane feeding sites, six toe-snares have been installed, and some sites have been pre-baited with maize and mazuri crane diet to attract the cranes. While waiting to trap cranes, sampling station was arranged nearby the snares. Once the cranes become trapped, ensnared cranes are quickly removed by using a run-and-catch technique. The handlers technically hold the cranes and use a hood to cover the eyes to avoid visual stimuli but also minimize stress which by then followed by physical health checkup to make sure that the cranes which are going to be out fitted with GPS tag is free from any physical problems. When the crane's physical health has been checked, the GPS tag is attached to its right leg, and is then turned on. Afterward, the crane is released in the flock after gently removing its hood (RWCA, Unpublished data)

This study used data recorded using GPS-GSM loggers tagged on ten cranes from the key crane areas located nearby Rwandan borders. Ecotone GPS-GSM loggers are developed by Ecotone to assist researchers in learning about the behavior and biology of wild animals. They are designed to be proportionate to the animal's body weight. The data recorded by GPS tags includes GPS positions (latitude and longitude), temperature, land cover (type of habitat) and the exact time of the place where the crane individuals located (minutes, hour, date and year) (RWCA, Unpublished data).

GPS-GSM are synchronized to record individual GPS positions (latitude and longitude), temperature, and land cover (types of habitat) which includes wetland, crop land, water bodies, broadleaf, tree open, herbaceous and shrub and the exact time of the place where the crane individuals were located (minutes, hour, date and year). These data were used to answer the study questions where latitude and longitude data were used and analyzed to answer question (1) by estimating and modelling the cross border home range of tagged Grey Crowned Cranes.

3.2.2. Rainfall data

Rwanda is divided into different topographical regions which lead to variation of rainy fall distributions and intensities change across the country. Meteo Rwanda, the governmental meteorological agency has placed rain gauge stations around the country to record rain fall data (Ntwali et al., 2016). In this study, precipitation and minimum and maximum temperature data were collected by consulting archive of weather parameters from Meteo Rwanda for the period of

2019, 2020, and 2021. These data were used and analyzed to answer question (2) by determining the seasonal influence on the movement of grey crowned cranes.

Land cover type is linked to precipitation and temperature which includes the temperature collected by GPS GSM loggers and minimum and maximum temperature data from Meteo Rwanda, and I expected a strong interrelation between the distribution of cranes and these three environmental factors which were recorded by the GPS GSM loggers fitted on the cranes (temperature and land cover type) and precipitation data and minimum and maximum temperature data collected from Meteo-Rwanda. The data collected by the GPS loggers are retrieved from RWCA's server to determine the correlation between habitat use and the movement of cranes (question 3). In addition, the data from Meteo-Rwanda and the data from RWCA were used to answer question (4) by investigating the influence of "land cover" and "precipitation and temperature" on the cranes' movements as environmental factors.

3.3. Data analysis

Data were retrieved and processed with ArcGIS Pro to produce the maps used to understand the cross-border movement of Grey Crowned Cranes (Smith, 2022) and 50%, 90% and 95% Kernel density estimates to model the cross-border home range of Grey Crowned Cranes. Moreover, to answer questions 2, 3 and 4, R core team (2019) was used. The combination of standard linear regression and Generalized Linear Models (GLMs) were used to provide the results for research questions (Hara & Kotze, 2010).

3.3.1. Home range analysis

Home range size were estimated based on 38,866 GPS data points taken by Ecotone GPS-GSM during data collection using fixed Kernel Density Estimate (KDE) (Kim & Scott, 2012). The smoothing parameter of 6 km has been used to estimate overall year 95% KDE home range of Grey Crowned Crane in each season (LRS: Long Rainy Season/March, April, May; LDS: Long Dry Season/ June, July, August; SDS: Short Dry Season/ December, January, February; SRS: Short Rainy Season/ September, October, November) . After that, the 90% KDE, 95% KDE and 50% KDE were applied to calculate the seasonal variation in home range of Grey Crowned Crane every year (2019, 2020 and 2021). All analyses were conducted through the Adehabitat packages (Calenge, 2006) in R software (R Development CoreTeam, 2015).

3.3.2. Factors influencing movement of Grey Crowned Cranes

Data were pair plotted in Generalized Linear Mixed Models (GLMM) to test the multi-collinearity between independent variables (Kanagaraj, Wiegand, Mohamed, & Kramer-Schadt, 2013). The variables did not present multi-collinearity as neither of the presented values approached 0.7 of correlation coefficient (r) (Figure 2). I used the variance inflation factor (VIF) test but no variable present had a value greater than 1 which indicates no correlation among our variables.

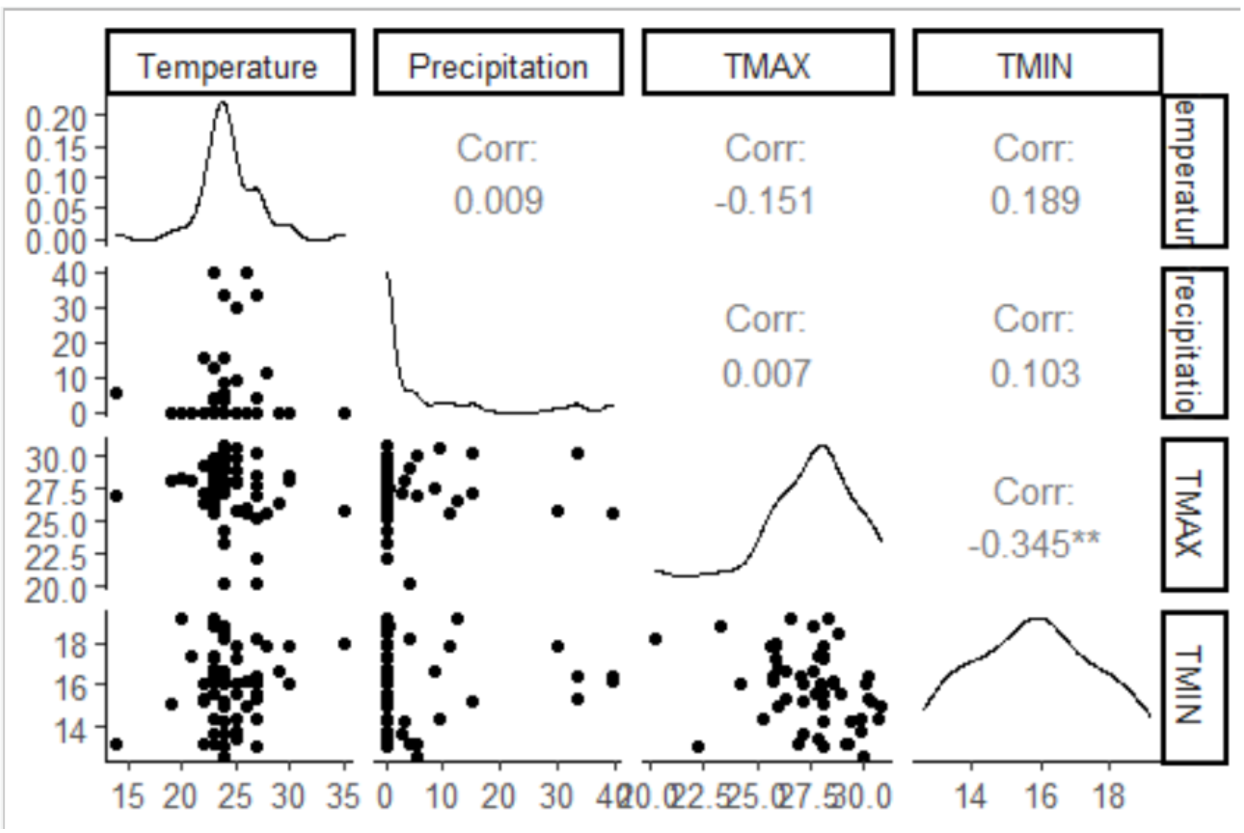

Figure 2. Pair plot present the correlation among the independent variables. The value of 0.7 present high correlations among those variables.

The variables are indicating site covariates in the home range of Grey Crowned Cranes, with some of the data brought from GPS data points and others are from Meteo-Rwanda (TMIN, TMAX and Precipitation). All explanatory variables were used in the modelling process to test their influence in the movement of Grey Crowned Cranes to the neighboring countries (Tanzania, Uganda and Burundi). In model building the response variable was the presence of crane in Rwanda (1) or absence in Rwanda (0) which implies their movement to nearby the country since all cranes fitted with GPS in Rwanda were the starting point for this analysis, therefore, their absence in Rwanda implies the cross-border movement to neighboring country. By using multiple logistic regression analysis (Hosmer et al., 1989; Lemeshow et al., 1988), the first step was modelled through Negative Binomial (Hoef & Boveng, 2007), while the second step was modelled through Random effect of sites to test if there is influence of Sites in the reduction of spatial auto-correlation of residuals as an issue in model diagnostic (Figure 15), however this did not solve the problem. The outcomes were explained in odds ratio. In model diagnostics, three points (Cook's distance, mean > 3) were considered as influential (Figure 16), their removal improve the significance of Minimal temperature. Final models and variable coefficients with a P-value ≤ 0.10 were considered significant unless otherwise stated. For spatial autocorrelation that was identified, I used random effects of sites however this did not solve the problem and I concluded that I do not have enough data to fix spatial autocorrelation issue.

CHAPTER 4. RESULTS

Introduction

This study was aimed at the assessment of the movement patterns of Grey Crowned Cranes across Rwanda's borders. The results showed that the temperature is the main environmental factor influencing the movement of cranes across Rwanda's borders. The home range of Grey crowned cranes varies by seasons. In additiona, the mostly used Cropland and wetland habitats.

4.1. Modeling Grey Crowned Crane home range

By using 95% KDE analyses and smoothing parameter of 6 km, this study reveals that the home range of Grey Crowned Cranes vary by seasons from Short dry season (3048 km^2) and Long rainy season (3017 km^2) to Long dry season (2241 km^2) and Short rainy season (2707 km^2) (Figure 6).

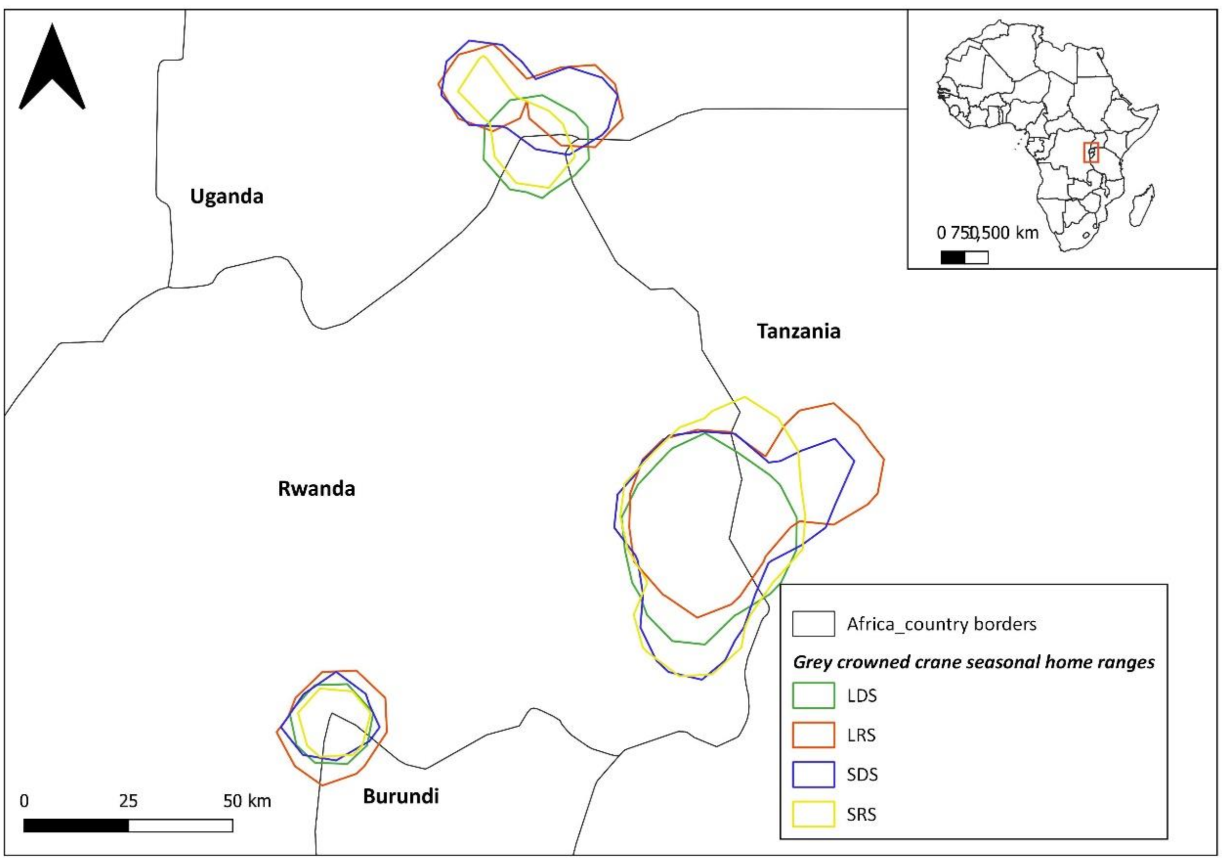

Figure 3. The change in home range size of Grey Crowned Cranes by seasons in three different sites.

LDS: Long Dry Season LRS: Long Rainy Season SDS: Short Dry Season

SRS: Short Rainy season with a smoothing parameter of 6 km.

The analysis of seasonal variation in home range of Grey Crowned Cranes shows that the home range increases seasonally every year. This is shown in both 50% KDE (Table 2), 90% KDE (Table 3) and 95% KDE (Table 4).

Table 2. Seasonal variation in home range at 50% Kernel Density estimate.

Seasons	Year	Area (ha)	Area (Km2)
Long dry season	2019	156.0746	1.56
Short dry season	2019	299.4564	2.99
Short rain season	2019	212.8015	2.13
Long dry season	2020	52523.057	525.23
Long rain season	2020	215.675	2.16
Short dry season	2020	6402.347	64.02
Short rain season	2020	111137.059	1111.37
Long rain season	2021	283829.1	2838.29
Short dry season	2021	242994.1	2429.94

Table 2 is the 50% KDE seasonal variation in home range of Grey Crowned Cranes in every year from 2019 to 2021. There is an increase of Grey Crowned Cranes' home range from 2.99 km^2 in 2019 to 2429.94 km^2 in 2021 in short dry season (SDS) and in long rainy season (LRS) the increase in home range is from 2.16 km^2 in 2019 to 2838.29 km^2 in 2021 and the increase from 2.13 km^2 to 1111.37 km^2 in short rainy season (SRS) in 2020.

Table 3. Seasonal variation in home range at 90% Kernel Density estimates.

Seasons	Year	Area (ha)	Area (Km^2)
Long dry season	2019	1180.273	11.80
Short dry season	2019	1296.853	12.97
Short rain season	2019	1451.827	14.52
Long dry season	2020	279366.595	2793.67
Long rain season	2020	976.541	9.77
Short dry season	2020	91173.704	911.74
Short rain season	2020	462572.296	4625.72
Long rain season	2021	968196.8	9681.97
Short dry season	2021	962261.4	9622.61

Table 3 is the 90% KDE home range of Grey Crowned Cranes varies seasonally in every year from 2019 to 2021. Comparing the home range sizes of Grey Crowned Cranes, there is variation increase of home range for instance, in Short Dry Season, the home range varied from 12.97 km^2 in 2019 to 911.74 km^2 in 2020 and 9622.61 km^2 in 2021.

Table 4. Seasonal variation in home range at 95% Kernel Density estimates.

Seasons	Year	Area (ha)	Area (Km2)
Long dry season	2019	1594.209	15.94
Short dry season	2019	1694.05	16.94
Short rain season	2019	2032.403	20.32
Long dry season	2020	386456.379	3864.56
Long rain season	2020	1333.087	13.33
Short dry season	2020	173096.928	1730.97
Short rain season	2020	612599.095	6125.99
Long rain season	2021	1251659	12516.59
Short dry season	2021	1274545	12745.45

Table 4 shows 95% KDE seasonal variation in home range of Grey Crowned Cranes in every year from 2019 to 2021. It also shows an increase of the home range in every season across the study period (2019, 2020 and 2021).

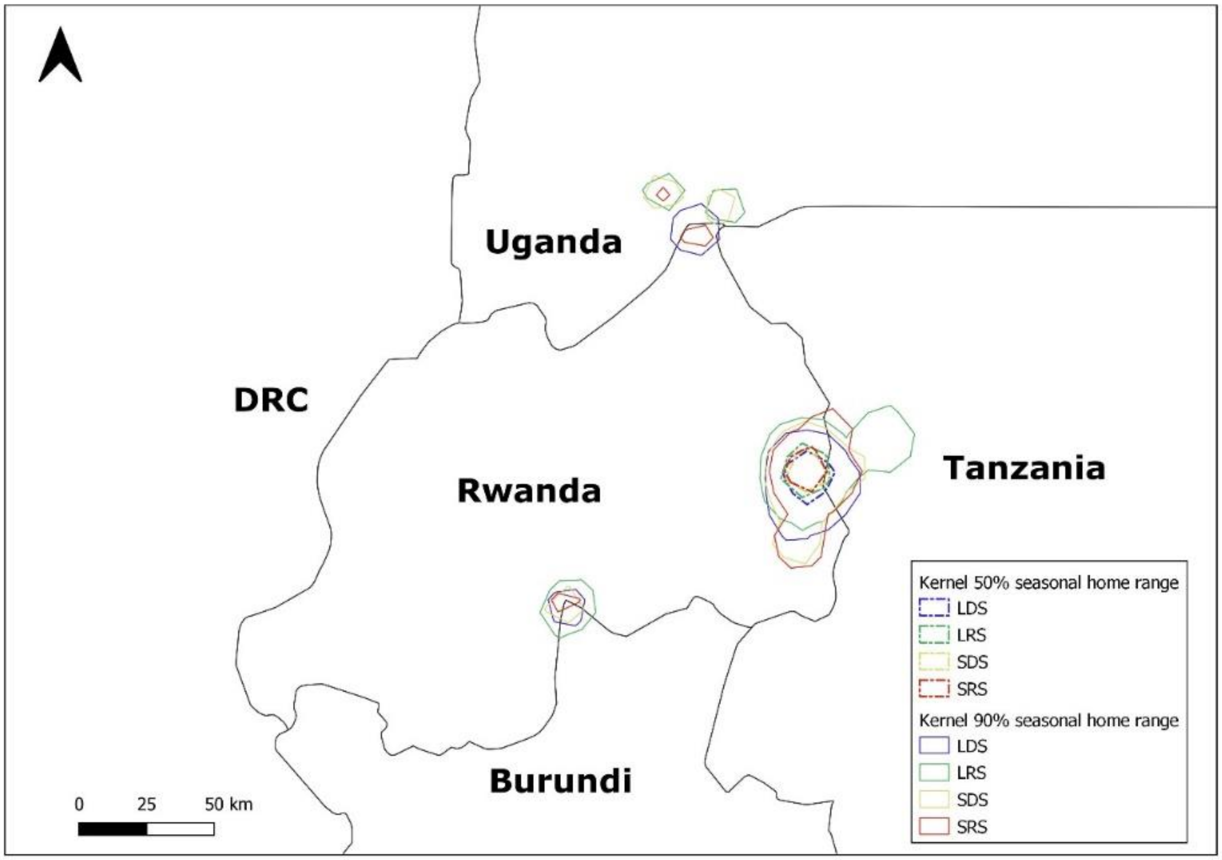

Figure 4. The seasonal home range of Grey Crowned Cranes during this study by 50% KDE and 90% KDE on the same map.

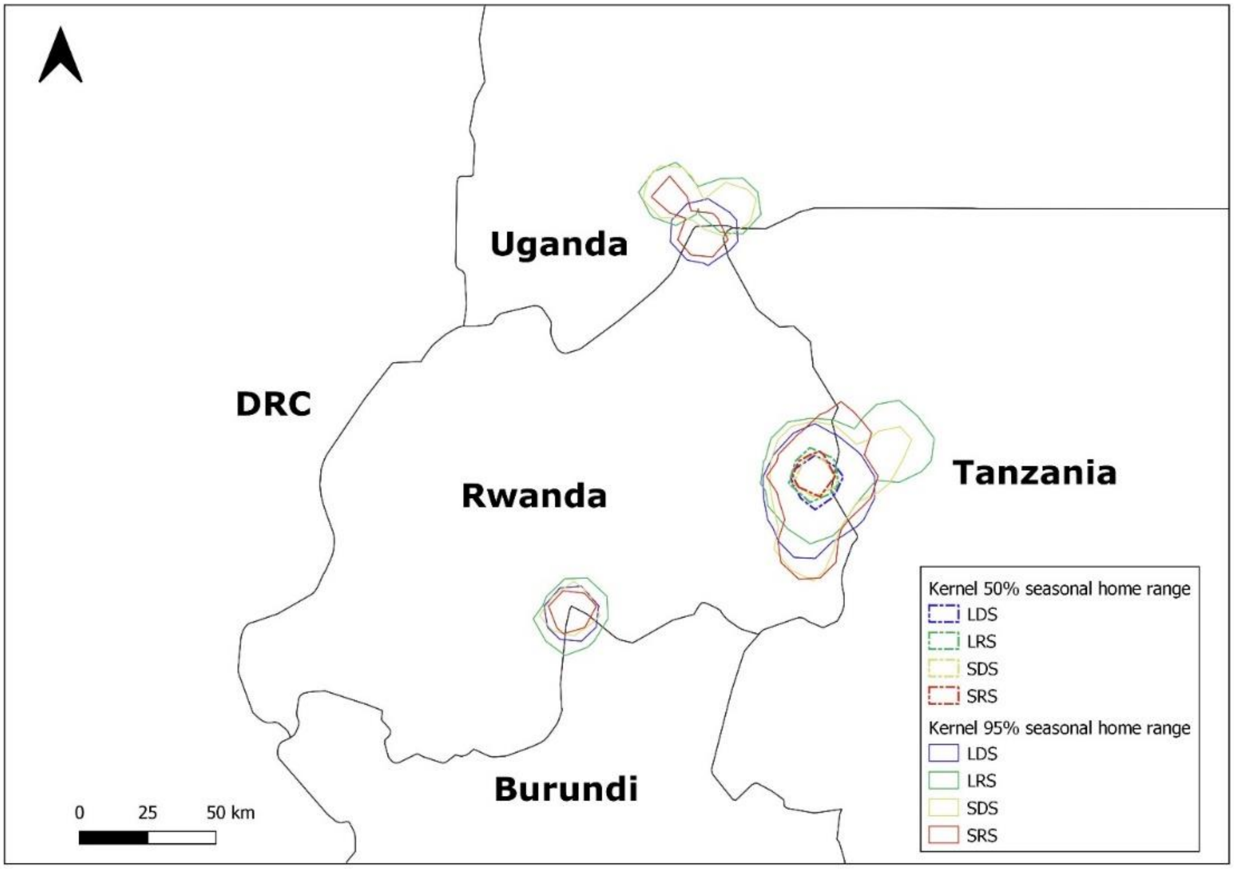

Figure 5. The seasonal home range of Grey Crowned Cranes during this study by 50% KDE and 95% KDE on the same map.

4.2. Environmental factors influencing the movement of Grey Crowned Cranes

Grey Crowned Cranes cross the boarders in every season at different rates. Generalized Linear Mixed Models (GLMM) reveal that temperature related variables, seasons and land cover type are the main predictors of Grey Crowned Crane movements throughout the seasons. All variables from Akaike's Information Criterion model that were <10 (Table 5) have been considered. GLMM revealed that there is no clear relationship between precipitation and presence/absence of Grey Crowned Cranes in Rwanda. By comparing temperature related variables, the additive model of temperature and minimal temperature improved the base model of temperature and this explains that temperature and minimal temperature are the only environmental factors found to influence the movement of GCC from Rwanda to the neighboring countries (Table 5).

Table 5. The model selection among environmental factors based on Akaike's Information Criterion AICcWt

Variable name	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
temp+tmin	3	73.75	0.00	1.00	0.25	-33.64	0.25
Temperature	2	73.77	0.02	0.99	0.25	-34.77	0.49
TMIN	2	74.90	1.15	0.56	0.14	-35.33	0.63
temp+preci+tmin	4	75.99	2.24	0.33	0.08	-33.60	0.72
Temp+preci	3	76.00	2.24	0.33	0.08	-34.76	0.80
TMAX	2	76.15	2.40	0.30	0.07	-35.96	0.87
Preci	2	76.30	2.55	0.28	0.07	-36.04	0.94
Full	5	77.73	3.98	0.14	0.03	-33.25	0.97
temp+preci+tmax	4	78.29	4.53	0.10	0.03	-34.74	1.00

Table 5 shows the model selection among environmental factors and their AICcWt. Models containing Temperature and Minimal temperature are the top models with AICcWt > 64; while Maximal temperature (TMAX) and precipitation (preci) show no evidence that they have influence on the presence of Grey Crowned Crane in Rwanda.

```
Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)    0.4126     3.4883   0.118   0.9058
Temperature    0.1946     0.1099   1.771   0.0765
TMIN          -0.2906     0.1786  -1.627   0.1037
---
Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 5 shows the influence of environmental factors on the movement of Grey Crowned Cranes. The explanation of coefficients requires the formula ($e^{\beta 1}$) that for an increase of 1 unit of temperature, we increase the odds of Grey Crowned Cranes being present in Rwanda by 1.22 times. Though the explained variance for this model is not higher (R^2 = 7%) this shows that temperature has positive influence in the presence of Grey Crowned Crane in Rwanda as the value is >1 while Minimal Temperature has negative influence as the value is <1 and this is shown in response curves below.

4.2.1. Temperature and Seasonal influence on the movement of Grey Crowned Cranes

Both temperature ($p < 0.10$, df = 54) and minimal temperature ($p = 0.10$, df = 54) had significant relationship with crane movement in log-likelihood. Increase in seasonal temperature had the greatest impact on the presence/absence of Grey Crowned Cranes in Rwanda. Their absence in Rwanda implies their cross-border movements. Grey Crowned Cranes crossed the borders in all the seasons of the year but at different frequency related to the seasons. The increase of temperature from 20°C to 30ºC in short rainy season increased the probability of cranes being present in Rwanda (Figure 10). Both seasonal levels are significant (X2= 89, df= 3, $p < 0.001$) and have relationship with the movement of Grey Crowned Cranes (Figure 9).

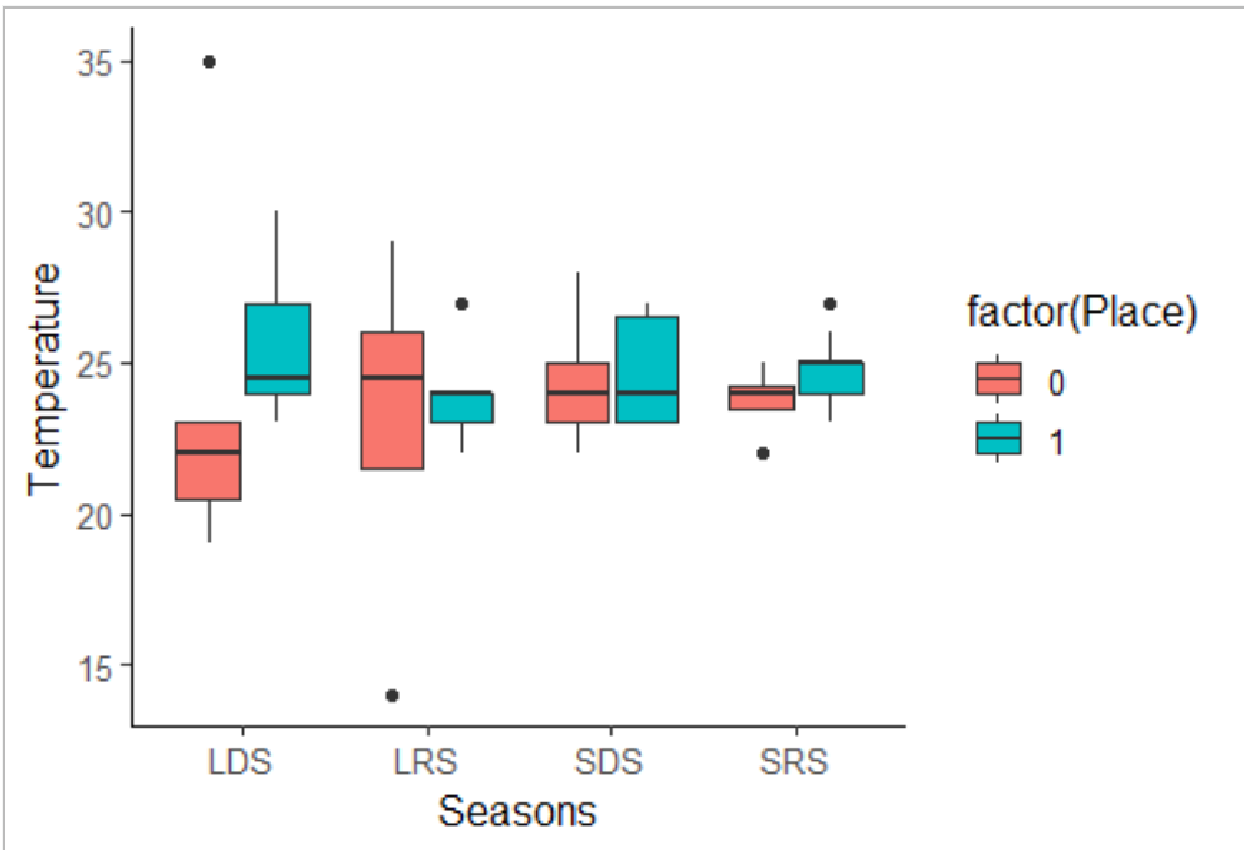

Figure 6. The relationship between temperature and presence (1) and absence (0) of cranes in Rwanda across the four seasons.

LDS: Long Dry Season LRS: Long Rainy Season SDS: Short Dry Season SRS: Short Rainy Season).

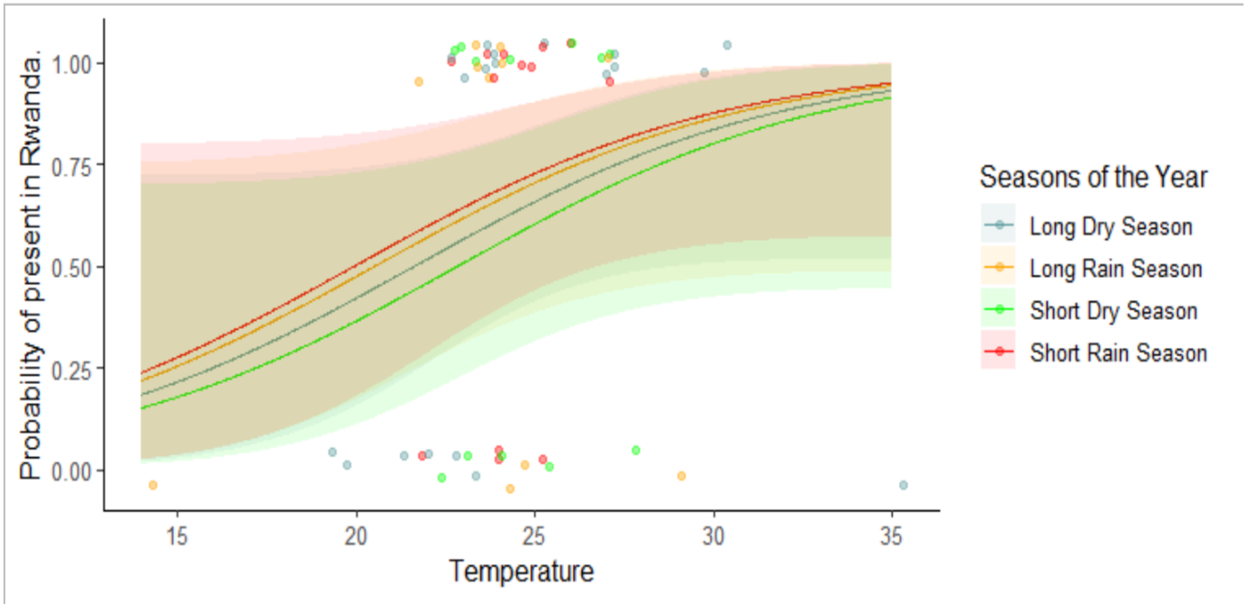

Figure 7. The relationship between temperature, seasons and probability of presence/absence of cranes in Rwanda.

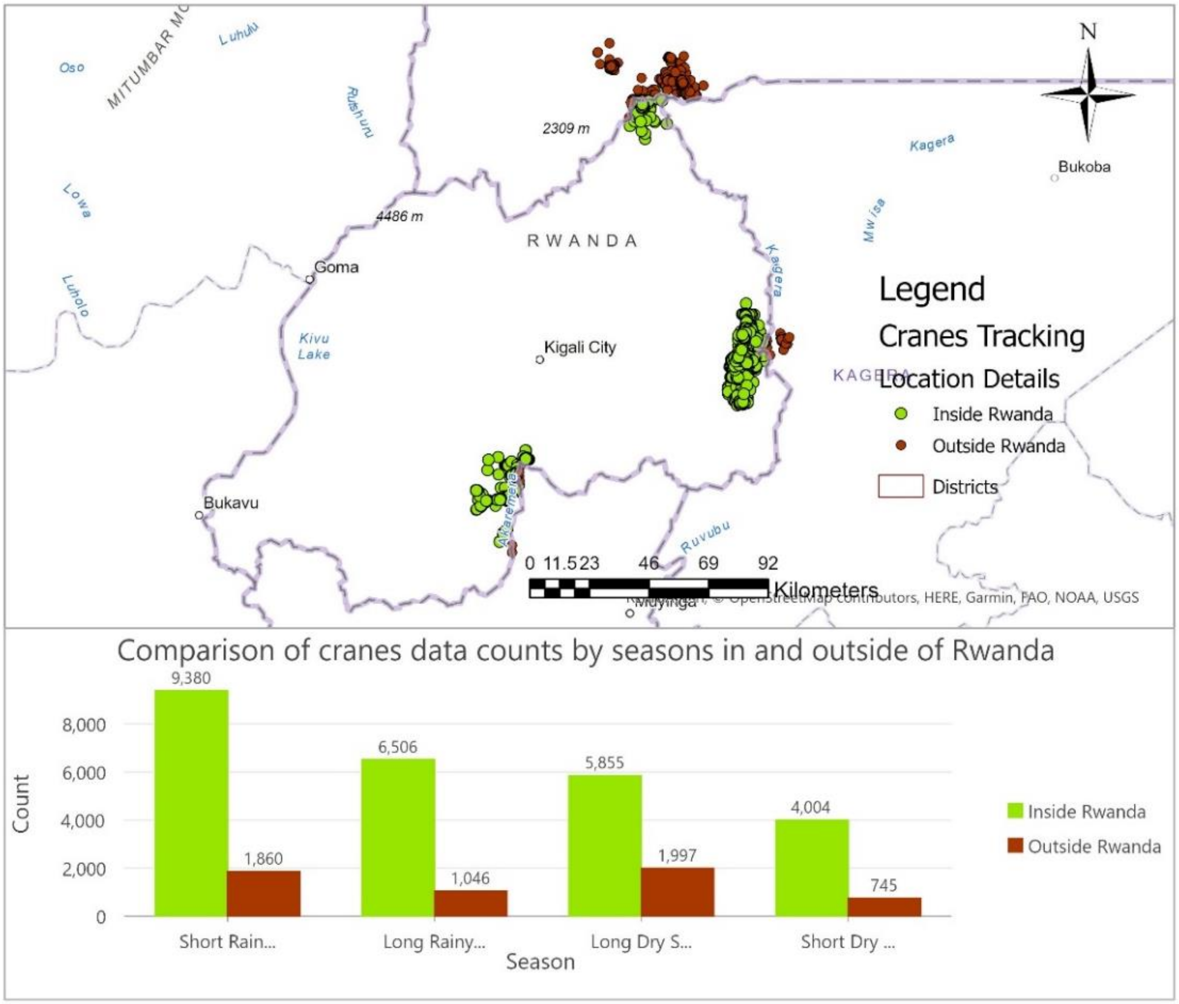

Figure 8. Crane data counts at different seasons in and outside of Rwanda.

Most of the way points of cranes have been taken in the rainy season in Rwanda (Figure 8). The frequency of occurrence outside Rwanda was higher in the short rainy season and long dry season even though the cranes move all year round on both sides of Rwanda.

4.2.2. Land cover effects on the movement of Grey Crowned Cranes

The movement of Grey Crowned Cranes are significantly influenced by all habitat types with the P value which is $p < 0.001$, except shrubs and water body ($p > 0.1$) with overall explained variance ($R^2 = 18\%$) (Table 6 and Figure 12). Cranes were mostly found in cropland and wetlands in both countries while they were also presented in broadleaf deciduous forest in Rwanda (no cranes were found in deciduous forest outside Rwanda based on the GMS logger data). Crop land (0.016 odds ratio) and wetland (0. 0117) have a significant influence on the movement of Grey Crowned Cranes to the neighborhood country as both had p $<0.2\times10^{-6}$and their odd ratios are less than 1. In this study, I found that some habitat types which includes shrubs and water bodies showed minor influence of cross-border movement of Grey Crowned Cranes as shown in Figure 10, 11 and 12, respectively) of sites distribution of Grey Crowned Cranes in habitat type.

Table 6. Summary of temperature and habitat structure model with the estimates (Odds ratio), standard error, z value and p value.

The estimate with < |1| indicate the negative influence on the presence of Grey Crowned Cranes in Rwanda.

Habitat type	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	4.04	0.21	19.26	<2e-16
Temperature	0.04	0.00	12.12	<2e-16
Cropland	-4.12	0.20	-21.08	<2e-16
Herbaceous	-4.02	0.22	-18.38	<2e-16
Shrub	12.41	312.51	0.04	0.968
Open with trees	-3.46	0.20	-17.19	<2e-16
Water bodies	12.36	139.31	0.09	0.929
Wetland	-4.45	0.20	-21.87	<2e-16

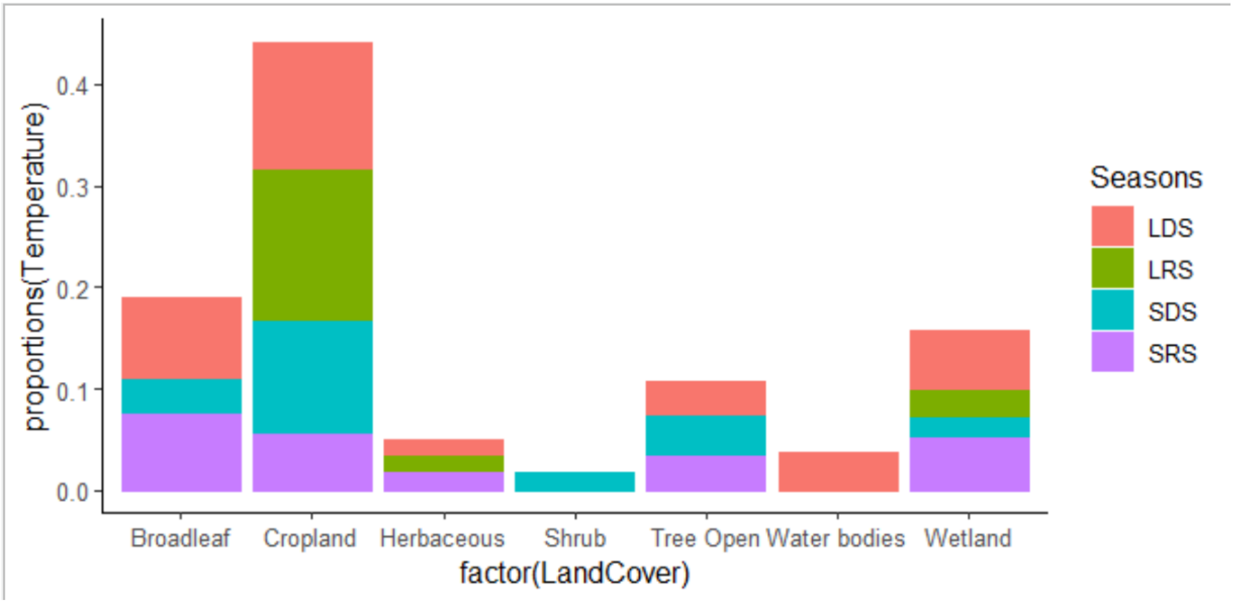

Figure 9. Seasonal temperature influence in the distribution of Grey Crowned Cranes habitat types.

The Grey Crowned Cranes were mostly found in Cropland, Wetland and Broadleaf across all the seasons. However, low points of Grey Crowned Cranes found in shrubs and water bodies.

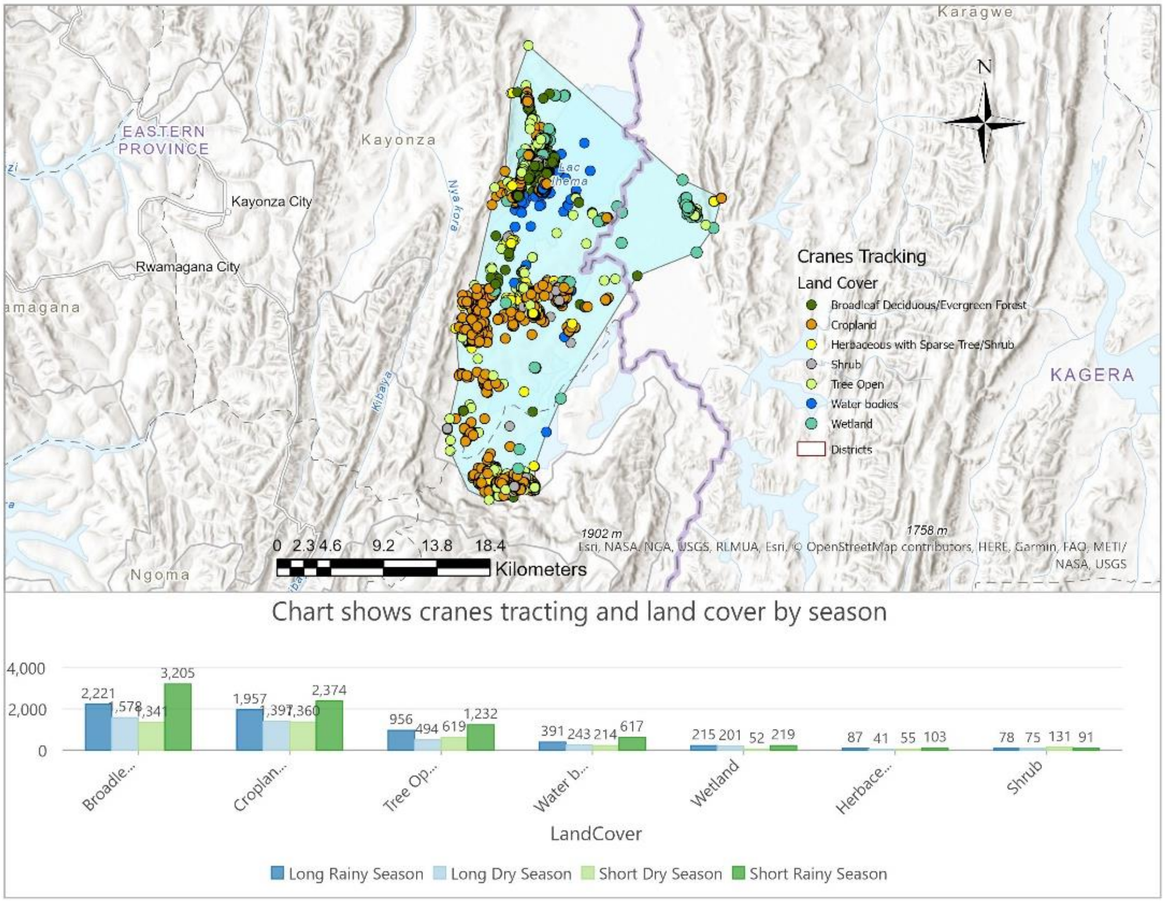

Figure 10. Map of seasonal movement of Grey Crowned Cranes and land cover types in the eastern part of the study site (Akagera National Park, Rwanda and Kagera, Tanzania).

In this study area, as shown above in the short and long rainy seasons, and the long and short dry seasons successively, cranes are found mainly in broadleaf, cropland, and tree habitats in Rwanda, with less occurrence in wetlands, herbaceous and shrub habitats.

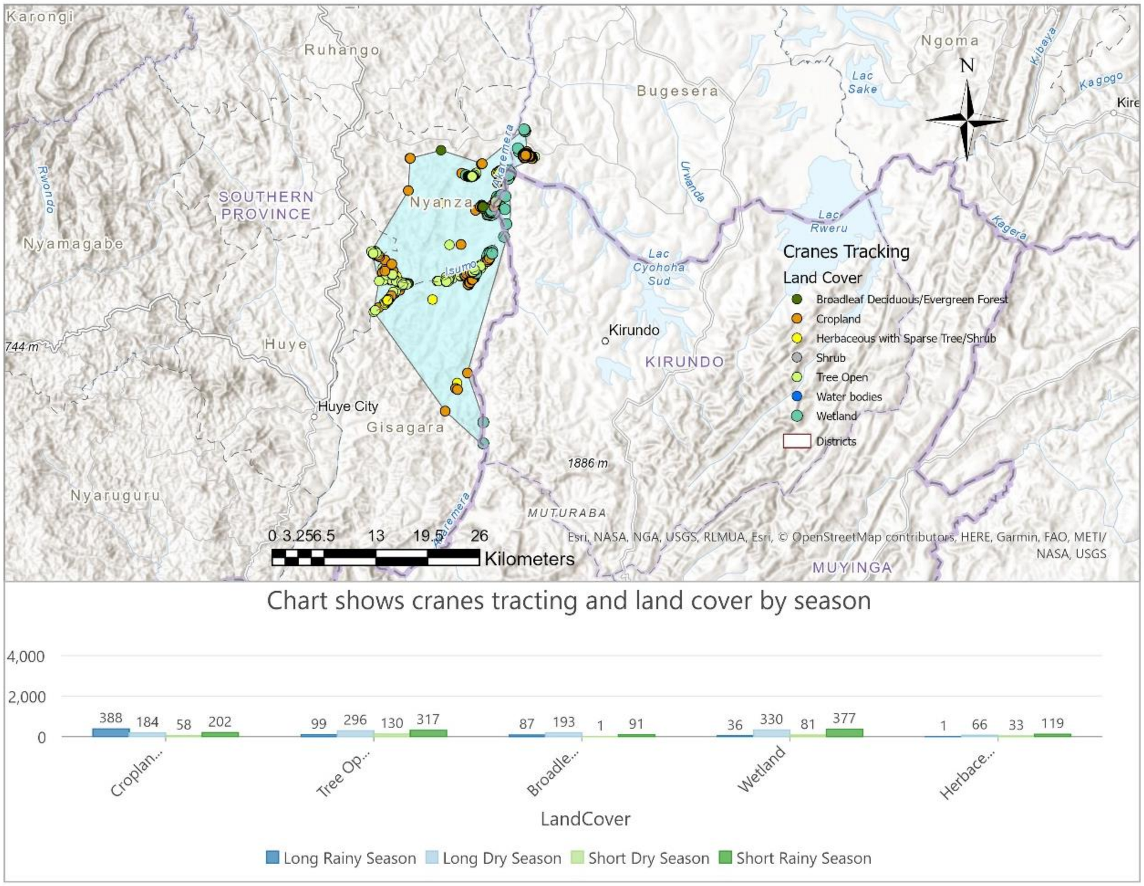

Figure 11. Map of seasonal movement of Grey Crowned Cranes and land cover in Akanyaru site (Nyanza district in Rwanda and Kirundo in Burundi).

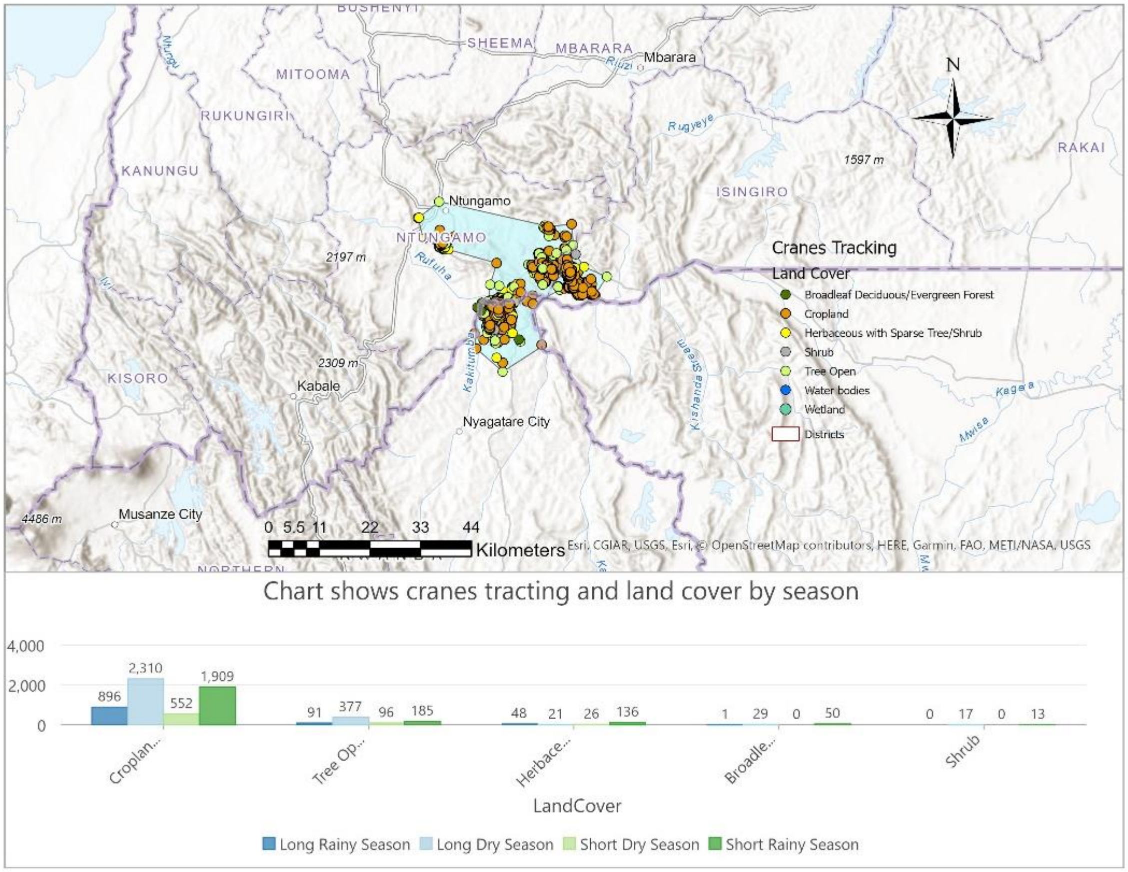

Figure 12. Map of seasonal distribution of Grey Crowned Cranes in Land cover in site of Nyagatare (Nyagatare district in Rwanda and Ntungamo in Uganda)

The cranes move all year round in both sides of the country and they are mostly found in cropland especially in the Long Dry and Short Rainy Seasons. The second habitat most frequently used by Grey Crowned Cranes was tree open areas.

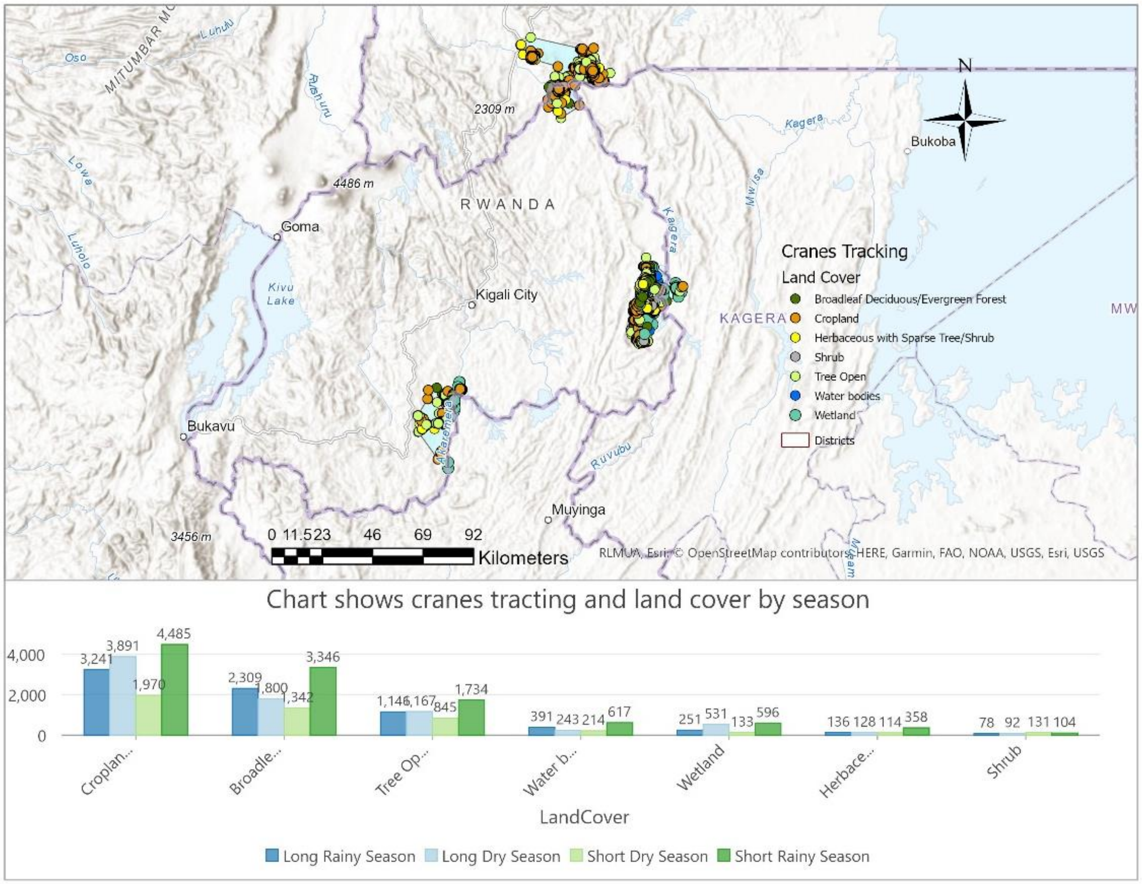

Figure 13. Map showing the influence of seasons and land cover on the movement of Grey Crowned Cranes in all sites.

CHAPTER 5. DISCUSSION

This study explored the home range of Grey Crowned Cranes in Rwanda, factors influencing their movements to the nearby countries and seasonal influence on their cross-boundary movement. Grey Crowned Cranes were observed to move across-borders every season of the year. Home range size differed among the four seasons. The home range of Grey Crowned Cranes increased in the Short Dry Season and Long Rainy season. The possible cause for the change in home range size in short dry and long rainy season may be due to food distribution. During the months of December and January, the short dry season, there is a short harvesting activities (Hunter et al., 2020) which influences food availability for the cranes and increase their home range compared with the long dry season. This may be the cause for the increase the home range of Grey Crowned Cranes as they move from one region to another to search for food, while in March (rainy season) they consume frogs, insects and other invertebrates in wetlands (Attenberger, 2021). Rolando (2002) found that home range size for bird species may depend upon the distribution of food, so that the more scattered the resources, the larger the range size. By using 95% KDE, the study found that the home range size of Grey Crowned Cranes changes in all season levels of the year in Rwanda, Burundi and Tanzania with an increase in dry seasons every year from 2019 to 2021.

In addition to changes in home range size, Grey crowned cranes were found to be sensitive to temperature. Generalized linear and mixed models revealed that the cranes are most likely to appear in Rwanda when the temperature is between 20^0C to 30^0C, but when the temperature decreased below 20 or increased above 30, the occurrence of Grey Crowned Cranes changes (inside and outside the country). A previous study showed that precipitation is the main factor influencing crane species occurrence in Rwanda (Attenberger, 2021), but temperature was not included as a variable which may be the reason to conclude that precipitation has the main influence on crane's occurrence. The fact that temperature is an important factor for birds diversity is emphasized by Srinivasan, Elsen and Wilcove (2019) who found that tropical species are sensitive to temperature and the highest variation in temperature has a significant impact on bird occurrence.

Among twelve factors influencing birds movements, habitat type and structure as well as human disturbance are on the top (Rolando, 2002). This study found that Grey Crowned Cranes use cropland, wetland, trees, open and broadleaf evergreen/deciduous forest more than other habitat types which includes water bodies, herbaceous, shrubs in all seasons of the year. A previous study about habitat suitability of Grey Crowned Cranes found that they use wetlands in rainy season and cropland in dry season (Attenberger, 2021). In terms of movement, cropland, wetland, broadleaf/deciduous forest and tree open have the highest influence in the cross-border movement of Grey Crowned Cranes in Rwanda, Uganda, Burundi and Tanzania while the other habitats which include herbaceous, water bodies and shrubs had shown minor influence in cross-border movement of cranes because they didn't appear frequently in one of these habitat outside of Rwanda in either of the three target countries during all the whole study time.

As expected, changes in seasons have a significant impact on the movement of Grey Crowned Cranes. Many studies have revealed that seasonal variation in environmental conditions corresponded to significant differences in collective movement patterns. This study found that an increase in temperature (as explanatory variable) to the moderate level (between 20^{o} C and 30^{o} C) increases the probability of occurrence of cranes in rainy season more than in dry season. Furthermore, this study showed that cranes have the probability of occurrence in both sides of the border every season of the year. Dry seasons show major influence on the movement of Grey Crowned Cranes outside Rwanda as the probability of occurrence in Rwanda is low while the rainy seasons show minor influence at moderate temperature. This observation is similar to that of a previous study which showed that groups of birds use much larger areas and travel longer distances on a daily basis in dry season, potentially in search of resources (Papageorgiou, Rozen-rechels, Nyaguthii, & Farine, 2021). Attenberger (2021) showed that Grey Crowned Cranes use wetlands in the rainy seasons for breeding and for food resource, while Papageorgiou et al. (2021) showed that the movement of birds during breeding time is low. The fact that cranes move outside in long rainy season may be due to the wetlands available in Rwanda compared to those in the nearby countries which have a lot of wetlands and rich in aquatic ecosystems which influence the movements of Grey Crowned Cranes and this implies the increase of home range in long rainy season which is exceptional. Therefore, these findings clarify the reason why Grey Crowned Cranes cross the boarders in Dry seasons than in rainy seasons.

CHAPTER 6. CONCLUSION and RECOMMENDATIONS

6.1. Conclusion

Grey Crowned Crane (*Balearica regulorum*) is an endangered bird species which uses a mix of habitats (wetland, cropland and forest) where 70% of the population of Grey Crowned Cranes in Rwanda have been counted nearby the borders close to the neighboring countries which includes Uganda, Tanzania and Burundi (Nsengimana & Becker, 2019). This study clarified temperature as the explanatory variable which is used to predict the cross-border movement of Grey Crowned Cranes. Grey Crowned Cranes in Rwanda cross the adjacent country borders every season of the year. The home range of Grey Crowned Cranes fluctuates seasonally every year. This study showed that in dry seasons, Grey Crowned Cranes use larger home range than in rainy season in which the food availability and distribution may be the reason in dry season and breeding time may be the cause in rainy season. Cropland and broadleaf forest in dry season as well as wetland in rainy season are the main habitat frequently used by Grey Crowned Cranes and this may drive their movements to the nearby countries. Cropland, wetland, tree open and broadleaf deciduous forest are the main habitat types used by Grey Crowned Cranes both outside and inside Rwanda.

During this study Nyagatare site showed the highest cross border movement of Grey Crowned Cranes while Akanyaru the least. This may be due to the human population volume in those sites which increase agriculture. Although the present study clarified the cross border movement of Grey Crowned Cranes, we do not know the factors influencing the fluctuation in the home range size as well as the seasonal change in food availability of Grey Crowned Cranes. Furthermore, the cross-border survey with different study design is needed to solve different questions raised during this study including spatial autocorrelation in modelling.

6.2. Recommendations

1. The trans-boundary collaboration is urgently recommended to ensure the safety of the cranes by restoring cranes' habitats and protecting wetlands as breeding habitats for concerned species, especially in rainy season.
2. RWCA and other conservation organizations and institutions are highly recommended to collaborate and develop policies which enable the farmers to live friendly with cranes.
3. A regional conference to raise awareness for protecting Grey crowned Crane in the study area countries: Rwanda, Uganza, Tanzania and Burundi

4. Conduct similar study to determine the ecology and movement patterns of the other birds for instance Shoebill in Akagera NP, which is an endemic bird of the Lake Victoria region and attracts many tourists.

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Appendix

Photo 1: Tagged crane with GPS/GSM

Photo 2: Setting snares to catch cranes

Photo 3: Putting Ecotone GPS/GSM on crane's right leg

Photo 4: Putting GPS/GSM on crane

Photo 5: Releasing the cranes after tagging with Ecotone GPS/GSM

Photo 6: Tagged crane walking in its habitat

Photo 7: Tagged crane flying with the flock

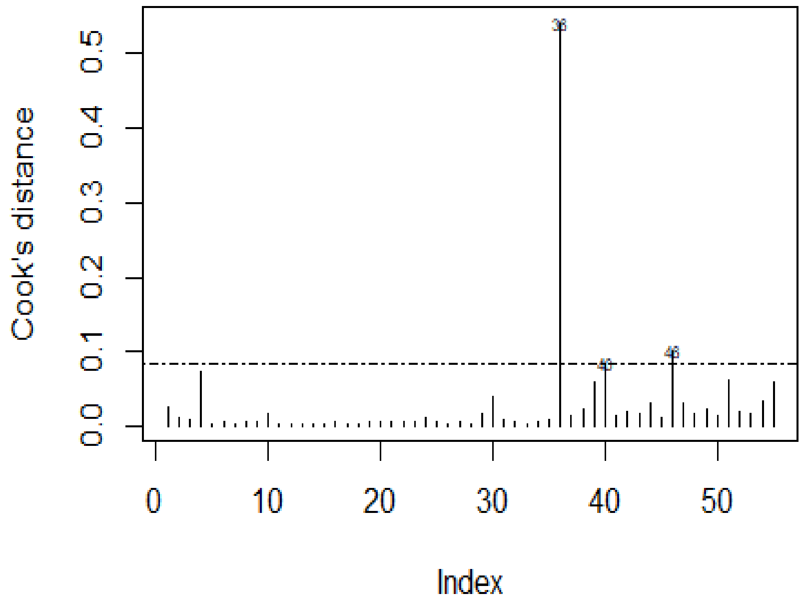

Figure 14. The influential points. Cook's distance (cd) > 3* mean (cd). Three points (36, 40 and 46) are influential in temperature

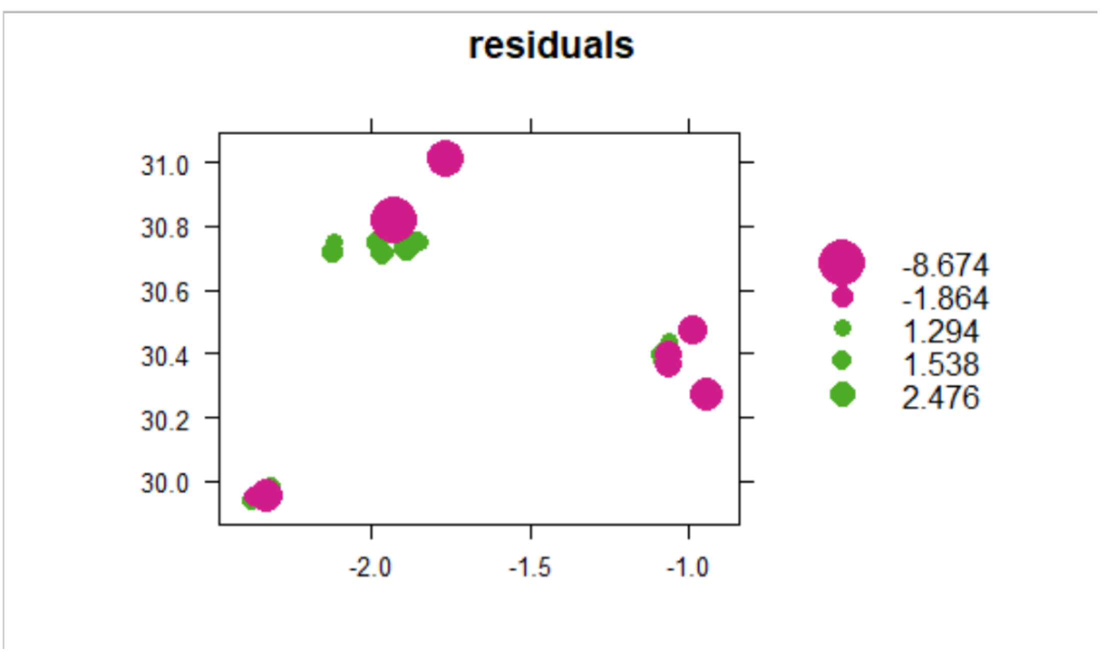

Figure 15: The spatial autocorrelation of residuals.

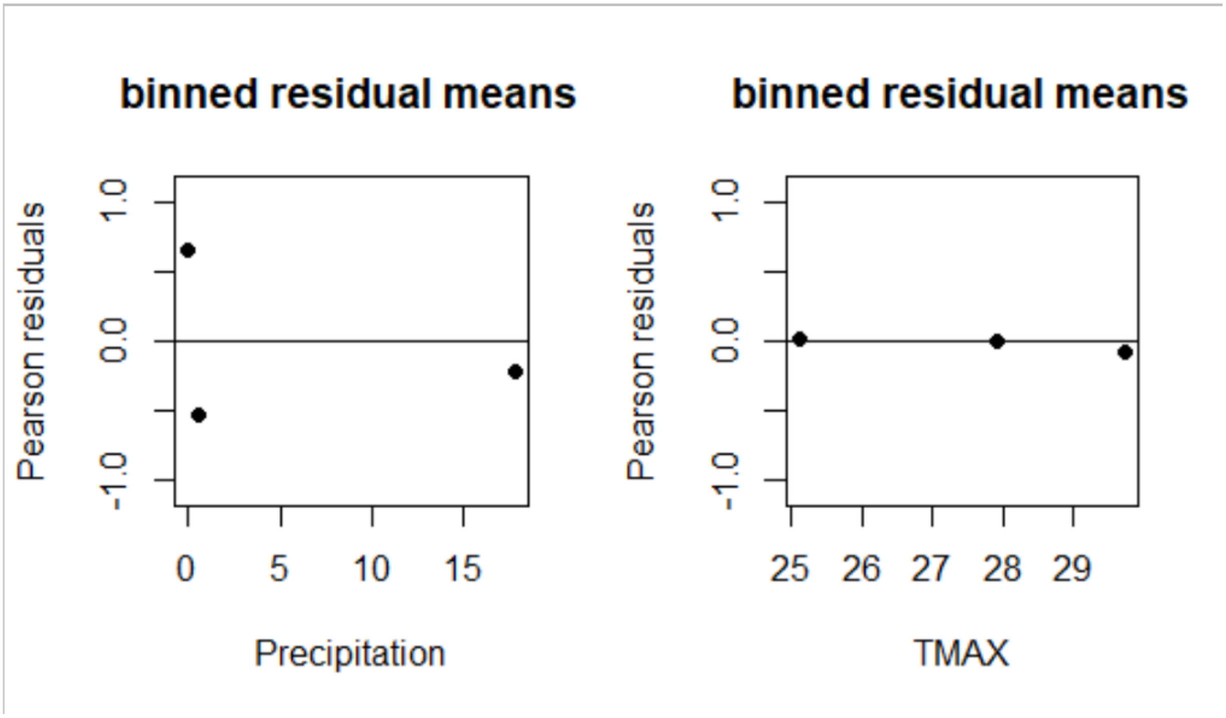

Figure 16. The correlation of binned mean residual of unused variables.

TMAX shows the highest relationship with response variables though it didn't improve model of TMIN and ordinal temperature.