

https://dspace.org/

Home range establishment of translocated African elephants (Loxodonta africana) in a savanna environment

Ngorima, Patmore

2023-09
University of the Witwatersrand, Johannesburg
https://hdl.handle.net/10539/42558
Ngorima, Patmore. (2023). Home range establishment of translocated African elephants (Loxodonta africana) in a savanna environment. [Master's dissertation, University of the Witwatersrand, Johannesburg]. https://hdl.handle.net/10539/42558

Downloaded from a DSpace repository. https://dspace.org/

Home range establishment of translocated African elephants (*Loxodonta africana*) in a savanna environment

by
Patmore Ngorima
(2482687)

A research report submitted in partial fulfilment of the requirements for the degree

Master of Science

In

Resource Conservation Biology

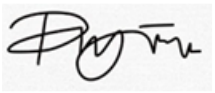
in the Faculty of Science, University of the Witwatersrand, Johannesburg, South Africa

Supervisors: Professor Francesca Parrini
Dr Melinda Boyers
Ms Elena Mariotti

October 2023

Declaration

I declare that this thesis is my own, unaided work. It is being submitted for the Master of Science degree at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.



_____

(Signature of candidate)

October 2023

Abstract

Data from nine female African elephants translocated to Hurungwe Safari Area that had been collared was used to estimate home range patterns. Monthly home ranges for each elephant were estimated using the 50% and 95% Kernel Density Estimates (KDEs) method for a period of 20 months following translocation. At the population level, a linear regression model was used to test for the effect of months from release on the home range patterns. The findings revealed that the 95% home range of the elephants increased over time, while the 50% home range decreased since their initial release. I went further to compare the individual differences using the generalised additive model. The results showed some individual differences in patterns of exploration, with some displaying more linear home range patterns than others. Over and above, a considerably positive and relevant relationship between time and variation in the extent of the home range was observed.

Keywords: African elephant, home range, translocation, linear regression model, generalised additive model, savanna.

Dedication

I dedicate this work to my wife, Harriet Sibanda-Ngorima for her love, encouragement, and prayers throughout my studies. I also dedicate it to my daughter, Priela Ngorima as a symbol of hard work, determination, and dedication. To my wife and daughter: You have made me stronger, better, and more complete than I could have ever imagined.

Acknowledgements

First and foremost, I would like to express my heartfelt gratitude to my supervisors, Professor Francesca Parrini, Dr Melinda Boyers and Ms Elena Mariotti. I greatly appreciate your wisdom and experience and I would like to acknowledge your role in the completion of this thesis. Your encouragement and belief in my potential gave me the strength to persevere during tough times.

I would also like to thank my employer, Zimbabwe Parks and Wildlife Management Authority (ZPWMA), for allowing me to conduct this study in Hurungwe Safari Area as part of my work.

A special thank you to the African Wildlife Foundation, which funded my education to study at the University of Witwatersrand, Johannesburg, South Africa. Without their financial support through the Charlotte Fellowship Scholarship, completion of this Master's would not have been possible.

I am grateful to everyone who has helped me in my struggle to achieve my dream. I appreciate the generous assistance of Mr Blessing Kavhu, Mr Kudzai Shaun Mpakairi, Dr Henry Ndaimani, Dr Matipano, Mr Jeremiah Chakuya, Mr Tafadzwa Shumba and Mrs Roseline Chikerema-Mandisodza.

I cannot begin to express my gratitude to my family for all of the love, support, encouragement and prayers they have sent my way along this journey. To my grandmother, your unconditional love and support have meant the world to me from day one, I hope that I have made you proud. To my wife and daughter, Harriet and Priela, you are my inspiration to achieve greatness!

Finally, I render the utmost gratitude to the Almighty God for the wisdom and guidance throughout my studies.

Table of Contents

Declaration i

Abstract ii

Dedication iii

Acknowledgements iv

Chapter 1: Introduction

1.1 Motivation for the study 1

1.2 Aim 2

1.3 Objective 2

1.4 Literature review 2

1.4.1. African elephant social structure 2
1.4.2 African elephant conservation and ecology 3
1.4.3 African elephant management options 3
1.4.4 Translocation 4
1.4.5 Home range establishment 5
1.4.6 Factors affecting home range establishment 5
1.5 Predictions 8

Chapter 2: Materials and Methods

2.1. Study areas 9

2.1.1 Source site: Save Valley Conservancy (Sango Ranch) 9
2.1.2 Release site: Hurungwe Safari Area (Rifa) 10
2.2. Field Data collection 11

2.2.1 Elephant translocation 11
2.2.2 Data collection 11
2.2.3 Data analysis 12

Chapter 3: Results

3.1 First Prediction: Population level 14

3.2 Second Prediction: Individual variations (95% GAM) 16
3.3 Second Prediction: Individual variations (50% GAM) 21

Chapter 4: Discussion 25

Chapter 5: Conclusion and Recommendations 29

References 30

List of Figures

Figure 1: Map of Sango ranch in Save Valley Conservancy, Zimbabwe 9

Figure 2: Map of Hurungwe Safari Area in the mid-Zambezi valley region, Zimbabwe. 10

Figure 3: The workflow displaying the steps taken in the data analysis process to calculate home range establishment patterns for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe..... 13

Figure 4: Predictive margins with 95% CIs for the results of the linear regression model for the association between home range size for the (A) 95% isopleth (area) and (B) 50% isopleth (area) across months since initial release for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe. 15

Figure 5: Temporal trends in the monthly home range pattern at 95% KDE of nine female African elephants translocated to Hurungwe Safari Area. The results are presented at six-month intervals from the initial month of translocation.... 18

Figure 6: Change in monthly home range extent (km) over time (months) at (95% KDE) of nine female African elephants translocated to Hurungwe Safari Area in Zimbabwe from the initial month of introduction..... 20

Figure 7: Temporal trends in the monthly home range pattern at 50% KDE of nine female African elephants translocated to Hurungwe Safari Area. The results are presented at six-month intervals from the initial month of translocation... 22

Figure 8: Change in monthly home range extent (km) over time (months) at (50% KDE) of nine female African elephants translocated to Hurungwe Safari Area in Zimbabwe from the initial month of introduction..... 24

List of Tables

Table 1: Summary of tracking periods on nine matriarch African elephants translocated to Hurungwe Safari Area, Zimbabwe, which were collared with Africa Wildlife Tracking (AWT) GPS collars recording hourly locations. 11

Table 2: Results of linear regression models comparing the 95% home range size and the core 50% home range size for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe, over 20 months since release. 14

Table 3: Generalised Additive Model results comparing the temporal 95% home range patterns of nine female African elephants translocated to Zimbabwe's Hurungwe Safari Area. Ann was used as the reference category. 17

Table 4: The smoothing factors from the GAM explaining the linearity and complexity of the relationship at 95% KDE for change in home range extent over time for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe. Non-linear relationship: $1 < edf \leq 2$; strong non-linear relationship: $edf > 2$ 19

Table 5: Generalised Additive Model results comparing the temporal 50% home range patterns of nine female African elephants translocated to Zimbabwe's Hurungwe Safari Area. Ann was used as the reference category. 23

Table 6: The smoothing factors from the GAM model explaining the linearity and complexity of the relationship at 50% KDE for change in home range extent over time for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe. Non-linear relationship: $1 < edf \leq 2$; strong non-linear relationship: $edf > 2$ 23

List of Appendices

Appendix 1: Results of Kernel Density Estimate Home Range Size at 95% for Nine Female African Elephants Translocated to Hurungwe Safari Area, Zimbabwe, over 20 months since Release..... 39

Appendix 2: Results of Kernel Density Estimate Home Range Size at 95% for Nine Female African Elephants Translocated to Hurungwe Safari Area, Zimbabwe, over 20 months since Release..... 40

Appendix 3: Post-hoc results of the pair-wise comparison of 95% KDE home range temporal patterns of nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe. 41

Appenidx 4: Post-hoc results of the pair-wise comparison of 50% kernel density home range temporal patterns of nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe..... 19

Chapter 1: Introduction

1.1 Motivation for the study

Animal translocation is a common practice that has been adopted all over the world for the management and conservation of animals (Pinter-Wollman et al., 2009; Hoffmann et al., 2015; Evans et al., 2023). This approach has been used in the field of conservation to humanely manage wildlife populations for rescue purposes, reintroduction, and solving human-wildlife conflicts (Seddon et al., 2007; Seddon et al., 2014). Other wildlife management approaches that are used to control and manage elephant population growth include culling and the use of birth control measures. All the above-mentioned methods have their limitations and pitfalls. For example, animal translocation is considered a costly strategy to undertake, and there is no guarantee that the animals will not return to their original source area (Berger-Tal et al., 2020). Culling is viewed as "cruel" or unethical, while the use of birth control measures is too risky, and its long-term impacts are not fully known (Chutipongvivate et al., 2019; Slotow et al., 2021). However, when families can be moved intact, animal translocation is considered the most humane method of managing high elephant densities and an ideal choice (Dublin and Niskanen, 2003; Evans et al., 2023). All these methods have typically focused on trying to establish viable elephant numbers at desirable levels where their impacts are considered not detrimental to the environment (Wambwa et al., 2001; Dublin and Niskanen, 2003; Resende et al., 2021).

In 2018, Rhino Force Zimbabwe was given a permit by the Zimbabwe Parks and Wildlife Management Authority to translocate 100 African elephants (*Loxodonta africana*) from Save Valley Conservancy (Sango Ranch), in the south-eastern Lowveld, to Hurungwe Safari Area (Rifa), in the Mid-Zambezi Valley (Ngorima and Ngwenya, 2018). Of the 100 translocated elephants, nine adult female matriarchs were collared to allow for post-translocation monitoring after release. Though the literature is replete with studies that evaluate the home range establishment of elephants in savanna ecosystems (Shannon et al., 2006; Shannon et al., 2009; Ngene et al., 2017; Ndaimani et al., 2017), little is known about the home range size of female African elephants after translocation, yet this is an important gap that needs to be filled (Garnier et al., 2021). Studying elephant home ranges post-translocation is crucial, as it adds to the adaptive management framework and also creates baseline knowledge to improve and guide future translocations. In addition, it also feeds back into management to guide the monitoring of translocated elephants.

The result of this study will provide a conceptual and quantitative representation of translocated African elephant matriarch herds' home range establishment over time. Information on home range establishment is necessary to maximise the effectiveness of conservation efforts in wildlife management and to better understand temporal trends in the monthly home range size of translocated female elephants, what locations the elephants prefer to reside in, and how the elephants use space (Ndaimani et al., 2017). Henceforth, as an entry point, this study will provide greater understanding and meaningful insights with regard to improving planning, monitoring, and conservation of translocated African elephants' post-translocation to safeguard their future in a novel environment.

1.2 Aim

This study aims to analyse the home range establishment of nine translocated female African elephants in the Hurungwe Safari Area, Zimbabwe.

1.3 Objectives

1. To assess and compare trends in monthly home range size of translocated female African elephants from the day of initial introduction.
2. To explore individual variations on home range sizes and movement patterns.

1.4 Literature review

1.4.1. African elephant social structure

African elephants have a social structure led by the eldest female elephant, known as the matriarch (Lee and Moss, 1986). The matriarchal elephant and its dependent offspring are known as a "family or herd" (Leggett et al., 2011). Literature records that this social structure has a positive impact on the calf survival rate (Leggett et al., 2011; Archie and Chiyo, 2012). Additionally, if these social groups are too large, they may split up into different herds based on family lines and form a bond group. Bond groups can be identified when they are reunited with their families through extravagant behavioural mannerisms (Leggett et al., 2011). Another extremely important characteristic of elephants is that they can communicate with each other using low-frequency sounds over a distance of up to 10 km^2 (Garstang, 2004). African elephants also require vast areas to cater for their needs,

which include but are not limited to feeding, mating, water, and lookout positions. These areas are referred to as their "home range" (White and Garrott, 1990).

1.4.2 African elephant conservation and ecology

African elephants are a charismatic species and one of the world's largest mammals, with enormous economic, environmental, cultural, and aesthetic value (IFAW, 2005). The first ever "red list" assessment of the African elephant recorded that there are two separate species, which are the forest elephant (*Loxodonta cyclotis*) and the savanna elephant (Loxodonta *africana*) (IUCN/SSC, 2021). The forest elephant has been classified by the IUCN as critically endangered, while the savanna elephant is listed as endangered (IUCN/SSC, 2021). Dublin and Taylor (1996) noted that some of the most important decisions made in managing African wildlife revolve around the African elephant. This shows how important this animal is in the field of wildlife conservation and management. African elephants are often considered the pillar of protection for all their habitats (Bandara and Tisdell, 2004). African elephants are key species in the trophy hunting industry because they are part of the big five; hence, they generate high revenue in consumptive tourism (Ngorima et al., 2015). In addition, they are also iconic species and important for non-consumptive eco-tourism (photographic safaris) (Martin-Lopez et al., 2008).

The IUCN Red List currently classifies the African elephant as vulnerable and endangered on CITES Appendix I (IUCN/SSC, 2021). However, in countries that include Botswana, Namibia, South Africa, and Zimbabwe, elephant populations are listed under CITES Appendix II because of their high numbers (Lindsay et al., 2017). Elephants are widely distributed in Africa, and their population dynamics also vary from one elephant range area to another, particularly in most of southern and eastern Africa (Blanc et al., 2007). Of concern is that in some elephant range areas in southern and eastern Africa, elephant populations have, in most protected areas, gone beyond the ecological capacity, which in turn has some negative effects on natural vegetation and associated biodiversity (Peng et al., 2019). This is because African elephants are ecosystem engineers and major ecological drivers in the African savanna (Duffy et al., 2011; Fritz, 2017). Therefore, this calls for proper management strategies to maintain their numbers at desirable levels that are not detrimental to the environment.

1.4.3 African elephant management options

Elephant population management is a subject of concern that has stirred great debate in the field of wildlife management (Dublin and Taylor, 1996). In most southern African countries that have elephant range areas, such as Botswana and Zimbabwe, elephants' overabundance is an issue of concern that often affects wildlife conservation and management (Wambwa et al., 2001). It has been seen as deleterious or undesirable because of its ecological impacts on the environment (Dublin and Niskanen, 2003). In addition, an overabundance of elephants is also harmful, not only to protected areas but also to adjacent communal areas, where at times the elephants may destroy crops, human property, and even human life (Dublin and Niskanen, 2003). As such, several elephant management options have been identified to address such scenarios, including culling, the use of birth control pills (contraception), range expansion, manipulation of water sources, and translocation to a new location (Wambwa et al., 2001; Cumming and Jones, 2005). All these efforts have typically focused on trying to establish viable elephant numbers at desirable levels where their impacts are considered not detrimental to the environment (Wambwa et al., 2001).

However, of the identified options to manage elephant populations, translocation is considered the most humane and sensitive when managing high elephant densities (Dublin and Niskanen, 2003). This is because elephant culling, which used to be accepted, has been banned in Zimbabwe and is viewed as unethical by animal activist groups. While the use of birth control pills to keep elephant numbers at desirable levels may be tempting, the long-term effects are not fully known (Chutipongvivate et al., 2019; Slotow et al., 2021). Furthermore, this option disputes the conservation goal of maintaining wildlife heterogeneity because it attempts to stabilise elephants' numbers at a certain level (Van Aarde and Jackson, 2007). While this could be a noble idea, other conservationists fear that it may affect habitat heterogeneity and resilience, ultimately reducing species richness (Gillson and Lindsay, 2003).

1.4.4 Translocation

Translocation refers to the movement of animals from one place to another, with the primary aim being to improve the conservation of the species in the context of recovery, reintroduction, and population control (Hoffmann et al., 2015; IUCN/SSC, 2021).

Translocation of wildlife as a means of managing populations is now a common practice that has been adopted as a management tool all over the world (Hoffmann et al., 2015). Even though they are commonly applied to manage wildlife populations, they are a high-cost strategy (Berger-Tal et al., 2020).

Translocation is usually considered ideal when managing high elephant densities (Balfour et al., 2007). Several countries, including Kenya, Botswana, South Africa and Zimbabwe, have been involved in elephant translocation locally and internationally as a conservation approach to managing elephant populations (Pinter-Wollman, 2012). In Sri Lanka, translocation has been the main approach adopted to manage cases of human-elephant conflict (Fernando et al., 2011; Fernando et al., 2012), while in the Mid-Zambezi Valley, more than 200 elephants have been translocated into the region from Save Valley Conservancy as a measure to manage high elephant densities. Therefore, post-translocation monitoring should be undertaken to maintain population estimates within acceptable carrying capacities (Balfour et al., 2007).

1.4.5 Home range establishment

An animal's home range is the area where it lives, performing its daily activities to meet its survival needs (Burt, 1943). It can also be defined as a sub-space of activity territory encompassing frequently visited points that are easily accessible from the inhabitant's home (Hasanzadeh et al., 2017). Other literature states that the home range is not the entire area where an animal moves, but it includes the area where the animal usually moves within the period under study (White and Garrott, 1990). Therefore, in this study, the definition of home range was borrowed from Burt (1943), who stated that home range is an area used by an individual during its normal activities, including but not limited to foraging, mating, and predator avoidance.

1.4.6 Factors affecting home range establishment

Distribution patterns of African elephants are significantly influenced by the season, which regulates surface water and forage availability and distribution (Redfern et al., 2003). However, different studies argue about how the seasons affect the size of elephant home ranges. For example, Loarie et al. (2009) discovered that elephant herds usually stay within 10 km^2 of permanent water sources during the dry season when forage is available. African lephants tend to choose riparian habitats that provide various resources such as water, feed, and shade (Shannon et al., 2006). Therefore, this may influence the home

range patterns being centred around water sources (Loarie et al., 2009). On the contrary other researchers suggested a different view, noting that during the wet season, elephants tend to explore smaller habitats compared to the dry season, when elephants expand their territory by travelling further in search of food and water (Osborn, 2004). Indeed, during the rainy season, both food and water are readily available, farming is much more intensive, and elephant habitat would correspondingly appear to be reduced. A study in the Mid-Zambezi Valley that determined habitat use by African elephants found that elephant home ranges in areas with high food quality were smaller (94 km^2) than in areas with poor food quality (263 km^2) (Dunham, 1986).

Human disturbance is another factor affecting elephant habitat size and movement patterns. Elephants may reduce their movement patterns, exploratory movements, and home range size due to increased human disturbance (Beirne et al., 2021). This suggests that human disturbance creates a landscape of fear for elephants, which in turn affects the establishment of their home range (Tucker et al., 2018). Other impacts of human disturbance on elephants, especially near human settlements and infrastructure, include increased vigilance, reduced foraging, or increased restlessness. (Kumar and Singh, 2011; Szott, 2020; Keil, 2022).

Man-made landscape barriers, such as roads, and natural barriers, such as rivers, also affect the movement patterns and foraging routes of both small and large mammals (Johnson et al., 2002; Robert and St. Clair, 2004). Such barriers restrict animal movement patterns by preventing free roaming into adjacent areas (Bauman et al., 1999). In addition, roads create obstacles that may restrict wild animals' free movement because of the noise and traffic associated with them (Laurance et al., 2006; Vanak et al., 2010), forcing animals to avoid them and stay within confined areas (Hayward and Kerley, 2009). Barriers not only prevent animal dispersal and limit movement between spaces but can also create multifaceted pathways that may affect animal movement patterns (Stamps et al., 1987).

Hunting is another factor that also affects the movement of elephants. In response to hunting events, wildlife often exhibits a variety of behavioural responses that may include outright avoidance of the hunting area, changes in diet, increased use of vegetation, or changes in the core area used in the home range (Millspaugh et al., 2000; Burke, 2008; Granados et al., 2012). In addition, wild animals' responses to hunting effects may vary from one individual to the next, as some animals may avoid open grass, avoid human activity, or avoid hunting areas altogether and move into areas where hunting is not conducted (Harris et al., 2008; Graham et al., 2009). Galanti et al. (2006) identified female

elephants as exhibiting this behaviour. This indicates that elephant movement patterns are affected by areas where hunting is practiced.

Elephant sex is one of the factors affecting individual differences in habitat selection. Poole et al. (1988) found that males migrate and disperse for longer distances in search of mates compared to females, who tend to stay with their young in a herd. Thus, males are more likely to display a larger home range than females because they explore more widely, while female movement patterns are limited by the mobility of their offspring or herd (Foley, 2002).

In addition, the physical condition of an animal is another factor that has been reported to suggest individual differences in movement patterns (Kays et al., 2015). Literature has documented that fitness level (body condition) may affect the movement behaviour of an individual in terms of the ability to find resources, mate, and survive (Owen-Smith et al., 2010; Kays et al., 2015). Additionally, individual variation is often advocated for by conservationists, who are of the view that it facilitates the coexistence of multiple individuals by reducing competition for resources in the same landscape (Araujo et al., 2011).

Age and experience are also factors that control the social and spatial information of elephants, as old elephants have been proposed to be repositories of information (McComb et al., 2001; Evans and Harris, 2008). McComb et al. (2001) used breeding experiments on African elephants to show that the increased discrimination ability of the elephant matriarch can influence the social behaviour and movement pattern of the group. This indicates that older matriarch elephants are repositories of information and, in some cases, may possess experience that they may use to influence the whole group, especially if they are female matriarchs, by influencing their spatial behaviour and patterns.

1.5 Predictions

1. Translocated female African elephants use a larger home range and core areas during the early months' post-translocation as they explore the new environment, while their home range and core area will become larger within the two-year study period as they settle into the new environment.
2. Translocated female African elephants will show some individual variation in patterns of exploration, with some displaying more linear home range patterns than others because of their different exploration intensities.

Chapter 2: Materials and Methods

2.1. Study areas

2.1.1 Source site: Save Valley Conservancy (Sango Ranch)

Sango Ranch is located in the Save Valley Conservancy, Masvingo Province, situated in the south-eastern lowveld of Zimbabwe. Sango Ranch is composed of four properties, namely Chapungu, Musawezi, Sabi, and Chanurwe (Figure 1), and it covers an area of 600 km^2. Of the four properties, only Chapungu is reserved for photographic tourism, and no form of legal hunting is allowed there. The mean annual temperature ranges from 16°C to 22.5°C, with October being the hottest month. Like most high-seasonal semi-arid ecosystems, surface-water availability varies greatly, as in the wet season surface water is available and dries up in the dry season, particularly in September and October (Joubert, 2013).

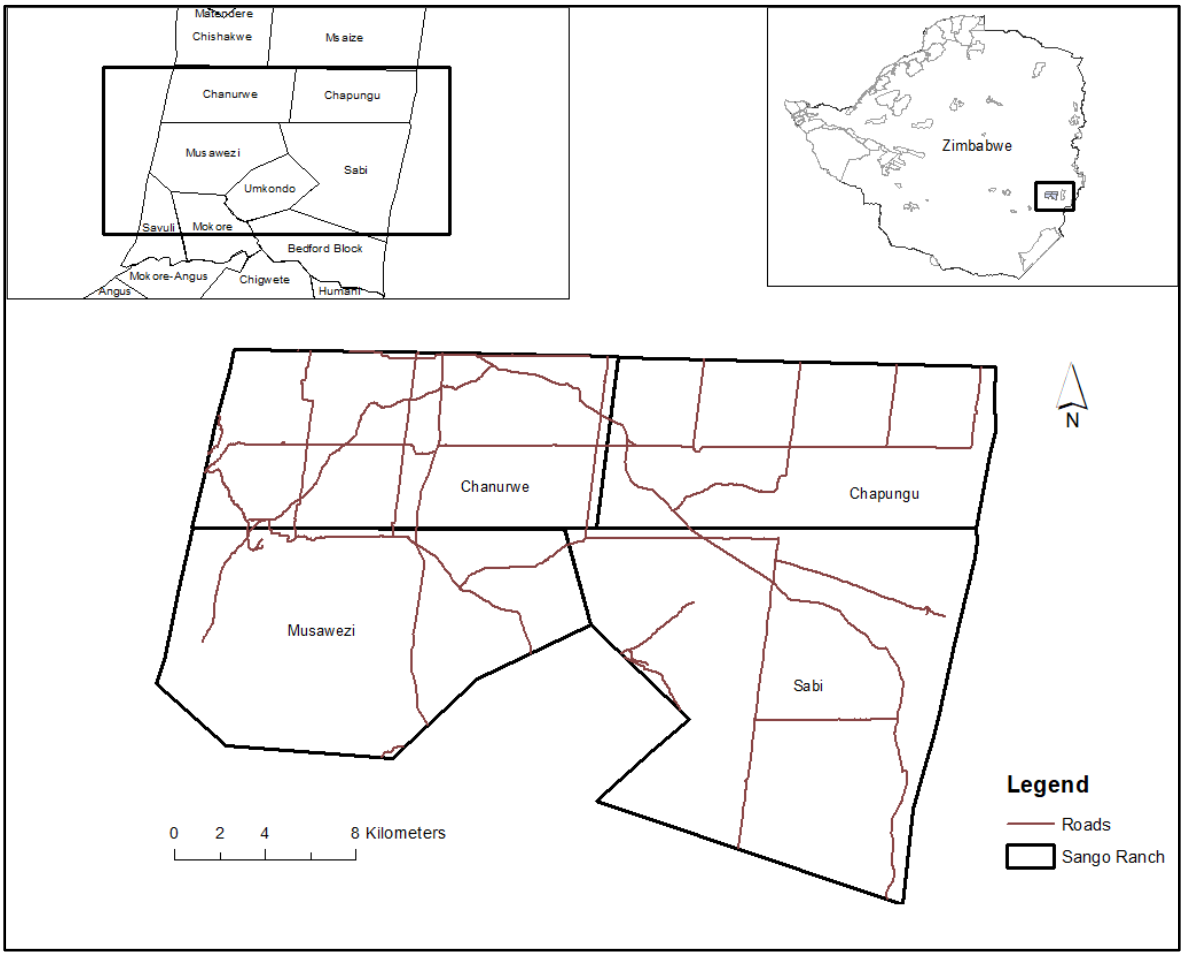


Figure 1: Map of Sango ranch in Save Valley Conservancy, Zimbabwe **.**

2.1.2 Release site: Hurungwe Safari Area (Rifa)

The study was conducted in Hurungwe Safari Area (HSA), located in the Mid-Zambezi Valley Region, northern Zimbabwe. It covers an area of 2 956 km2 and is divided into two protected areas: Nyakasanga, which is 1 136 km2 on the east of the A1 highway, and Rifa, which is 619 km2 on the west of the A1 highway (Figure 2). Hurungwe Safari Area borders Mana Pools National Park to the east and Charara Safari Area to the south. To the north and west, the park is bordered by the Zambezi River. The area experiences two separate seasonal conditions, characterised as the dry season (May to October) and the wet season (November to April). The mean annual temperature ranges from 18°C in the wet season to 38°C in the dry season with an average annual rainfall of 768 mm (Sibanda et al., 2016; Ngorima et al., 2022).

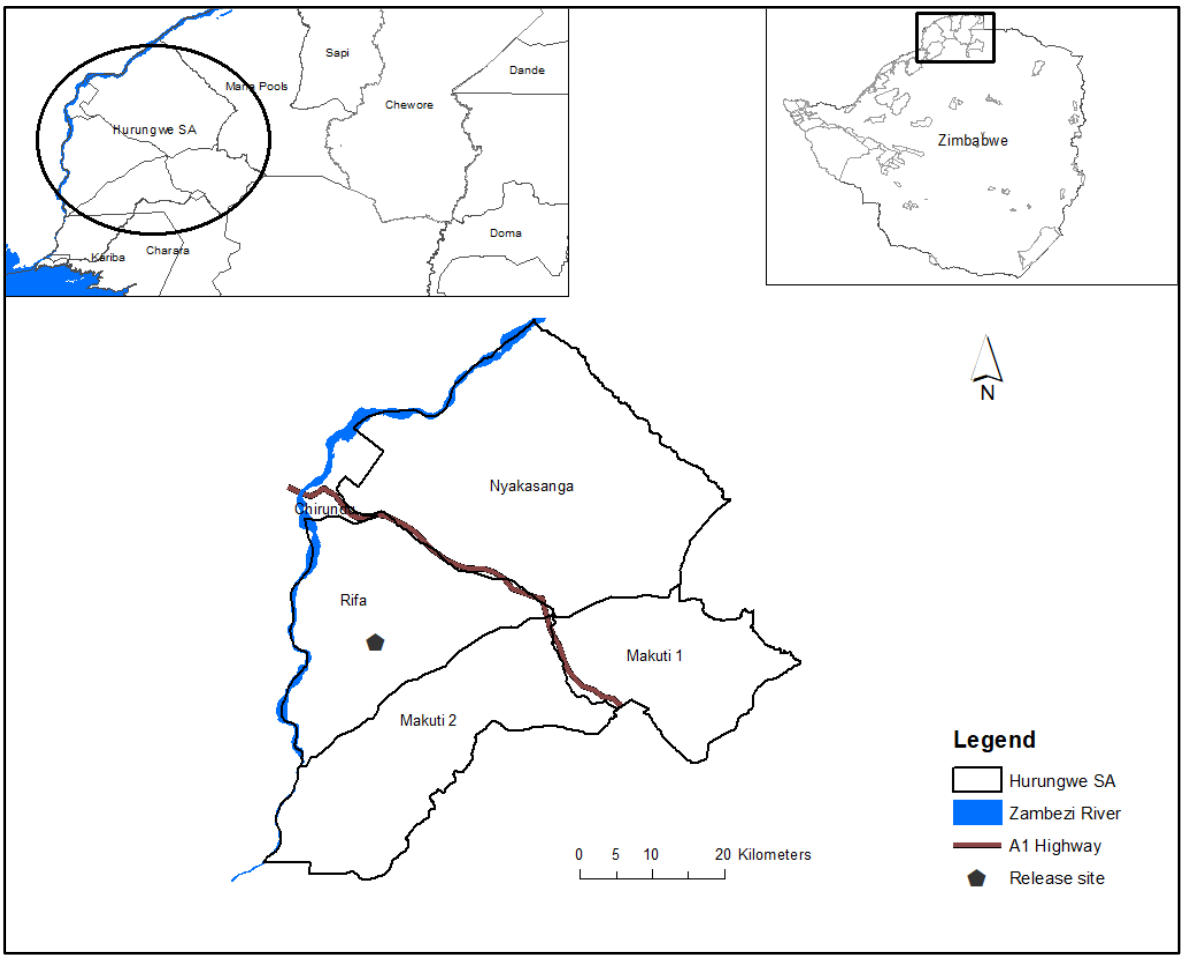


Figure 2: Map of Hurungwe Safari Area in the mid-Zambezi valley region, Zimbabwe.

2.2. Field Data collection

2.2.1 Elephant translocation

A total of 100 African elephants were translocated from Save Valley Conservancy in the south-eastern Lowveld to Hurungwe Safari Area in the Mid-Zambezi Valley between September 14 and October 15, 2018. The translocation was conducted by Deock Trading (PVT) Ltd t/a African Wildlife Management and Conservation (AWMC), funded by Rhino Force Zimbabwe. The elephants were released using the "hard release" method, i.e., they were released in a boma and monitored for 4 to 5 hours before being allowed to walk directly into the park. The elephants were collared using the GPS collars (Africa Wildlife Tracking (AWT) Inc., Pretoria, South Africa) that were programmed to automatically record elephant coordinates every hour. Data were transmitted to the Africa Wildlife Tracking Cloud via an Inmarsat satellite network for each successfully recorded elephant location.

2.2.2 Data collection

A total of 12 elephants were collared in Hurungwe Safari Area following translocation. However, of the 12 elephant collars, three had some technical faults that affected the quality of the data collected. Hence, in this study, only data coming from nine matriarchs was used, from nine different herds totaling 77 individuals. In Hurungwe Safari Area, where the study was conducted, resident elephants were also there, but they were not collared, hence they could not be used for the study. In addition, elephant matriarchs were purposively collared with the aim of understanding the movement patterns of the elephant herds. Since the elephant matriarchs belonged to different herds and elephant herds moved together, I assumed that the movements represented the whole herd. Data from the Africa Wildlife Tracking Cloud was downloaded every month for the entire 20-month study period. The elephants were collared at different intervals. Hence, the data used varied from one elephant to the next (Table 1).

Table 1: Summary of tracking periods on nine matriarch African elephants translocated to Hurungwe Safari Area, Zimbabwe, which were collared with Africa Wildlife Tracking (AWT) GPS collars recording hourly locations

Elephant name	Herd size	Date of first GPS fix	Date of last GPS fix	Overall tracking duration	Number of usable GPS fixes
Anna	10	16/10/2018	29/05/2020	19 months 13 days	14 137
Hanna	8	15/09/2018	29/05/2020	20 months 14 days	14 752
Kristin	8	08/10/2018	29/05/2020	19 months 21 days	14 104
Lorraine	7	26/09/2018	29/05/2020	20 months 2 days	14 498
Lucie	9	22/09/2018	29/05/2020	20 months 7 days	14 462
Rita	10	29/09/2018	29/05/2020	20 months	14 537
Spiwe	7	12/10/2018	29/05/2020	19 months 17 days	14 189
Tendai	10	02/10/2018	29/05/2020	19 months 27 days	14 432
Tracey	8	21/09/2018	29/05/2020	20 months 8 days	14 601

2.2.3 Data analysis

The GPS positions were reprojected from their native coordinate systems, the World Geodetic System (WGS-84 ellipsoid), to a projected coordinate system (WGS-Universal Transverse Mercator (UTM) Zone 35s), to ensure accurate geometry estimations using ArcGIS 10.8 (ESRI, 2021). All locations were used to calculate the monthly 50% (core area) and 95% (utilisation area) home range size using the fixed Kernel Density Estimator (KDE) method for each individual (Getz et al., 2007). All home range analyses were executed using R Statistical Software (version 4.1.0; R Core Team 2021). I conducted the Generalised Linear Mixed Model (GLMM) in lme4 (Bates et al., 2015). In addition, to compare the translocated female African elephant home range establishments at the population level, the monthly 50% and 95% KDEs were used to run a Linear Regression Model (LRM). The model had monthly individual home range size at 50% and 95% as the dependent variables and variation between individuals and month from release as the independent variables.

I went further to compare the individual differences using the Generalised Additive Model (GAM), using monthly home range extent at 50% and 95% as the dependent variables, time in months, and elephant IDs as independent fixed effects. I used GAM because it allows to determine non-linear relationships. The β coefficient values of the model outputs and the confidence interval of the coefficients were used to establish the effect and significance of time on the change in home range extent for the female translocated elephants. A post-hoc test of the pair-wise comparisons of 50% and 95% KDE home range temporal patterns of nine female African elephants was also conducted to identify exactly which female elephant home range sizes differ from each other, with Ann being used as the reference level since she was mentioned first using alphabetical order (Figure 3).

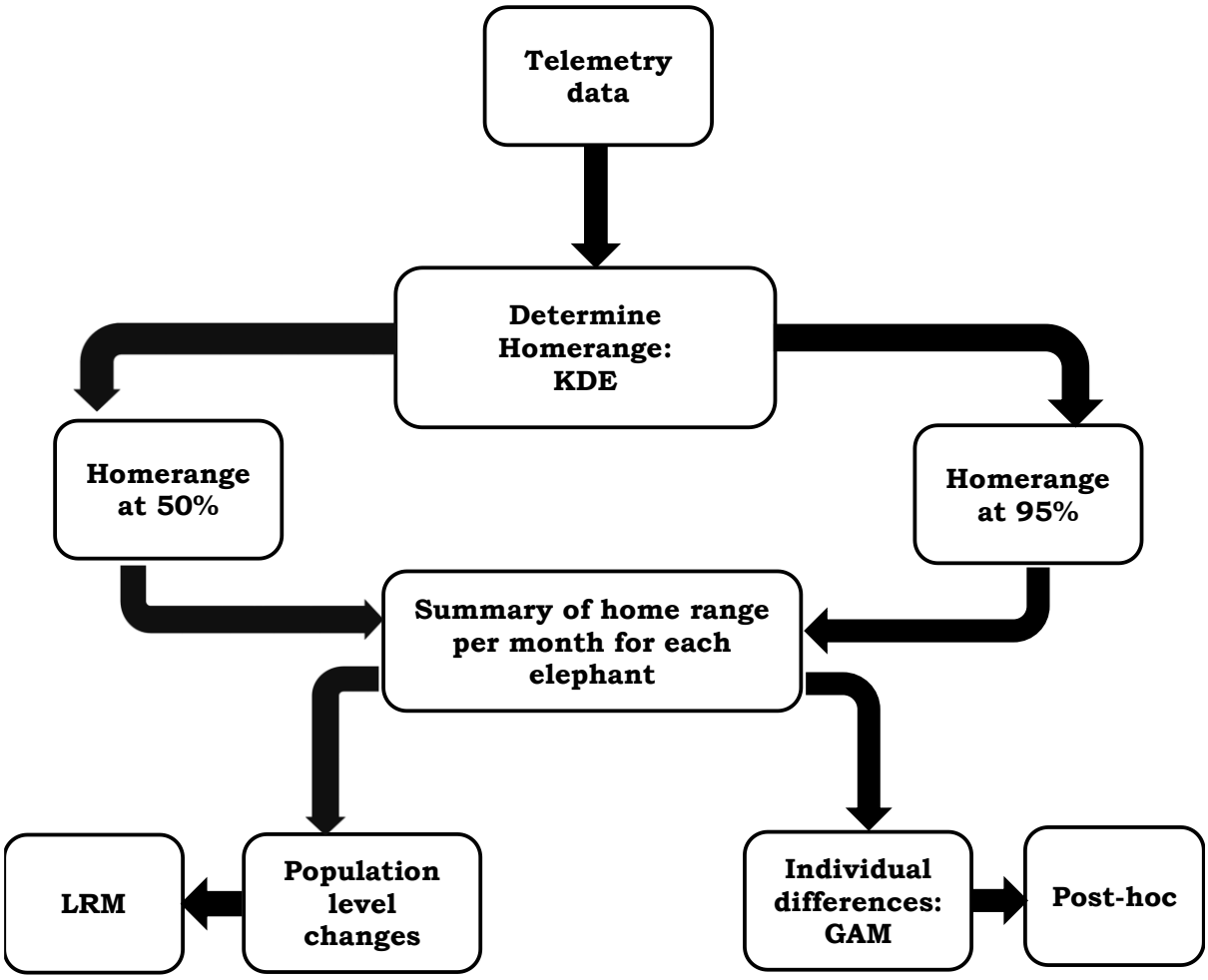


Figure 3: The workflow displays the steps taken in the data analysis process to calculate home range establishment patterns for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe.

Chapter 3: Results

3.1 First Prediction: Population level

The results at 95% KDE home range size indicated that the largest average home range size among individuals per month was recorded in the wet season with 1067 km^2 in month seven as compared to the dry season with 854 km^2 in month thirteen (Appendix 2). However, the results for the 50% KDE over the 20-month study period revealed that individual elephants' home range sizes ranged from 17 km^2 to 530 km^2, showing a large variation (Appendix 1).

According to the results of the linear regression model (Table 2), translocated female African elephants' 95% home range size tended to increase as time (months) since release went by (Figure 4A) although the increase was not statistically significant (Table 2). Interestingly, the size of the 50% home range decreased as time (months) passed since the initial release (Figure 4B), but it was also not significant (Table 2).

Table 2: Results of linear regression models comparing the 95% home range size and the core 50% home range size for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe, over 20 months since release

Linear regression model	Home range size	Estimate	Standard Error	T-value	P-value	R^2-value
95 % Home range	Intercept	678.985	105.055	6.463	< 0.001 ***	
	Month since release	15.435	8.954	1.724	0.087	0.017
50 % Home range	Intercept	130.063	11.671	11.144	< 0.001 ***	
	Month since release	-1.846	0.995	-1.856	0.065	0.019

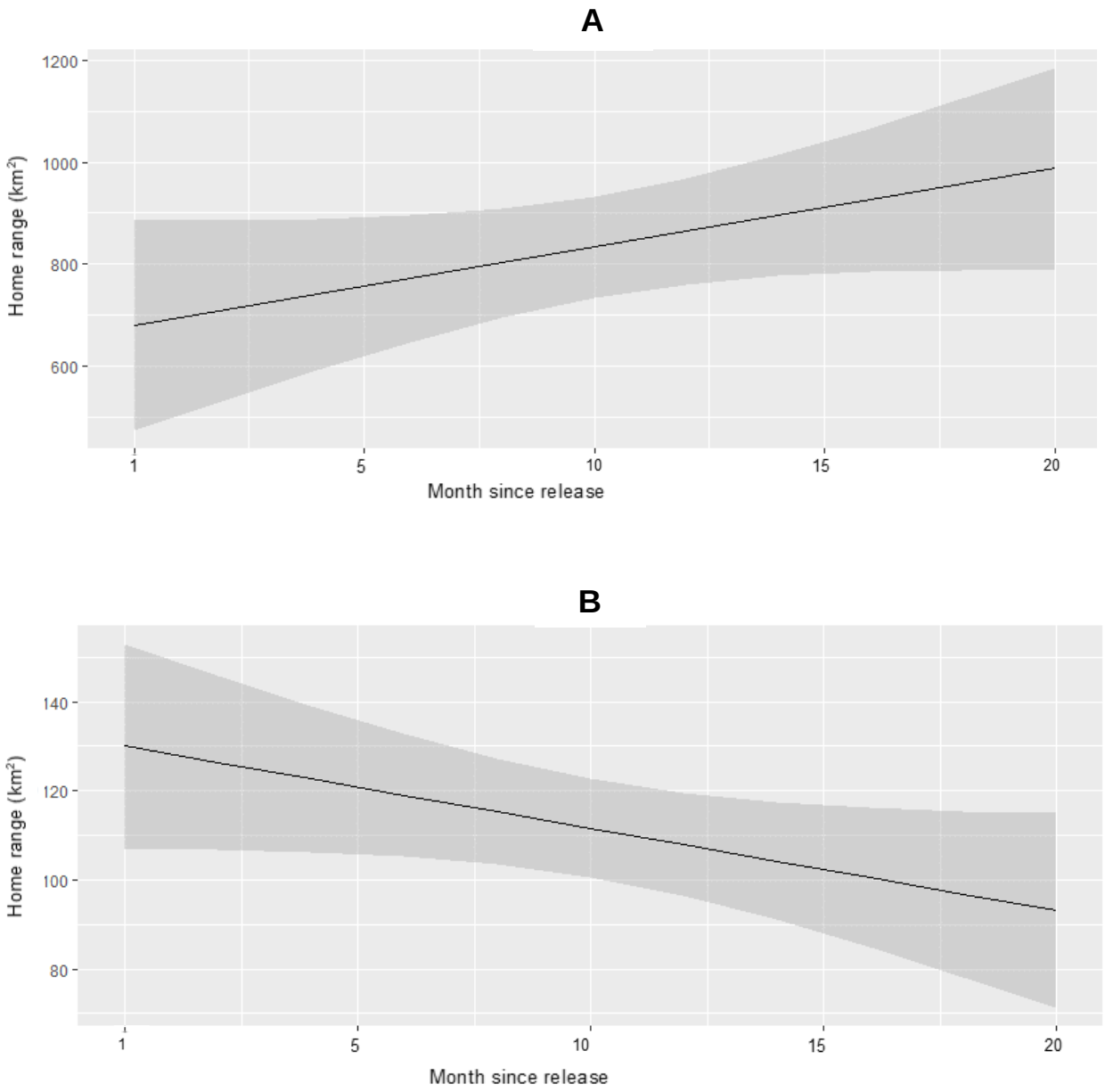


Figure 4: Predictive margins with 95% confidence intervals (CIs) for the results of the linear regression model for the association between home range size (km^2) for the (A) 95% isopleth (area) and (B) 50% isopleth (area) across months since initial release for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe.

3.2 Second Prediction: Individual variations (95% GAM)

The generalised additive model explained 97% of the variance within the dataset. All translocated female African elephants had monthly home range patterns that were significantly different from Ann's, whose home range patterns were used as the reference level (Table 3).

Ann and Rita showed similar utilisation home range patterns, as both had a steady initial increase followed by a stabilisation (Figures 5 and 6) and non-significant non-linear relationships between the home range size and time since release (Table 4). Both of these elephants' home ranges were limited to the Rifa conservation area, where they were released and stayed for the entire study period, with Rita's home range being consistently smaller than Ann’s home range (Figure 5).

Lorrain and Tracey also had similar temporal monthly home range patterns (Appendix 3), with Lorrain showing a strong, significant non-linear relationship between home range extent and time, while Tracey explored a highly non-linear exploration pattern. Moreover, they were both mostly limited to the Rifa conservation area where they were first released (Figure 5). Both showed excursions further north in the Nyakasanga conservation area after month 13 of translocation, with Lorraine’s home range pattern being consistently larger than Tracey’s (Figure 6).

While Spiwe and Tendai had excursions northwest into Mana Pools National Park (Figure 5), they also showed a strong non-linear significant relationship between home range size and time since release (Table 4 and Appendix 3). Spiwe and Tendai's utilisation home range pattern peaked at month seven post-translocation, as shown by the red colour, followed by a steady decline (Figure 6).

Lucie was the only elephant with a home range that extended north of the Sapi Safari Area (Figure 5). She also exhibited a strong non-linear exploration pattern. A significant difference was observed in her home range extent compared with that of Rita and Tracey (Appendix 3).

Hanna and Kristin were the two elephants with the largest home ranges (Figure 6), and both had strong temporal complexity in home range patterns (Table 4). Furthermore, they were the only two elephants whose home range included the Chewore Safari Area, with Kristin also travelling south and using a portion of the Charara Safari Area (Figure 5).

Table 3: Generalised Additive Model results comparing the temporal 95% home range patterns of nine female African elephants translocated to Zimbabwe's Hurungwe Safari Area. Ann was used as the reference category.

Elephant name	Estimate Std.	Standard Error	T-value	P-value
Ann (intercept)	451.34	24.22	18.632	< 0.001 ***
Hanna	1208.19	33.83	35.711	< 0.001 ***
Kristin	1551.40	34.82	44.559	< 0.001 ***
Lorraine	-72.15	33.82	-2.134	0.035 *
Lucie	467.28	33.84	13.808	< 0.001 ***
Rita	-142.88	34.25	-4.172	< 0.001 ***
Spiwe	193.90	34.32	5.651	< 0.001 ***
Tendai	435.74	33.84	12.876	< 0.001 ***
Tracey	-121.65	33.81	-3.598	0.000 ***

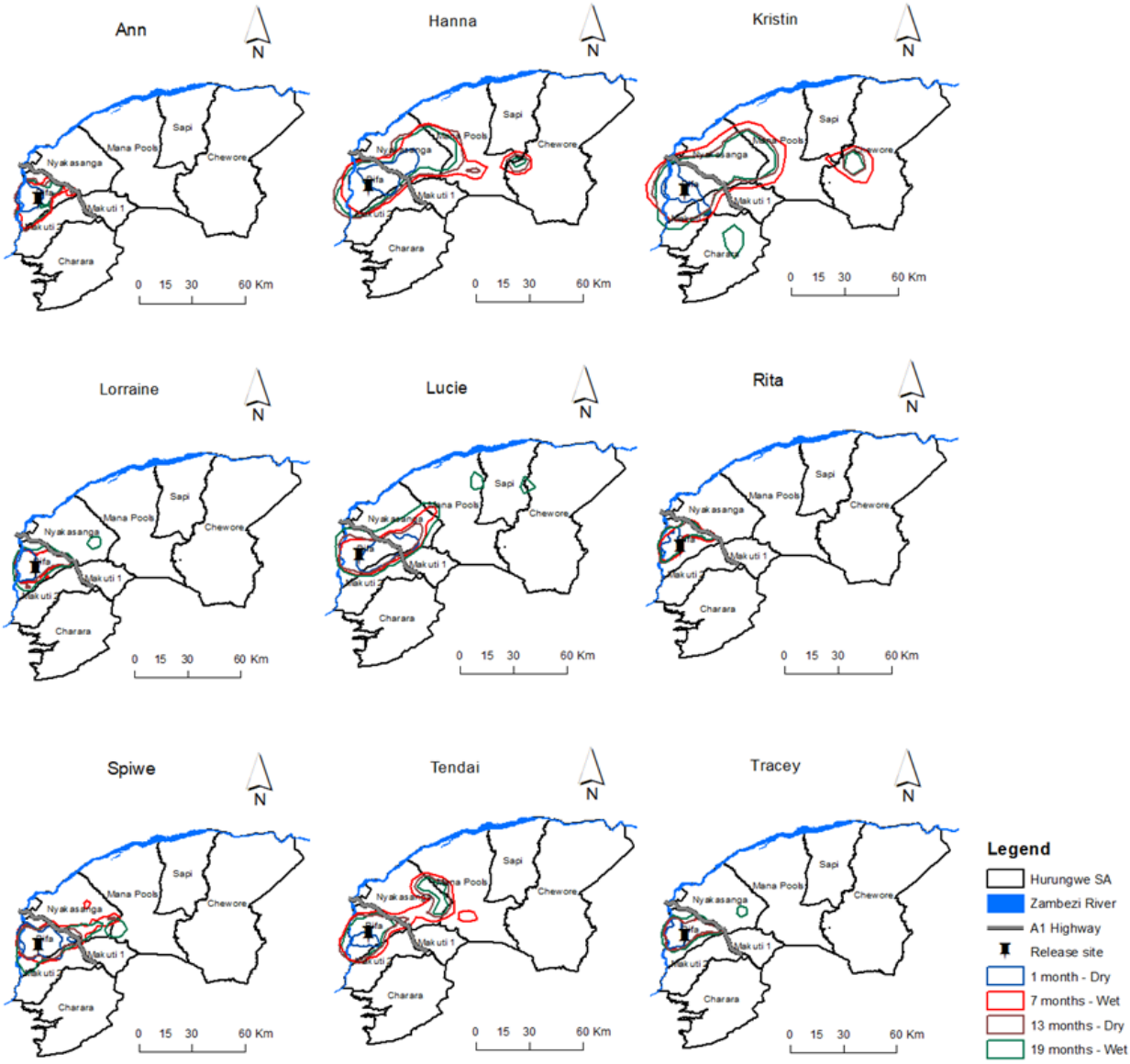


Figure 5: Temporal trends in the monthly home range pattern at 95% KDE of nine female African elephants translocated to Hurungwe Safari Area. The results are presented at six-month intervals from the initial month of translocation.

Table 4: The smoothing factors from the GAM explaining the linearity and complexity of the relationship at 95% KDE for change in home range extent over time for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe. Non-linear relationship: 1 < edf ≤ 2; strong non-linear relationship: edf > 2.

Elephant name	Effective degrees of freedom (edf)	Reference degrees of freedom	F-value	P-value
Ann	2.236	2.785	2.845	0.070.
Hanna	4.968	6.056	78.243	< 0.001 ***
Kristin	7.834	8.616	107.597	< 0.001 ***
Lorraine	2.938	3.653	3.235	0.021 *
Lucie	6.368	7.515	17.471	< 0.001 ***
Rita	1.989	2.481	1.151	0.425
Spiwe	3.472	4.297	4.809	0.001**
Tendai	6.233	7.387	27.668	< 0.001 ***
Tracey	2.621	3.262	1.833	0.143

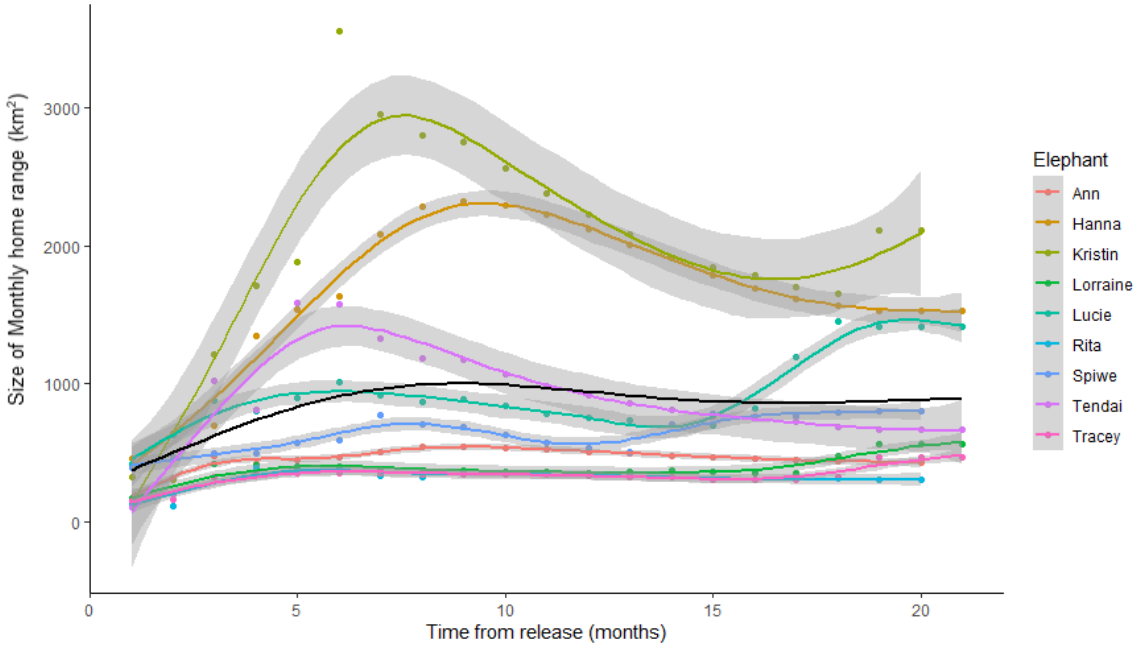


Figure 6: Change in monthly home range extent (km^2) over time (months) at (95% KDE) of nine female African elephants translocated to Hurungwe Safari Area in Zimbabwe from the initial month of introduction.

3.3 Second Prediction: Individual variations (50% GAM)

The generalised additive model explained 96.6% of the variance within the dataset of the individual translocated female African elephants at a 50% confidence interval. The majority of the translocated female African elephants had home range patterns that were significantly different from Ann, whose home range was used as the reference, except for Spiwe and Tendai (Table 5).

All the translocated female African elephants had a non-linear relationship between change in home range extent and time, though for Lorraine and Tracey, this was not statistically significant (Table 6). This is also exhibited by their core home range pattern maps, which showed that their home range extent peaked at month seven, followed by a steady decline in the later months (Figure 8). Of all the translocated female elephants, Kristin had the most complex core home range pattern (Table 6 and Figure 8).

Ann, Lorraine, Tendai, and Tracey showed similar utilisation home range patterns in terms of areas where they were found, as their core home ranges were all limited to the Rifa conservation area, where they were released, for the entire two-year study period (Figure 7). However, their core home range temporal patterns were not the same, with Ann and Tracey differing (Table 8). Specifically, Tracey had a smaller core home range extent than the others (Figures 7 and 8).

Kristin, Lucie, Rita, and Spiwe were the other translocated female African elephants to have travelled north-east and east of Rifa along the A1 highway, which is the main tarred road from Harare to the Chirundu border, passing through the two conservation areas of Rifa and Nyakasanga (Figure 7). However, their temporal patterns of utilisation varied between the different individuals (Appendix 4).

The home range patterns for Hanna and Kristin showed that they both moved in the same direction, west of the Rifa conservation area, and were the only two translocated female African elephants to have crossed the Zambezi River (Figure 7). However, there were significant differences between Hanna and Kristin's temporal home range patterns (Appendix 4). Of interest is the fact that Kristin crossed the Zambezi River in month seven, while Hanna crossed in month 13 (Figure 7).

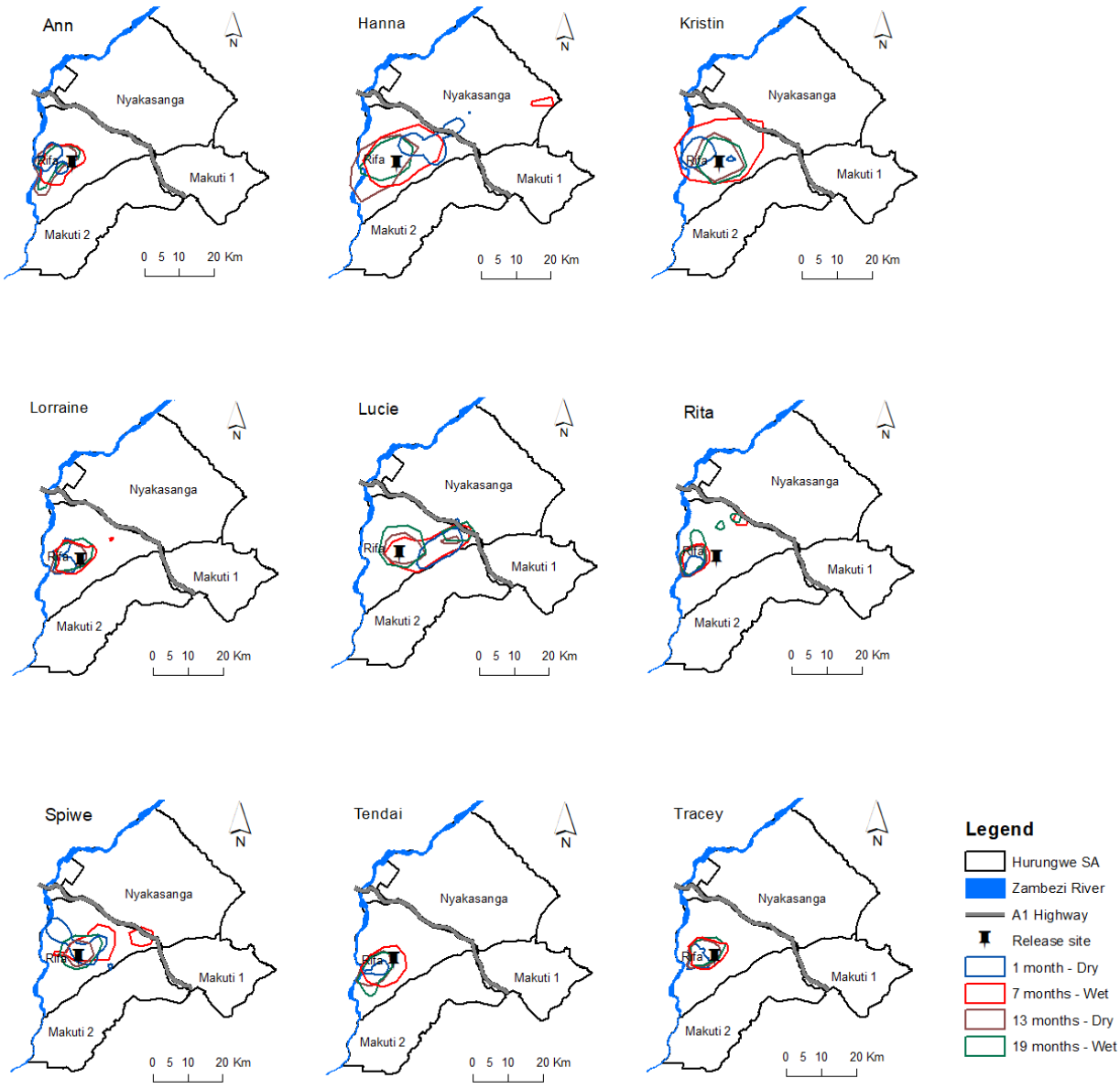


Figure 7: Temporal trends in the monthly home range pattern at 50% KDE of nine female African elephants translocated to Hurungwe Safari Area. The results are presented at six-month intervals from the initial month of translocation.

Table 5: Generalised Additive Model results comparing the temporal 50% home range patterns of nine female African elephants translocated to Zimbabwe's Hurungwe Safari Area. Ann was used as the reference category.

Elephant name	Estimate Std.	Standard Error	T-value	P-value
Ann (intercept)	88.716	3.032	29.263	< 0.001 ***
Hanna	111.589	4.231	26.374	< 0.001 ***
Kristin	112.446	4.381	25.668	< 0.001 ***
Lorraine	-20.127	4.230	-4.758	< 0.001 ***
Lucie	47.357	4.232	11.190	< 0.001 ***
Rita	-30.529	4.298	-7.104	< 0.001 ***
Spiwe	7.992	4.309	1.855	0.066 .
Tendai	-7.949	4.232	-1.878	0.063 .
Tracey	-28.103	4.229	-6.645	< 0.001 ***

Table 6: The smoothing factors from the GAM model explaining the linearity and complexity of the relationship at 50% KDE for change in home range extent over time for nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe. Non-linear relationship: $1 < edf \leq 2$; strong non-linear relationship: $edf > 2$.

Elephant name	Effective degrees of freedom (edf)	Reference degrees of freedom	F-value	P-value
Ann	2.895	3.596	6.554	0.000 ***
Hanna	5.230	6.347	72.381	< 0.001 ***
Kristin	8.645	8.958	178.495	< 0.001 ***
Lorraine	3.833	4.737	2.085	0.065 .

Lucie	6.520	7.656	20.166	< 0.001 ***
Rita	4.340	5.324	3.622	0.004 **
Spiwe	5.443	6.551	9.451	< 0.001 ***
Tendai	6.098	7.255	10.915	< 0.001 ***
Tracey	3.369	4.178	1.821	0.120

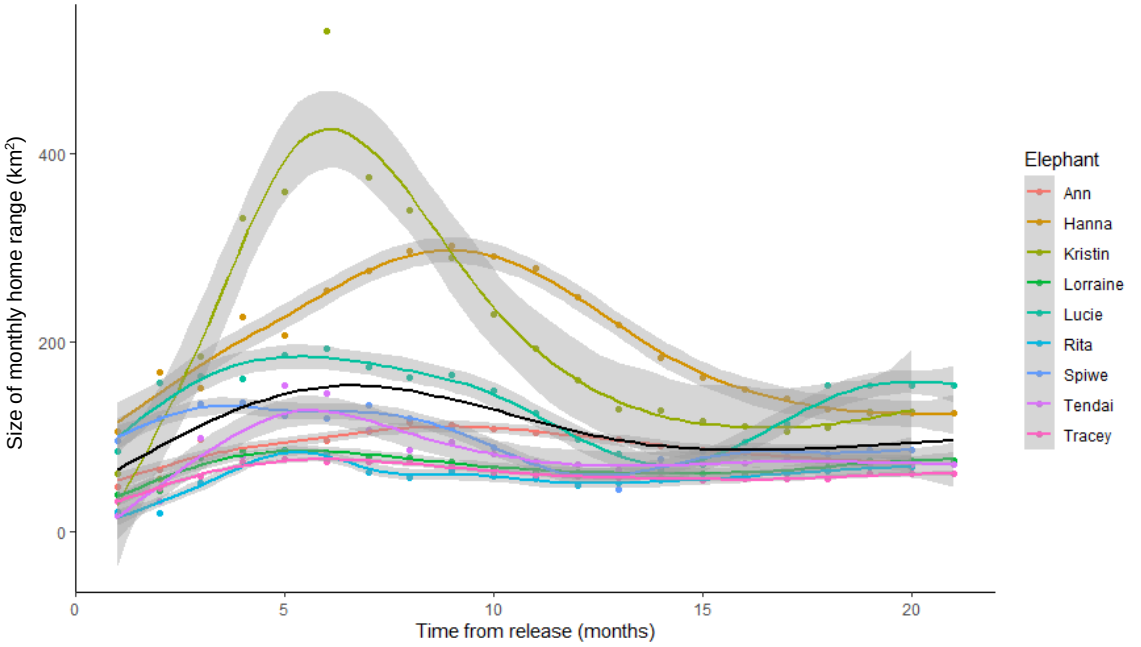


Figure 8: Change in monthly home range extent (km^2) over time (months) at (50% KDE) of nine female African elephants translocated to Hurungwe Safari Area in Zimbabwe from the initial month of introduction.

Chapter 4: Discussion

In this study, I sought to investigate the home range establishment of nine female translocated African elephants in the Hurungwe Safari Area, Zimbabwe. At the population level, the translocated female African elephants gradually increased their 95% home ranges over time as they explored the area. Instead, they used a wider core (50%) home range during the early months following translocation as they explored the new area, then their core home range decreased before month ten and seemed to have become more stable after month twelve as they settled into their new environment.

Contrary to the 50% KDE and contrary to what I had hypothesised, translocated female African elephants use a wider home range during the early months' post-translocation as they explore the new environment, while their home range will become more established within the two-year study period as they settle into the new environment. The results for the 95% KDE home range sizes seem to have slightly increased over time since their release. Some of the elephants' home range patterns expanded to cover areas west of Rifa along the Zambezi River. This may be due to the effect of the season on the initial release. The elephants were translocated in September and October, which are dry-season months in the savanna ecosystem. In addition, before the elephants were translocated to Rifa, a site suitability assessment was conducted to ascertain habitat suitability, and forage of good quality and water were available at the release area (Ngorima and Ngwenya, 2018). The results from the assessment showed that the release site presented adequate resources, including water, and suitable forage quality because of the riverine vegetation along the Zambezi River, while there was limited forage in most parts of the protected area and some inland pans had dried out due to the dry season. Hence, the translocated elephants might have stayed close to the release site and utilised the western side of Rifa, where water was, along the Zambezi River. Previous studies have shown that season influences home range patterns and habitat use, with smaller home ranges observed in the dry season than in the wet season (Cushman et al., 2005; Ross, 2016; Ashiagbor and Danguah, 2017). The findings from this study are consistent with previous research on savanna elephant home ranges (Western et al., 1984; Ross, 2016), showing that during the dry season, African elephants will be concentrated in areas where water is available and expand their range during the wet season.

As I had hypothesised, for the 50% (core range) at the population level, the overall translocated female African elephants' home range sizes seemed to gradually decline

over time, though this result was not statistically significant. Changes in home range size may therefore represent a change in search intensity, from large-scale search in the early stages of release to smaller-scale search as the elephants became more familiar with their environment. This can be attributed to the capture, translocation, and release processes. Indeed, previous studies have shown that the whole process elephants endure during a translocation has the potential to influence their behaviour upon release in a new environment (Garnier et al., 2021). Experiencing the translocation process might lead to longer-distance movements as the elephants search for suitable areas in which to settle upon release. The observed large home range size of 130 km2 upon release observed in this study (Figure 4) may also be attributed to 'homing'. Homing, which is an attempt by translocated species upon release in a novel environment to return home, will most likely result in home range sizes being highest upon release and declining over time as the elephants settle in the new environment (Fernando et al., 2012). This is a common feature for mammals following translocation and has been recorded in previous studies (Matsumura et al., 2011; Fernando et al., 2012).

In my study, at 95% KDE, the average mean monthly home range size revealed that the largest average home range size among individuals per month was recorded in the wet season with 1067 km^2 in month seven as compared to the dry season with 854 km^2 in month thirteen. Similar observations were made by Ngene et al. (2017), with female elephants recording a larger mean home range during the wet season compared to the dry season, with 430 km^2 and 143 km^2, respectively, suggesting that home range sizes of female elephants are larger in the wet than the dry season.

However, the home range sizes of the elephants were not the same throughout the study. As hypothesized, these translocated female African elephants showed individual differences among their exploration patterns, with some displaying more linear home range patterns than others. This may be attributed to differences in body condition since individual body condition has been suggested to influence movement behaviour and patterns of exploration to find resources, survive, and reproduce (Kays et al., 2015). Elephants with healthier body conditions are likely to disperse more, hence covering a larger home range than others (Debeffe et al., 2012). Moreover, the age and experience of elephants may govern their social and spatial knowledge, which also has the potential to influence their movement patterns (Evans and Harris, 2008), with translocated adult mammals generally covering a larger home range as compared to juveniles (Ryckman et al., 2010). However, in this study, all the collared elephants were adult females, so age might have had a minimal contribution. In addition, the elephants were translocated into

an area that was new to them. Therefore, the different individuals did not have more knowledge of the area when compared to one another, but I suppose that they did have different levels of knowledge based on their past experiences. It has been suggested that adult elephants are information repositories; hence, their knowledge and experience may guide their decision-making (McComb et al., 2001). As such, this might explain the observed individual variation in the linear and erratic patterns of exploration.

The results for the 50% KDE over the 20-month study period revealed that individual elephants' home range sizes ranged from 17 km^2 to 530 km^2, showing a large variation. The results are within the general home range size of elephants that were studied by Dunham (1986) in the same environment (Mid-Zambezi Valley). In his study, he observed that home range sizes also had a wide variation between individuals, ranging from 94 km^2 to 263 km^2. Similar results showing high individual variation were also reported in southern and central Kenya and in northern Tanzania, where they recorded home range sizes ranging from 11 to 5520 km^2 and 191 to 3698 km^2 respectively (Douglas-Hamilton et al., 2005; Kikoti, 2009).

Among the nine female elephants, Hanna was the only one to have explored and utilised areas west of Nyakasanga, while Kristin, Spiwe, Lucie, and Rita only utilised areas along the edge, and no elephants utilised Makuti 1 and 2 conservation areas. This may be attributed to the fact that Hurungwe Safari Area, which forms the study area, is divided into four sections: Rifa, Nyakasanga, Makuti I, and Makuti II, with Rifa acting as the source area since there is no hunting. Hunting is indeed one of the factors known to affect elephants' home range patterns (Burke et al., 2008), and it is also still conducted in Sango Ranch, where these elephants were translocated from. It has been argued that animals may respond to hunting pressure by avoiding areas where hunting is conducted (Harris et al., 2008; Graham et al., 2009). Therefore, this might have influenced the elephants' behaviour in the study to avoid using Makuti 1 and 2 areas.

The differences in distribution patterns among the nine elephants noticed within this study may also, in part, be attributed to the A1 highway. Roads are known to impede animal movement patterns by prohibiting free roaming in adjacent areas (McDonald and St. Clair, 2004; Jaeger et al., 2005). In addition, Hayward and Kerley (2009) suggest that the potential impact of roads on animal behaviour and movement patterns is a subject of concern because they cause habitat fragmentation. Studying the individual home range maps, it is evident that the majority of the elephants at 50% KDE never crossed the A1 highway (Makuti to Chirundu), which cuts in between the Rifa and Nyakasanga areas.

The A1 highway is usually busy with heavy vehicles (trucks) from South Africa and the DRC to Zambia (Chirundu border) (pers.obs). Major highway roads may create barriers that may impede wild animals from freely roaming because of the noise and traffic associated with them (Laurance et al., 2006; Vanak et al., 2010). Therefore, some elephants might have deliberately avoided crossing into Nyakasanga because of the A1 highway.

During the twenty months covered by this study, none of the translocated African elephants settled into predictable home range patterns. Therefore, the main question remains: how long would it take for the translocated elephants to reach stable home ranges and settle into the new environment? This aspect, as well as how and why home range size varies among individuals, is not well studied or understood in most species. As much as this study provided some insights on the subject following the release of African elephants into a novel environment, it was short-term and could not provide an in-depth analysis to help understand and reach a definite inference on this question. This shows that for translocated elephants to establish predictable home range patterns, it is a long process that can last longer than 20 months. Therefore, more data should be collected on this subject to yield a better understanding of the home range used by translocated elephants.

Chapter 5: Conclusion and Recommendations

The translocated female African elephants showed individual differences in patterns of exploration for both the 50% and 95% KDEs, with some displaying more linear temporal home range patterns than others. The interaction of different factors such as experiences, seasons, human disturbance, and exploration intensity may have influenced the observed variations in individual home range patterns. The observed variations in individual home range patterns emphasise that no two elephants are the same, which can present challenges and opportunities for ecologists in designing conservation measures to guide post-translocation monitoring. Over and above, a considerably positive and relevant relationship between time and change in the extent of the home range was observed. The results provide insights into the subject of home range establishment for elephants in the Mid-Zambezi Valley Region and the savanna environment at large by assessing the home range establishment of translocated female African elephants following their introduction into a novel environment. It draws attention to matters related to the monitoring and conservation of translocated elephants in savanna ecosystems. The study recommends that post-release elephant monitoring become a prerequisite and that individual differences be taken into account.

The study showed some seasonal differences in home range sizes and habitat use, as some home range sizes were confined to smaller areas during the dry season and only started to increase in the wet season. This pattern was displayed by some elephants that stayed close to the release site and utilised the western side of Rifa, where water was available, along the Zambezi River. However, their home ranges only started to increase during the wet season as they started to utilise locations as far as Nyakasanga. This pattern of exploration bears some implications in relation to the subject of human-elephant conflict, as also suggested by some elephants getting close to the highway. This is further reason for future studies to also include anthropogenic factors when investigating elephant use of space.

References

Araujo, M.S., Bolnick, D.I. and Layman, C.A., 2011. The ecological causes of individual specialisation. Ecology Letters, 14(9), 948-958.

Archie, E.A. and Chiyo, P.I., 2012. Elephant behaviour and conservation: social relationships, the effects of poaching, and genetic tools for management. Molecular Ecology, 21(3), pp.765-778.

Ashiagbor, G. and Danquah, E., 2017. Seasonal habitat use by Elephants (Loxodonta africana) in the Mole National Park of Ghana. Ecology and Evolution, 7(11), 3784-3795.

Balfour, D., Dublin H. T., Fennessy, J., Gibson, D., Niskanen, L., and Whyte I. J., 2007. Review of Options for Managing the impacts of locally overabundant African elephants. 1st edition. The World Conservation Union (IUCN), Gland, Switzerland.

Bandara, R., and Tisdell, C., 2004. The net benefit of saving the Asian elephant: a policy and contingent valuation study. Ecological Economics, 48(1), 93-107.

Bates, D., Maechler, M., Bolker, B and Walker, S 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48.

Bauman, P.J., Jenks, J.A. and Roddy, D.E., 1999. Evaluating techniques to monitor elk movement across fence lines. Wildlife Society Bulletin, 27(2), 344-352.

Beirne, C., Houslay, T.M., Morkel, P., Clark, C.J., Fay, M., Okouyi, J., White, L.J. and Poulsen, J.R., 2021. African forest elephant movements depend on time scale and individual behaviour. Scientific Reports, 11(1), 12634.

Berger-Tal, O., Blumstein, D. T., and Swaisgood, R. R., 2020. Conservation translocations: a review of common difficulties and promising directions. Animal Conservation, 23(2), 121-131.

Blanc, J. J., Barnes, R. F. W., Craig, G. C., Dublin, H. T., Thouless, C. R., Douglas-Hamilton, I., and Hart, J. A., 2007. African elephant status report 2007: An update from the African

Elephant Database. Occasional Paper Series of the ICUN Species Survival Commission, No. 33. IUCN/ SCC African Specialist Group. IUCN, Gland, Switzerland.

Burke, T., Page, B., Van Dyk ,G., Millspaugh, J and Slotow R., 2008. Risk and Ethical Concerns of Hunting Male Elephant: Behavioural and Physiological Assays of the Remaining Elephants. PLoS ONE, 3(6), e2417.

Burt, W. H., 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy, 24, 346–352.

Chutipongvivate, P., Homkong, P. and Chanachai, K., 2019. Risk Factors Associated with Post-operative Wound Complications in the Animal Birth Control Program, Chiang Mai Municipality, Thailand, 2017. OSIR Journal, 121), pp.1-6.

Cumming, D. H. M. and Jones, B., 2005. Elephants in southern Africa: management issues and options. WWF-SARPO, Harare, Zimbabwe.

Cushman, S. A., Chase, M., & Griffin, C., 2005. Elephants in space and time. Oikos, 109, 331–341.

Debeffe, L., Morellet, N., Cargnelutti, B., Lourtet, B., Bon, R., Gaillard, J.-M. and Hewison, A.J.M., 2012. Condition dependent natal dispersal in a large herbivore: heavier animals show a greater propensity to disperse and travel further. Journal of Animal Ecology, 81, 1327.

Douglas-Hamilton, I., Krink, T. and Vollrath, F., 2005. Movements and corridors of African elephants in relation to protected areas. Naturwissenschaften, 92,158-163.

Dublin, H.T and Niskanen, L.S (eds.) 2003. The African Elephant Specialist Group in collaboration with the Re-introduction and Veterinary Specialist Groups. IUCN/SSC AfESG Guidelines for the in situ Translocation of the African Elephant for Conservation Purposes. IUCN, Gland, Switzerland and Cambridge, UK.

Dublin, H.T. and Taylor, R.D., 1996. Making management decisions from data. Studying Elephants, 7, 10-17. In: Kangwana, K.F. (Ed.). Studying elephants. Technical Handbook Series no. 7. African Wildlife Foundation, Nairobi, Kenya.

Duffy, K. J., Dai, X., Shannon, G., Slotow, R and Page, B., 2011. Movement patterns of African elephants (Loxodonta africana) in different habitat types. South African Journal of Wildlife Research, 41(1), 21-28.

Dunham, K. M., 1986. Movements of elephant cows in the unflooded Middle Zambezi valley, Zimbabwe. African Journal of Ecology, 24(4), 287–29.

Environmental Systems Research Institute (ESRI). 2021. ArcGIS: ArcMap Version 10.8.
Evans, K. E., and Harris, S., 2008. Adolescence in male African elephants, Loxodonta africana, and the importance of sociality. Animal Behaviour, 76(3), 779-787.

Evans, M.J., Pierson, J.C., Neaves, L.E., Gordon, I.J., Ross, C.E., Brockett, B., Rapley, S., Wilson, B.A., Smith, K.J., Andrewartha, T. and Humphries, N., 2023. Trends in animal translocation research. Ecography, 2023(3), p.e06528.

Fernando, P., Jayewardene, J., Prasad, T., Hendavitharana, W., and Pastorini, J., 2011. Current status of Asian elephants in Sri Lanka. Gajah, 35, 93-103.

Fernando, P., Leimgruber, P., Prasad, T and Pastorini, J., 2012. Problem-elephant translocation: translocating the problem and the elephant? PloS ONE, 7(12), e50917.

Foley, L. S., 2002. The influence of environmental factors and human activity on elephant distribution. International Institute for Geo Information Science and Earth Observations, Enscheda, Netherlands.

Fritz, H., 2017. Long-term field studies of elephants: understanding the ecology and conservation of a long-lived ecosystem engineer. Journal of Mammalogy, 98(3), pp.603-611.

Galanti, V., Preatoni, D., Martinoli, A., Wauters, L.A. and Tosi, G., 2006. Space and habitat use of the African elephant in the Tarangire–Manyara ecosystem, Tanzania: Implications for conservation. Mammalian Biology, 71, 99-114.

Garnier, A., Bernard, A., Crampe, J.P., Estèbe, J., Aulagnier, S. and Gonzalez, G., 2021. Intrinsic factors, release conditions and presence of conspecifics affect post-release dispersal after translocation of Iberian ibex. Animal Conservation, 24(4), 626-636.

Garstang, M., 2004. Long-distance, low-frequency elephant communication. Journal of Comparative Physiology A, 190, 791-805.

Getz, Wayne., ScottFortmann-Roe, Paul C. Cross, Andrew J. Lyons, Sadie J. Ryan, and Christopher C. Wilmers., 2007. “LoCoH: Nonparametric Kernel Methods for Constructing Home Range and Utilization Distributions. PLoS ONE, 2: e207.

Gillson, L., and Lindsay, K., 2003. Ivory and ecology—changing perspectives on elephant management and the international trade in ivory. Environmental Science & Policy, 6(5), 411-419.

Graham, M.D., Douglas-Hamilton, I., Adams, W.M. and Lee, P.C., 2009. The movement of African elephants in a human-dominated land-use mosaic. Animal Conservation, 12, 445-455.

Granados, A., Weladji, R.B. and Loomis, M.R., 2012. Movement and occurrence of two elephant herds in a human-dominated landscape, the Bénoué Wildlife Conservation Area, Cameroon. Tropical Conservation Science, 5(2), 150-162.

Harris, G.M., Russell, G.J., van Aarde, R.I. and Pimm, S.L., 2008. Rules of habitat use by elephants Loxodonta africana in southern Africa: insights for regional management. Oryx, 42, 66-75.

Hasanzadeh, K., Broberg, A. and Kyttä, M., 2017. Where is my neighborhood? A dynamic individual-based definition of home ranges and implementation of multiple evaluation criteria. Applied geography, 84, pp.1-10.

Hayward, M.W. and Kerley, G.I., 2009. Fencing for conservation: restriction of evolutionary potential or a riposte to threatening processes? Biological Conservation, 142(1), 1-13.

Hoffmann, M., Duckworth, J.W., Holmes, K., Mallon, D.P., Rodrigues, A. S. L. and Stuart, S. N., 2015. The difference conservation makes to extinction risk of the world’s ungulates. Conservation Biology, 29, 1303–1313.

https://www.iucn.org/news/species/2021/african-elephant-species-now-endangered-and-critically-endangered-iucn-red-list

International Fund for Animal Welfare (IFAW). 2005. The debate on elephant culling in South Africa-an overview. IFAW, Cape Town, South Africa.

Jaeger, J.A.G., Bowman, J., Brennan, J., Fahrig, L., Bert, D., Bouchard, J., Charbonneau, N., Frank, K., Gruber, B. and von Toschanowitz, K.T., 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behaviour. Ecological Modelling, 185, 329-348.

Johnson, C.J., Parker, K.L., Heard, D.C. and Gillingham, M.P., 2002. Movement parameters of ungulates and scale-specific responses to the environment. Journal of Animal Ecology, 71(2), 225-235.

Joubert, C. J., 2013. A natural resource assessment of Chapungu Ranch, Save Valley Conservancy, Zimbabwe (Doctoral dissertation, University of Pretoria).

Kays, R., Crofoot, M. C., Jetz, W. and Wikelski, M., 2015 Terrestrial animal tracking as an eye on life and planet. Science, 348, 2478.2.

Keil, P.G., 2022. Living in elephant worlds: human-elephant relations on the fringe of forest and village in Assam, Northeast India (Doctoral dissertation, Macquarie University).

Kerley, G. I. H and Landman M., 2006 The impacts of elephants on biodiversity in the Eastern Cape Subtropical Thickets. South African Journal of Science, 102, 395–402.

Kikoti, A.P., 2009. Seasonal home range sizes, transboundary movements and conservation of elephants in northern Tanzania. University of Massachusetts Amherst.

Kumar, M.A. and Singh, M., 2011. Behaviour of Asian elephant (Elephas maximus) in a land-use mosaic: conservation implications for human-elephant coexistence in the Animalia hills, India. Wildlife Biology in Practice, 6, 69- 80.

Laurance, W.F., Croes, B.M., Tchignoumba, L., Lahm, S.A., Alonso, A., Lee, M.E., Campbell, P and Ondzeano, C., 2006. Impacts of roads and hunting on central African rainforest mammals. Conservation Biology, 20, 1251-1261.

Lee, P. C and Moss, C. J., 1986. Early maternal investment in male and female African elephant calves. Behavioural Ecology and Socio-biology, 18, 353-361.

Leggett, K., Brown, L and Ramey, R., 2011. Matriarchal associations and reproduction in a remnant subpopulation of desert-dwelling elephants in Namibia. Pachyderm, 49, 20-32.

Lindsay, K., Chase, M., Landen, K. and Nowak, K., 2017. The shared nature of Africa's elephants. Biological Conservation, 215, pp.260-267.

Loarie, S. R., van Aarde, R. J and Pimm, S. L., 2009. Elephant seasonal vegetation preferences across dry and wet savannahs. Biological Conservation, 142(12), 3099-3107.

Martin-Lopez, B. E. R. T. A., Montes, C and Benayas, J., 2008. Economic valuation of biodiversity conservation: the meaning of numbers. Conservation Biology, 22(3), 624-635.

Matsumura, M., Watanabe, Y.Y., Robinson, P.W., Miller, P.J., Costa, D.P. and Miyazaki, N., 2011. Underwater and surface behaviour of homing juvenile northern elephant seals. Journal of Experimental Biology, 214(4), 629-636.

McComb, K., Moss, C., Durant, S. M., Baker, L and Sayialel, S., 2001. Matriarchs as repositories of social knowledge in African elephants. Science, 292(5516), 491-494.

Millspaugh, J. J; Raedeke K. J; Brundige G.C and Gitzen R.A., 2000. Elk and hunter space use sharing in the Southern Black Hills, South Dakota. Journal of Wildlife Management, 64, 994–1003.

Ndaimani, H., Murwira, A., Masocha, M and Zengeya, F. M., 2017. Elephant (Loxodonta africana) GPS collar data show multiple peaks of occurrence farther from water sources. Cogent Environmental Science, 3, 1420364.

Ngene, S., Okello, M. M., Mukeka, J., Muya, S., Njumbi, S., and Isiche, J., 2017. Home range sizes and space use of African elephants (Loxodonta africana) in the Southern Kenya and Northern Tanzania borderland landscape. International Journal of Biodiversity and Conservation, 9(1), 9-26.

Ngorima, P and Ngwenya, N. 2018. (*Unpublished report*). An Ecological Assessment in Rifa (Hurungwe Safari Area) for area suitability to receive 100 Elephants from Sango (Save Valley Conservancy).

Ngorima, P., Mpakairi, K. S., Kavhu, B., Gara, T. W., Ndaimani, H and Chakuya, J., 2022. Trends in elephant poaching in the Mid-Zambezi Valley, Zimbabwe: Lessons learnt and future outlook. African Journal of Ecology, 00, 1–5.

Ngorima, P; Mhlanga, W and Tafangenyasha, C., 2015. Analysis of trends on trophy quality of African elephant, lion, buffalo and stakeholders perceptions in Sengwa Wildlife Research Area, Zimbabwe from 2003 to 2013. Research Council of Zimbabwe. (ISSN: 2412-2386): 369-380.

Osborn, F.V., 2004. The concept of home range in relation to elephants in Africa. Pachyderm, 37, 37–44.

Owen-Smith, N., Fryxell, J. M. and Merrill, E. H., 2010. Foraging theory upscale: The behavioural ecology of herbivore movement. Philosophical Transactions of the Royal Society B Biological Sciences, 365, 2267–2278.

Peng, B., Li, Y., Elahi, E. and Wei, G., 2019. Dynamic evolution of ecological carrying capacity based on the ecological footprint theory: A case study of Jiangsu province. Ecological indicators, 99, pp.19-26.

Pinter-Wollman, N., 2012. Human–elephant conflict in Africa: the legal and political viability of translocations, wildlife corridors, and transfrontier parks for large mammal conservation. Journal of International Wildlife Law & Policy, 15(2), pp.152-166.

Pinter-Wollman, N., Isbell, L. A., and Hart, L. A., 2009. Assessing translocation outcome: comparing behavioural and physiological aspects of translocated and resident African elephants (Loxodonta africana). Biological Conservation, 142(5), 1116-1124.

Poole, J. H., Payne, K., Langbauer, W. R., and Moss, C. J., 1988. The social contexts of some very low frequency calls of African elephants. Behavioural Ecology and Socio-biology, 22, 385-392.

R Core Team., 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org.

Redfern, J. V., Grant, R., Biggs, H., and Getz, W. M., 2003. Surface-water constraints on herbivore foraging in the Kruger National Park, South Africa. Ecology, 84(8), 2092-2107.

Resende, P.S., Viana-Junior, A.B., Young, R.J. and Azevedo, C.S., 2021. What is better for animal conservation translocation programmes: Soft-or hard-release? A phylogenetic meta-analytical approach. Journal of Applied Ecology, 58(6), pp.1122-1132.

Robert, M.W. and St. Clair, C. C., 2004. The effects of artificial and natural barriers on the movement of small mammals in Banff National Park, Canada. Oikos, 105(2), 397-407.

Ross, C., 2016. Elephant forage behaviour. The Evergreen State College, 3–8.

Ruggiero, R., 1990. The effects of poaching disturbance on elephant behaviour. Pachyderm, 13, 42- 44.

Ryckman, M.J., Rosatte, R.C., McIntosh, T., Hamr, J. & Jenkins, D., 2010. Postrelease dispersal of reintroduced elk (Cervus elaphus) in Ontario. Canada. Restoration Ecology, 8, 173– 180.

Seddon, P. J., Armstrong, D. P., and Maloney, R. F., 2007. Developing the science of reintroduction biology. Conservation Biology, 21(2), 303-312.

Seddon, P.J., Griffiths, C.J., Soorae, P.S. & Armstrong, D.P., 2014. Reversing definition: restoring species in a changing world. Science, 345, 406–412.

Shannon, G., Matthews, W. S., Page, B. R., Parker, G. E., and Smith, R. J., 2009. The effects of artificial water availability on large herbivore ranging patterns in savanna habitats: a new approach based on modelling elephant path distributions. Diversity and Distributions, 15 (5), 776-783.

Shannon, G., Page, B., Slotow, R., and Duffy, K. J., 2006. African elephant home range and habitat selection in Pongola Game Reserve, South Africa. African Zoology, 41, 37–44.

Sibanda, M., Dube, T., Bangamwabo, V. M., Mutanga, O., Shoko, C., & Gumindoga, W. (2016). Understanding the spatial distribution of elephant (Loxodonta africana) poaching incidences in the mid-Zambezi Valley, Zimbabwe using geographic information systems and remote sensing. Geocarto International, 31, 1006–1018.

Slotow, R., Blackmore, A., Henley, M., Trendler, K. and Garaï, M., 2021. Could Culling of Elephants Be Considered Inhumane and Illegal in South African Law? Journal of International Wildlife Law & Policy, 24(3-4), pp.181-206.

Szott, I.D., 2020. The impact of wildlife tourism on elephants, Loxodonta africana, in South Africa (Doctoral dissertation, Liverpool John Moores University (United Kingdom).

Tucker, M.A., Böhning-Gaese, K., Fagan, W.F., Fryxell, J.M., Van Moorter, B., Alberts, S.C., Ali, A.H., Allen, A.M., Attias, N., Avgar, T. and Bartlam-Brooks, H., 2018. Moving in the Anthropocene: Global reductions in terrestrial mammalian movements. Science, 359(6374), 466-469.

Van Aarde, R.J. and Jackson, T.P., 2007. Megaparks for metapopulations: addressing the causes of locally high elephant numbers in southern Africa. Biological conservation, 134(3), pp.289-297.

Vanak, A.T., Thaker, M. and Slotow, R., 2010. Do fences create an edge-effect on the movement patterns of a highly mobile mega-herbivore? Biological Conservation, 143(11), 2631-2637.

Wambwa, E., Manyibe, T., Litoroh, M., Gakuya, F., and Kanyingi, J., 2001. Resolving human–elephant conflict in Luwero District, Uganda, through elephant translocation. Pachyderm, 31, 58-62.

Western, D. and Lindsay, K., 1984. Seasonal herd dynamics of a savannah elephant population. African Journal of Ecology, 22, 229-224.

White, G.C. and Garrott, R.A., 1990. Analysis of Wildlife Radio-tracking Data. (Academic Press: San Diego). New York.

Appendices

Appendix 1: Results of Kernel Density Estimate Home Range Size at 95% for Nine Female African Elephants Translocated to Hurungwe Safari Area, Zimbabwe, over 20 months since Release.

Ann	Hanna	Kristin	Lorraine	Lucie	Rita	Spiwe	Tendai	Tracey	Month
170	455	325	168	421	134	391	99	145	1
315	637	303	162	629	110	467	196	162	2
475	690	1209	414	875	323	489	1024	325	3
416	1345	1709	403	804	389	498	813	346	4
446	1538	1882	394	900	379	569	1580	346	5
466	1631	3557	394	1013	366	593	1579	352	6
500	2079	2950	378	915	330	771	1328	350	7
538	2283	2803	364	868	319	704	1186	342	8
537	2324	2752	364	887	346	687	1177	343	9
533	2295	2558	362	838	336	626	1071	337	10
519	2226	2380	356	783	344	570	979	336	11
506	2121	2227	351	755	333	535	914	330	12
495	2005	2079	361	733	328	507	853	324	13
476	1910	1914	369	703	320	705	812	324	14
464	1784	1847	357	692	306	782	762	304	15
455	1691	1781	350	816	299	749	762	301	16
443	1611	1702	350	1191	300	758	719	298	17
436	1564	1648	473	1451	307	795	687	326	18
429	1531	2109	558	1416	303	800	661	460	19
429	1531	2109	558	1416	303	800	661	460	20

Appendix 2: Results of Kernel Density Estimate Home Range Size at 50% for Nine Female African Elephants Translocated to Hurungwe Safari Area, Zimbabwe, over 20 months since Release.

Ann	Hanna	Kristin	Lorraine	Lucie	Rita	Spiwe	Tendai	Tracey	Month
47	106	61	39	85	20	96	17	32	1
66	168	55	43	157	19	120	32	46	2
97	153	186	78	164	52	136	99	59	3
86	227	331	85	162	73	136	79	73	4
86	208	359	86	186	85	122	154	76	5
96	254	530	82	194	83	120	147	73	6
106	276	375	80	174	63	133	108	73	7
116	297	340	78	163	57	119	87	73	8
113	303	290	73	165	63	110	95	69	9
109	291	230	67	148	59	89	82	62	10
105	278	194	64	125	55	72	74	60	11
101	249	161	62	97	49	60	71	58	12
97	218	130	63	82	51	44	66	57	13
91	184	128	63	66	54	77	69	57	14
86	163	117	61	70	55	86	73	54	15
83	151	112	62	95	57	84	73	55	16
78	141	105	63	114	61	80	76	56	17
77	130	110	68	155	64	82	75	55	18
74	125	127	75	155	68	86	71	61	19
74	125	127	75	155	68	86	71	61	20

Appendix 3: Post-hoc results of the pair-wise comparison of 95% KDE home range temporal patterns of nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe.

Contrast	Estimate	Standard Error	Degrees of freedom	T-vale	P-value
Ann - Hanna	-1736.10	64.4	137	-26.973	< 0.001
Ann - Kristin	-1887.01	75.8	137	-24.879	< 0.001
Ann - Lorraine	147.88	55.2	137	2.677	0.166
Ann - Lucie	-286.09	69.9	137	-4.091	0.002
Ann - Rita	173.21	51.4	137	3.369	0.027
Ann - Spiwe	-114.66	58.5	137	-1.960	0.574
Ann - Tendai	-492.24	69.4	137	-7.090	<0.001
Ann - Tracey	176.84	53.8	137	3.285	0.034
Hanna - Kristin	-150.92	84.4	137	-1.789	0.690
Hanna - Lorraine	1883.97	66.5	137	28.346	< 0.001
Hanna - Lucie	1450.01	79.1	137	18.333	< 0.001
Hanna - Rita	1909.30	63.3	137	30.157	< 0.001
Hanna - Spiwe	1621.44	69.2	137	23.431	< 0.001
Hanna - Tendai	1243.86	78.6	137	15.816	< 0.001
Hanna - Tracey	1912.94	65.3	137	29.298	< 0.001
Kristin - Lorraine	2034.89	77.6	137	26.211	< 0.001
Kristin - Lucie	1600.92	88.7	137	18.051	< 0.001
Kristin - Rita	2060.22	75.0	137	27.486	< 0.001
Kristin - Spiwe	1772.35	80.0	137	22.157	< 0.001
Kristin - Tendai	1394.78	88.3	137	15.798	< 0.001
Kristin - Tracey	2063.86	76.6	137	26.931	< 0.001
Lorraine - Lucie	-433.97	71.9	137	-6.038	< 0.001
Lorraine - Rita	25.33	54.0	137	0.469	0.910
Lorraine - Spiwe	-262.54	60.8	137	-4.317	0.001
Lorraine - Tendai	-640.11	71.4	137	-8.968	< 0.001
Lorraine - Tracey	28.96	56.3	137	0.514	0.910
Lucie - Rita	459.30	69.0	137	6.660	< 0.001
Lucie - Spiwe	171.43	74.4	137	2.304	0.347
Lucie - Tendai	-206.15	83.3	137	-2.476	0.253
Lucie - Tracey	462.93	70.8	137	6.540	< 0.001
Rita - Spiwe	-287.87	57.3	137	-5.020	0.000
Rita - Tendai	-665.45	68.4	137	-9.722	< 0.001
Rita - Tracey	3.63	52.6	137	0.069	1.000
Spiwe - Tendai	-377.58	73.9	137	-5.107	< 0.001
Spiwe - Tracey	291.50	59.5	137	4.897	0.000
Tendai - Tracey	669.08	70.3	137	9.519	< 0.001

Appendix 4: Post-hoc results of the pair-wise comparison of 50% kernel density home range temporal patterns of nine female African elephants translocated to Hurungwe Safari Area, Zimbabwe.

Contrast	Estimate	Standard Error	Degrees of freedom	T-vale	P-value
Ann - Hanna	-170.913	8.49	130	-20.124	< 0.001
Ann - Kristin	-98.661	10.00	130	-9.863	< 0.001
Ann - Lorraine	37.199	7.76	130	4.794	0.000
Ann - Lucie	-22.038	9.10	130	-2.422	0.281
Ann - Rita	49.355	8.15	130	6.056	< 0.001
Ann - Spiwe	28.242	8.73	130	3.236	0.040
Ann - Tendai	28.796	8.91	130	3.232	0.040
Ann - Tracey	41.245	7.50	130	5.496	< 0.001
Hanna - Kristin	72.252	10.88	130	6.641	< 0.001
Hanna - Lorraine	208.112	8.86	130	23.489	< 0.001
Hanna - Lucie	148.875	10.06	130	14.806	< 0.001
Hanna - Rita	220.268	9.20	130	23.931	< 0.001
Hanna - Spiwe	199.155	9.72	130	20.489	< 0.001
Hanna - Tendai	199.709	9.88	130	20.208	< 0.001
Hanna - Tracey	212.158	8.64	130	24.562	< 0.001
Kristin - Lorraine	135.860	10.32	130	13.169	< 0.001
Kristin - Lucie	76.623	11.36	130	6.745	< 0.001
Kristin - Rita	148.015	10.61	130	13.946	< 0.001
Kristin - Spiwe	126.902	11.06	130	11.470	< 0.001
Kristin - Tendai	127.457	11.21	130	11.373	< 0.001
Kristin - Tracey	139.905	10.13	130	13.816	< 0.001
Lorraine - Lucie	-59.237	9.44	130	-6.273	< 0.001
Lorraine - Rita	12.155	8.53	130	1.425	0.886
Lorraine - Spiwe	-8.958	9.09	130	-0.986	0.987
Lorraine - Tendai	-8.403	9.26	130	-0.908	0.992
Lorraine - Tracey	4.045	7.92	130	0.511	0.910
Lucie - Rita	71.393	9.77	130	7.309	< 0.001
Lucie - Spiwe	50.279	10.25	130	4.903	0.000
Lucie - Tendai	50.834	10.41	130	4.884	0.000
Lucie - Tracey	63.283	9.24	130	6.852	< 0.001
Rita - Spiwe	-21.113	9.42	130	-2.241	0.386
Rita - Tendai	-20.559	9.59	130	-2.144	0.449
Rita - Tracey	-8.110	8.30	130	-0.977	0.987
Spiwe - Tendai	0.555	10.09	130	0.055	1.000
Spiwe - Tracey	13.003	8.87	130	1.466	0.869
Tendai - Tracey	12.449	9.05	130	1.376	0.905