BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF NATURAL RESOURCES

DEPARTMENT OF NATURAL RESOURCES

Using baited camera traps to estimate the population size and sex structure of leopards (*Panthera pardus*) at Malilangwe Wildlife Reserve, Zimbabwe.

DYLAN CHINHOI

(B212804B)

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE BACHELOR OF SCIENCE HONOURS DEGREE IN NATURAL RESOURCES MANAGEMENT (BSc. Hons. NRM)

JUNE 2025

DEDICATION

This study is dedicated to my parents, Steve and Lindah Chinhoi, for their support, love, and encouragement throughout my academic journey. My siblings, Sharon and Itai, have been there for me as well.

ACKNOWLEDGEMENTS

I send my deepest gratitude to the heavens above, every day is a gift from God, and I am forever thankful. I count my blessings and thank God for each one.

Without the help of some people and organizations, this study would not have been feasible. In no particular order, I would like to express my gratitude to:

- The director of The Malilangwe Trust, Chiredzi, Mr. Mark Saunders, for allowing me to carry out an internship on their property.
- Dr. Bruce W. Clegg, the Senior Ecologist at Malilangwe Wildlife Reserve (MWR), Dr. Allan Tarugara, my field supervisor, and Mr. Colin. Wenham, for giving me mentorship, guidance, and feedback throughout my internship period.
- My academic supervisor, Mr. W. Mhlanga, for his support and scholarly advice during the creation of this manuscript.
- Christoffel J. Joubert for pioneering the baited camera-trapping method, which is the central research design upon which this study is premised.
- Pandeni Chitimela, Philmon Chivambu, and Benny Tshuvuka, for their technical assistance during fieldwork.
- The security department and the Malilangwe staff at large, their help cannot go unmentioned.
- My friends, M. Ngwerume, E. Kadozora, B. Matsa, A. Remwa and E. Simango, for their love and support.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The study investigated the application of the baited camera trapping method as an essential tool for estimating the population size, sex structure, and determining the spatial distribution of leopards (*Panthera pardus*) as well as inventorying other carnivores such as lions (*Panthera leo*) and spotted hyenas (*Crocuta crocuta*) at Malilangwe Wildlife Reserve (MWR) in Zimbabwe. In order to determine the population size of leopards at Malilangwe, the study used a total of 120 BCT stations, divided into four separate sampling occasions. Each sampling occasion had a total of 30 cameras, which collected data over a nine-day sampling period. The program DENSITY was used to generate leopard population size estimates. At MWR, the leopard population size was estimated at 59 (95% Cl = 55-70) animals [density = 12 leopards per 100 km^2], and the study was able to identify 52 leopards (32 females and 20 males) at the 69 cameras visited. The spatial distribution of large carnivores (leopards, lions, and spotted hyenas) was also assessed, and the study showed a spatial avoidance between leopards and lions; spotted hyenas were evenly distributed across the reserve.

Keywords: BCT, Density, Population size, Spatial distribution, Sampling occasions.

LIST OF APPENDICES

Chapter 1 INTRODUCTION

1.1 Background to the study.

Leopards are regarded as a member of the Felidae family, and one of the most recognizable large cats, and are found in various habitats, including forests, savannas, and mountains, from Africa to Asia (Searle, 2021). Leopards have an extensive range of areas where they can be found, but accurate population data is lacking in those areas (LeFlore et al., 2020). This could be because they are mostly nocturnal, solitary, and have cryptic colors which makes it relatively difficult to gather concrete information on them (Joubert et al., 2020). It has been noted that leopard numbers are decreasing due to factors like loss of habitat and fragmentation, illegal trade of their skins or body parts, poaching and persecution by humans, this subsequently makes it difficult to gather reliable information on their estimated population size (Weber & Rabonowitz 1996; Henschel et al. 2008). Leopards have been categorized as, “Vulnerable” on the Red List of threatened species by the International Union for Conservation of Nature (IUCN) (IUCN 2018; Stein et al. 2020). The same situation is being experienced in Sub-Saharan Africa, where leopards have disappeared from ≈37% of their historical range, with other populations being completely decimated or isolated (Jacobson et al., 2016; Williams et al., 2017). Leopards are now regarded as endangered in Zimbabwe, despite the country’s law trying by all means to protect these species (GoZ, 1982), 27% of the land was conserved for the protection of wildlife (Parks and Wildlife = 12.5% and CAMPFIRE, conservancies, and private reserves = 14.5%) (GoZ, 2019). Leopards should be protected at all cost as they are regarded as keystone species that are essential to maintaining an ecosystem (Mundy, 2006), and can facilitate ecosystem balance and function.

Accurate population estimates of leopards are needed to direct the management choices as well as the conservation efforts (Balme et al., 2009). Different carnivore estimation methods have been put to use, with common examples including spoor and scat counts, which assess the abundance of these species by monitoring their tracks and droppings, but these methods are not reliable to some extent, as they are vulnerable to unquantified biases and uncertainties (Alexandra et al., 2021). It is quite challenging to estimate carnivores by monitoring their scat because different carnivore species produce similar-looking droppings (Davison et al., 2002).

Management and conservation efforts can be affected by unreliable data on species abundance and presence which is due to misidentification (Manning et al., 2022).

On the positive side, camera trapping has been observed to be the most efficient technique for assessing carnivore density (Joubert et al., 2020). The study by Chapman and Balme (2010), showed that the BCT method is effective in determining the abundance of carnivore species like leopards when it is used together with capture-recapture analysis. The camera traps were tied to trees at Malilangwe to capture the photographs of animals that came near it (Joubert et al., 2020). After Karanth's 1995 seminal work to assess tiger *(Panthera tigris)* populations in India, camera traps were widely accepted as a useful tool. Additionally, the BCT method has been applied to census the population sizes of both lions and spotted hyenas (Joubert et al., 2020).

The BCT approach has been successfully applied at Malilangwe to assess the leopard population size, thereby getting new information on the abundance and spatial distribution of these species. The Malilangwe is a 490 km² piece of private land found in the South eastern region of Zimbabwe. The use of the BCT approach to survey leopards at Malilangwe, has been going on for over 12 years (Joubert et al. 2020). Currently, four BCT surveys have been done at the reserve in the years (2010, 2014, 2017, and 2022), and the observations proved useful towards the management and conservation of leopards (Tarugara et al., 2022). This study provides information on the estimated leopard population size for the 2022 year-survey. Ancillary information of other carnivore species captured at the camera stations like lions and spotted hyenas was also recorded.

1.2 Statement of the problem.

Although several field-based methods for estimating carnivores have been implemented, camera trapping emerged as the most effective tool for surveying leopards in their natural habitats (Joubert et al., 2020). In fenced areas like Malilangwe Wildlife Reserve, leopards can have a significant depressing effect on plains game or limit the population growth of fragile species (e.g.) sable antelope *(Hippotragus niger)*, and Lichtenstein's hartebeest *(Alcelaphus lichtensteinii)* (Clegg et al., 2013; Tarugara and Clegg (2022, *unpublished report*). This is the case because predators and prey fluctuate in relation to each other, as an increase in prey can lead to an increase in predators (Ballard, 2011). The presence of predators can have a stabilizing effect on ecosystems, preventing any one species from dominating and maintaining the diversity of prey species. Understanding these complex interactions is essential for managing ecosystems effectively and conserving biodiversity, and this can be achieved if leopard population sizes are known within reasonable limits.

1.3 Justification of the study.

The study aimed to provide updated information on the leopard population size and sex structure, since previous studies using the same method have been carried out at Malilangwe.

1.4 Research aim.

To investigate the leopard's population size, sex structure, and spatial distribution at the Malilangwe Wildlife Reserve.

1.5 Specific Objectives.

Listed below are the specific objectives for the study:

1. To estimate the abundance and sex structure of leopards at Malilangwe Wildlife Reserve.
2. To determine the spatial distribution of leopards at Malilangwe Wildlife Reserve.
3. To evaluate the applicability of baited camera trapping for inventorying other carnivores.

1.6 Research questions.

1. What is the estimated population size and sex structure of leopards in Malilangwe Wildlife Reserve using baited camera traps?
2. What is the spatial distribution of leopards within Malilangwe Wildlife Reserve?
3. Which other large carnivore species are present in Malilangwe Wildlife Reserve, and what is their spatial distribution within the reserve?

1.7 Significance of the study.

Monitoring leopards is necessary to provide information on the estimated population size and sex structure of these species within the reserve. Estimating the population size and sex structure of leopards provides crucial data for understanding their reproductive potential and overall health, which are vital for effective conservation management. At the same time, inventorying other large carnivores enhances knowledge of the ecosystem's biodiversity, helping to identify key species interactions. The findings will inform conservation strategies aimed at maintaining healthy leopard populations and their habitats, thereby contributing to the preservation of biodiversity in the reserve.

1.8 Assumptions.

- During the study period, the target species does not experience immigration, emigration, births, or deaths.
- The identification of every leopard caught by the camera traps was accurate.
- Throughout the study period, there was no change in the spot patterns of individual leopards.
- Leopard's choice and/or usage of habitat was unaffected by the presence of baits.
- It was believed that leopards mostly preyed on impala *(Aepyceros melampus)*. This is because impalas are abundant in many of the habitats where leopards live, making them a readily available food source, and they are an ideal prey size for leopards.

1.9 Limitations.

The introduction of bias occurred in situations whereby lions, and vultures *(Gyps spp.)* consumed the bait before the leopards did. Lions ably climbed the bait trees and the efforts to keep them from taking the bait, were to no avail. To overcome this problem, baits were replenished during the monitoring routines that took place every three days. Spotted hyenas visited bait sites and knocked off the leading poles in an attempt to feed on the bait. This presented problems as gathering sufficient photographs was impacted without the leading pole correctly positioned on the bait-tree. The toppled poles were repositioned if there was a need to do so during the monitoring routines of the camera stations. Other researchers have indicated that the activities of both lions and hyenas at the baited camera sites could have disturbed the detection of a particular age and sex classes of leopards from being included in the data (Tarugara et al., 2019). This was evidenced in the study by Tarugara et al. (2021) where male competing leopards, lions and spotted hyenas reduced the amount of time leopards spent consuming baits. Since the rosette patterns of leopards were clear from both the day and night photographs, the individual identification was not as difficult. After the nine-day sampling mark, several images of leopards were capture at most camera stations, and these were used for individual identification.

1.10 Definition of terms.

- Population size: the estimated number of individuals of target species in a population and which is often represented by the symbol *N*. The growth-rate of most population size is significantly influenced by immigration, emigration, births, and deaths. Carrying capacity, which depends on the resources available, is the largest population size that a species can support in its environment. Many traditional population models use *K* as the carrying capacity and *r* as the intrinsic growth rate (Population Dynamics, Retrieved 2021-12-08).
- Sex structure: refers to the structure of a population in terms of the ratio of males to females or simply the proportion of males to females of the target species, for instance, if we have 50 leopards, 40 females, and 10 males, then the sex structure is 1 male to 4 females (1: 4). A Poisson distribution describes the "ideal" sex structure, with the sex ratio at 50:50 and mating being random (Sinclair et al., 2006).
- Spatial distribution (of target species): the physical area or spatial unit that a species occupies. Since two species cannot typically inhabit the same ecological niche for an extended period in the same geographical territory, each species in a given environment that is shared by multiple species is typically restricted to its own microhabitat or spatial niche (Borregaard et al., 2008).

Chapter 2 LITERATURE REVIEW

2.1 Traditional methods of estimating leopard abundance and sex structure.

Globally, the stability of terrestrial carnivore populations is a conservation concern (Schaller, 1996). This is because the existence of carnivore populations is threatened by factors such as a reduction of prey, diseases, human-wildlife conflicts, trophy hunting that is not sustainable, poaching particularly for body parts, and killing without cause (Swanepoel et al., 2016). Obtaining accurate and reliable data on carnivore populations' condition, health, and welfare is essential for ensuring successful conservation efforts such as recovery, reintroduction, or management planning (Gese, 2001). However, this is challenging with free-ranging carnivores because they are difficult to survey. Nonetheless, monitoring populations for obtaining accurate estimates of their numbers is crucial to making informed management decisions. Many approaches to estimating carnivore density are in use, differing in application and practice depending on subject species and study environments. Traditional methods of determining the sex structure of carnivores include visual observation, measurement of external characteristics (body, tail, and ear length), Deoxyribonucleic acid (DNA) sexing, and physiological methods like urine and fecal analysis.

Sex structure is regarded as the composition of males to females in a population. An "ideal" sex structure is balanced where the number of males and females is roughly equal, with the sex ratio at 1:1 and mating being random, maintaining a stable population growth rate (Sinclair et al., 2006). Traditional methods like spoor and scat counts are commonly used for carnivore population estimation where animal presence is indicated by fecal evidence and their tracks. Various challenges are however related to these approaches, hence making their results unreliable (Birks et al, 2005). Differing carnivore species producing scat that is almost identical in shape and size, can make it difficult to differentiate between species (Reed and Hart, 2003). The composition of scat, including the presence of hair, bones, and plant material, can be similar across different species, thereby making scat analysis a big challenge (Rogers and Elder, 2001). Misidentification, which can affect management and conservation choices might lead to flawed data on a species presence and abundance (Manning et al., 2022). Detritivore and scat disintegration (Pitman et al., 2014; Tarugara et al., 2024).

2.2 The use of camera trap data in generating population statistics.

The two most commonly used methods to determine the population size of carnivores may include the conventional un-baited camera trapping, and the baited camera trapping method. Due to lack of baits to entice target species to camera stations, the conventional un-baited method suffers from low capture rates (du Preez et al., 2014; Negroes et al., 2012; Tarugara et al., 2021). The method mainly depends on placing camera traps in certain locations to capture animals that come near it. At the same time, the BCT method proved to be a reliable approach. This was proved in a study by Wang and Macdonald (2009), which showed that baited camera trapping is more effective in assessing the population size of carnivore species like leopards, tigers, and jaguars *(Panthera onca)*. The BCT method, coupled with the Hotspotter software, is the most reliable way for estimating the population sizes of elusive creatures like leopards. HotSpotter is a software designed for wildlife researchers and conservationists to assist in identifying and cataloging animals captured in camera trap images. Some studies have demonstrated the usefulness of this software as it has been used to identify other species such as Grevy's *(Equus grevyi)*, plains zebras *(Equus quagga)*, giraffes *(Giraffa camelopardalis)*, and leopards (Crall et al., 2013). The use of baits in this method enhances capture rates (du Preez et al., 2014), by enticing target species to the camera stations thereby increasing the likelihood that they may be captured and recorded (Joubert et al., 2020).

2.3 The advantages and disadvantages of baited-camera trapping in population estimation.

The BCT approach has its own benefits as well as some obstacles. One of the many benefits of this approach is its ability to collect high quality photographs that can be used to identify some animal species, for example, leopards. In some cases, camera traps do not always successfully capture all the animals that come near them as other animals may be too small, too fast, or even too far away to trigger an image (Randler at el., 2020). In reaction to this, researchers tend to use baits in order to increase the capture rates. With the use of baits, animals might linger longer in front of the cameras leading to more photographs for capture, and these photographs can then be used for individual identification (Randler at el., 2020). The leading poles are instrumental when it comes to enhancing the number of photographs that can be used for individual identification of the target species, for instance, leopards can move into positions that expose more of their body when they try to feed on baits, thereby making it easy to capture clear photographs. The BCT method as developed by Christoffel Joubert, has displayed an increase of about 6.2 capture frequencies in leopards, in Zimbabwe (du Preez et al., 2014; Tarugara et al., 2021). The other advantage of this method would be its cost-effective nature where the optimal population estimates stabilized at four sampling occasions and nine days. A reasonable budget of about US$47 km^{-2} was required to produce reliable evaluations, and the optimal range for surveying leopards in semi-arid environments was determined to be 0.24 cameras km^{-2} over a nine-day sampling period (Tarugara et al., 2019).

The introduction of bias was underlined as one of the limitations of applying the BCT method. Baits can attract certain individuals or species more than others, leading to biased detections (Rocha et al., 2016). In some cases, bait-shy individuals are left out of the study (du Preez et al., 2014; Tarugara et al., 2019; Joubert et al., 2020), thereby resulting in datasets that are small and therefore not statistically robust. In areas where hunting is practiced, e.g., safari areas, bait is used to lure leopards, and this associates baits with agonistic risk (Joubert et al., 2020).

Chapter 3 METHODOLOGY

3.1 Study area.

The Malilangwe Trust is a Zimbabwean non-profit organization that focuses on conservation, tourism, and community development. Located in the country's southeastern lowveld (20°58´-21°15´S, 31°47´-32°01´E), is fully fenced and borders the Gonarezhou National Park to the south (Figure 1). Mopane (*Colophospermum mopane*) woodlands dominate the vegetation, with a range of sandstone hills characterized by miombo vegetation (*Brachystegia torrei* and *Julbernadia globiflora*) occupying the northern third of the property. Main prey species for leopards included impala (*Aepyceros melampus*, 13.6 km^{-2}), nyala (*Tragelaphus angasii*, 0.38 km^{-2}), and bushbuck (*Tragelaphus sylvaticus*, 0.22 km^{-2}) (Tarugara et al., 2021). Other competing predators in the area may include wild dogs (*Lycaon pictus*, n = 27), lions (n = 48), and spotted hyenas (n = 60) (Clegg, 2017; Tarugara et al., 2021). Rainfall is seasonal (mean = 560 mm, n = 58 years), with the months between November and March accounting for about 84% of total precipitation (Clegg and O'Connor, 2012). Droughts frequently occur in the region, with an average lowest and highest monthly temperature range of 13.4˚C and 23.7 ˚C in July and December respectively; 23.2˚C and 33.9˚C in June and November, respectively (Clegg, 2010; Tarugara et al., 2021). Two major rivers found in the reserve are Chiredzi and Runde, which are essential for supporting life and attracting a variety of wildlife, and geological features like alluvium soils, sand stones, gneiss, and basalt rocks are also common in the area (Traile and Bigalke, 2007).

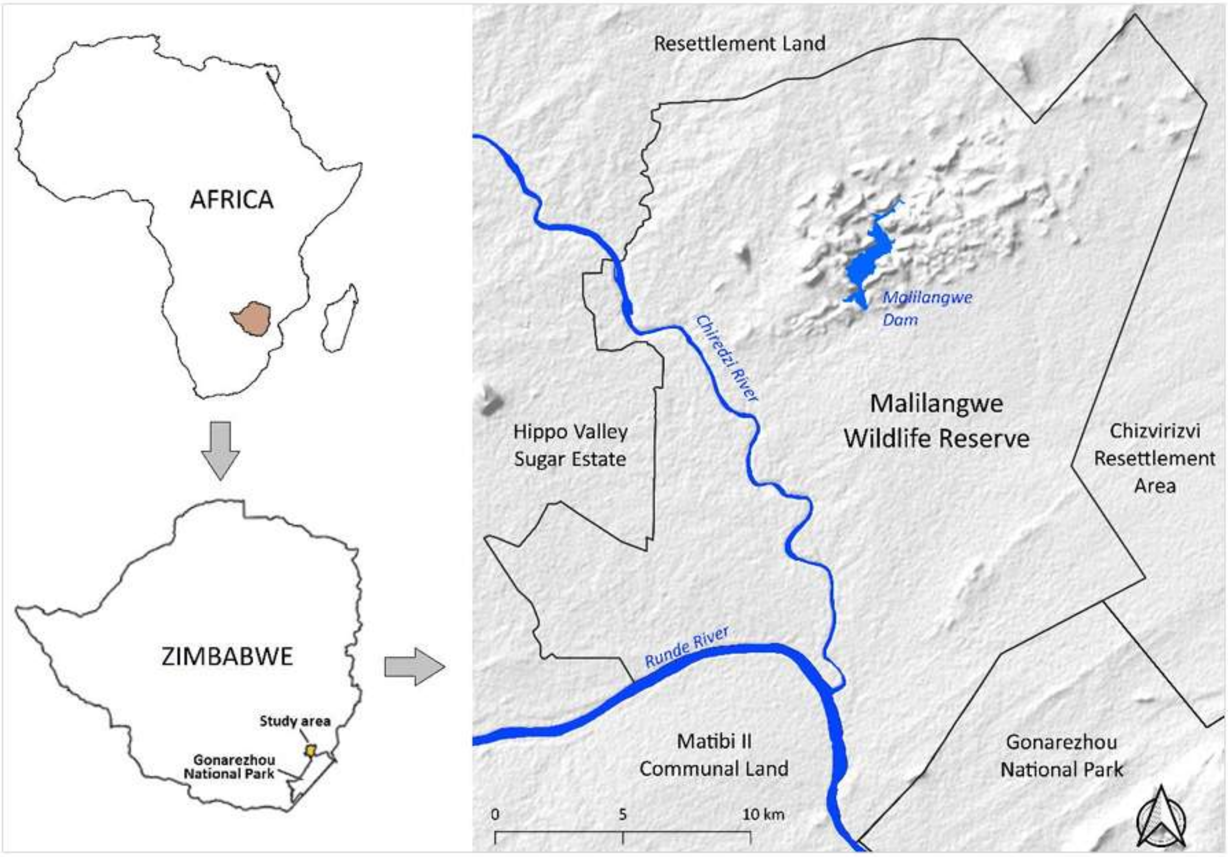

Figure 1: Map of Malilangwe Wildlife Reserve, Zimbabwe.

3.2 Placement of baited-camera traps.

Figure 2: Sampling stations across the study area.

The whole study area was surveyed over four sampling occasions with each running for a nine-day sampling period, each occasion having 30 cameras, thus a total sampling effort of 36 days. Sampling stations were uniformly distributed within the reserve in a stratified random sampling pattern, to avoid bias (Joubert et al., 2020). This was done to ensure the absence of large gaps where target species could live throughout the entire sampling period without a possibility of being detected (Joubert et al., 2020). The research started with sampling occasion 1, which then progressed to sampling occasions 2, 3, and 4. Photographic data of leopards was obtained from 120 BCT stations at Malilangwe (Figure 2) (Joubert et al., 2020). Measurements of a single grid square were calculated as follows;

$$\mathbf{g_1, g_2} = \sqrt{\frac{\boldsymbol{A}}{\boldsymbol{n}_t}}$$

where $\mathbf{g_1, g_2}$ = the length of a single grid square, and the width (km); with **A** being the size of the study region (km^2); then $\mathbf{n_t}$ = the number of stations required to sample the entire study region (Joubert et al., 2020).

The geographic extent of the grids was defined by bounding the coordinates of the study area using the Geographic Information System (GIS) software (Figure 3). For censusing leopards in semi-arid environments, 0.24 cameras km^{-2} was set as the optimal sampling effort, with $\mathbf{n_t}$ being **A** x 0.24 (Tarugara et al., 2019; Joubert et al., 2020). Using the setup at the MWR (**A** = 490 km^2), $\mathbf{n_t}$ rounded up to 120 stations, and $\mathbf{g_1, g_2}$ rounded to 2km (Joubert et al., 2020). The sampling points were randomly placed in each grid square as shown in Figure 3c. Since leopards normally use roads, the sampling stations were placed near these paths to try to increase capture rates (Joubert et al., 2020). For this reason, the placement of the camera stations was moved to the nearest road intersections (Figure 3d). This strategy was also convenient for the researchers since they used vehicles to survey the whole study region, and this was in line with the Malilangwe policy of protecting the area from the negative impacts of off-road driving (Tarugara et al., 2019). For those grid squares with no road intersections, the camera stations were moved to any nearby roads, and in the case that the grid square had no road intersections or any nearby roads, the camera stations were moved to any nearby road in the bordering grid squares (Joubert et al., 2020). A study carried out by Joubert et al. (2020), showed that several recaptures were needed to achieve the optimal sampling effort. To survey leopards in semi-arid environments, splitting the sampling effort ($\mathbf{n_t}$) into four separate repeats (sampling occasions) was recommended (Tarugara et al., 2019; Joubert et al., 2020). Total number of camera trap sites was calculated as;

$$\frac{\boldsymbol{n}_t}{4}$$

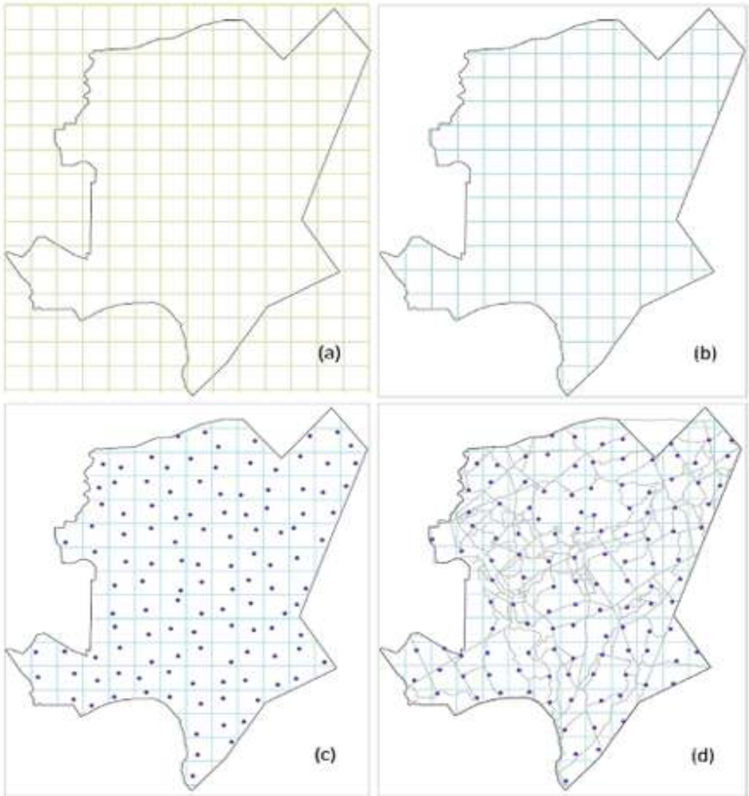

Figure 3: Using the map of Malilangwe to extract the sampling stations. (a) Applying a grid overlay to the study region, (b) the grid squares are clipped to the study region boundary, (c) sampling points are placed randomly in the grid squares, (d) the sampling points are placed along road networks (Source: Joubert et al., 2020).

3.3 Baited-camera trap setup.

A Global Positioning System (GPS) device and a map were used to locate the position of sampling stations in the field. Two trees spaced about 2-4 meters were selected at every site, with one being used for hanging the baits and the other tree for the camera, within a 50m radius of a GPS point. To protect the baits from vultures or other birds of prey, the most preferred bait tree was one with a broad, leafy canopy (Joubert et al., 2020). A skinned impala carcass was used as bait. Experience has shown that skinning the bait delays decomposition and extends the working life (Clegg and Joubert, 2010). The bait was tied with wire to a bait tree to prevent leopards and lions from stealing it, and feeding away from the camera's line of vision. Also, to prevent both spotted hyena and brown hyena *(Hyaena brunnea)* from feeding on the bait, the bait was hung on a tree in such a way that the lowest limbs were at least two meters above the ground (Joubert et al., 2020).

A forked leading pole that was about 3-4 meters long, and 0,2-0,3 meters in diameter was positioned against bait tree at an angle of about 45° to enable the target species to climb up and feed the bait (Figure 4) (Joubert et al., 2020). If the target species climbed up the leading pole, the cameras were triggered and captured images of it since the camera's line of vision was at a 90-degree-angle to the leading pole (Joubert et al., 2020). To increase the chances of bait discovery, offal and stomach contents were dragged the final 300m in the direction of the bait site, anticipating that leopards may be lured by the scent, and follow the trail. Some assumptions noted that the drag distance was made smaller to attract resident individuals only (Joubert et al., 2020). The motion sensor, with a one-minute interval set between photographs, was triggered whenever leopards or other animal climbed the leading poles to feed on the bait. The cameras captured photographs of the animal's right view, since they were positioned on the right side of leading poles.

Figure 4: (a) Researchers setting up materials at the baited camera stations, and (b) illustration of the configuration in action (Source: Joubert et al., 2020).

3.4 Data collection.

According to Tarugara (2019), the optimal sampling effort to survey leopards using the BCT method in the semi-arid region was set at four separate sampling occasions, comprising 9 days, and with a total of 30 camera stations in each sampling occasion. Sampling occasion 1 was the starting point, which progressed to sampling occasion 2, 3, and 4, respectively. It was advised that camera stations be put up in one day for uniform data collection, but where logistics did not permit, they would be set in the shortest possible period over consecutive days (Joubert et al., 2020). Camera stations were monitored every three days, especially given that the study area contains elephants *(Loxodonta africana)*, lions and hyenas, as these frequently visited the bait sites and disturbed the set-up (Joubert et al., 2020).

Lions usually stole the baits, while hyenas were notorious for toppling the leading poles. Baits that were finished before the target species got a chance to encounter them were to be replaced always, and the leading poles that were toppled were repositioned if needs be. The camera trap pictures were collected and downloaded regularly onto a laptop computer for backup. Using the photographs, a list of every animal that visited the bait site was created, and these included lions, spotted hyenas, civet *(Civettictis civetta)*, genet *(Genetta genetta)*, and leopard. This data was fed to an Excel sheet with information on date, camera ID, bait number, and number of individuals. After the camera traps recorded data for a nine-day period, the operation was stopped the following day as the baits were removed, batteries tested for power, and the camera traps were transferred to new locations for the next sampling event (Joubert and Tarugara, 2020).

3.5 Data analysis.

The leopard unique rosette patterns, made it easy to visually inspect, and identify them. Conspicuous scrotal sac on camera trap photographs made it easy to differentiate between males and females. However, this method was not as successful when it came to discerning the sex in sub-adult individuals as their scrotum was not easily seen on the camera trap photographs, especially for males <2 years old (Balme et al., 2012). The identification of leopards was done using the HotSpotter software v1.0 (Crall et al., 2013). The software relied on extracting points or "hotspots," which were the distinctive features on target species that were used to identify them, (for leopards, these were the rosette patterns). A sample of leopards (n=10), were identified with their region of interest (ROI) marked, and the data was fed on the software's database. A region of interest is a portion of the leopard's rosette pattern that was used as a training palette to identify similar patterned photographs using a machine learning algorithm (Crall et al., 2013). A sub-image was extracted from the ROI for reference, and this was called a "chip". After the chips were created, new pictures of leopards were fed into the program and run, to generate similar photographs or new individuals that had not been previously identified (Figure 5).

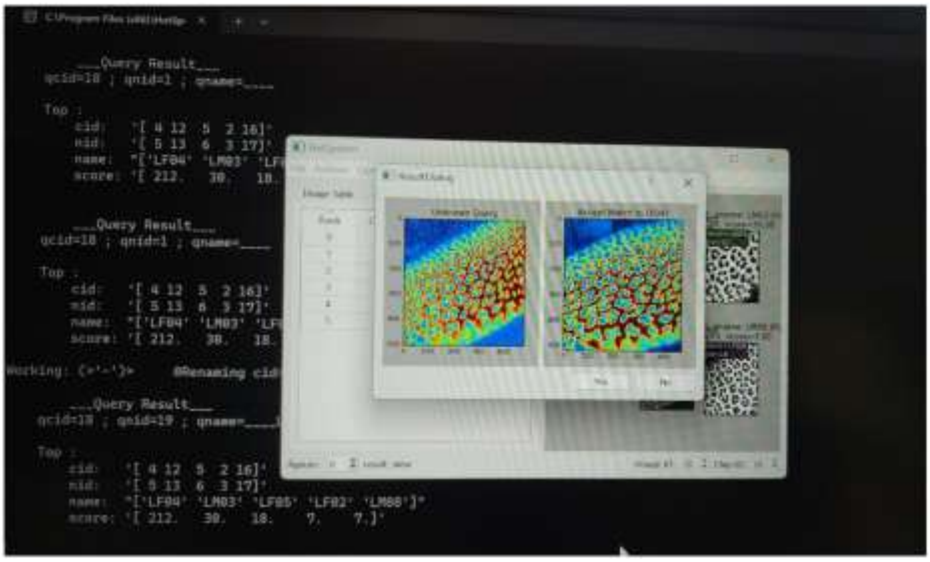

Figure 5: A screenshot with an example of an image matching output generated using HotSpotter software.

An identikit, which is a catalogue for indexing and referencing individuals, was created for the dataset. Capture histories of leopard encounters were constructed for each sampling occasion and fed into Program DENSITY, a spatially explicit capture-recapture software (Efford, 2014) for the generation of population size estimates. Each sampling occasion yielded population estimates with a 95% confidence interval (Joubert et al., 2020). Enough sampling would have been achieved if the estimates and confidence intervals for two consecutive occasions stabilize, at which sampling could be halted. Additional sampling occasions can be added for populations for which the optimum is to be identified, and in the cases that the estimates did not stabilize by the fourth occasion (Joubert et al., 2020) (Figure 6).

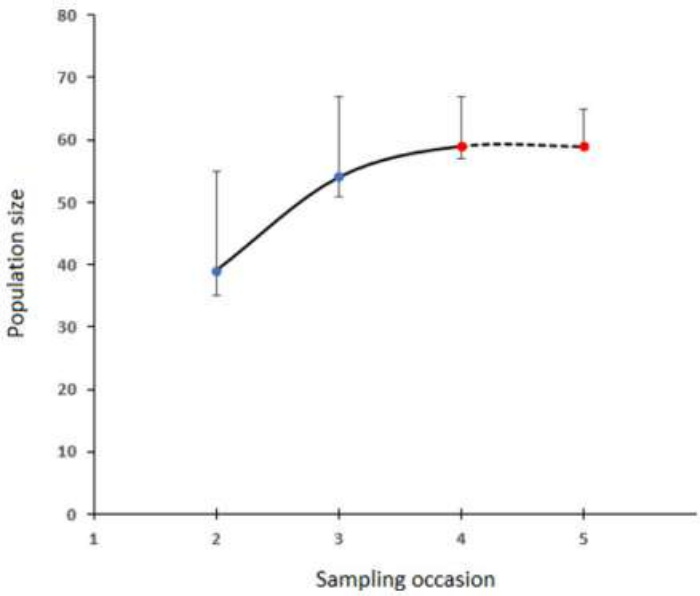

Figure 6: Calculating the ideal sampling effort. The dotted lines indicating an increase in sampling effort to stabilize the population estimates. Error bars indicating a 95% confidence interval of the population estimates (Source: Joubert et al., 2020).

Chapter 4 RESULTS

A total of 120 BCT stations collected data over four sampling occasions, each containing 30 camera stations, over a nine-day period (i.e., a 36 days sample effort). The cumulative survey effort of all the photographs collected was 1080 camera days, and 13 days were lost to camera failure; the observed camera failure was about 1.2%, which was deemed negligible. Camera failures mainly occurred where lions, hyenas, and elephants *(Loxodonta africana)* disturbed the camera trap set-up. The survey generated a total of 10,192 photographs, of which 2,151 contained leopard photographs, and of these, 849 photographs were usable for individual identification. Since leopards have unique rosettes, this made it easier to identify them, even if the photographs contained partial or skewed shots of leopards. Using the photographs, a list of every animal that visited the bait site was created, and these included lion, hyena, civet *(Civettictis civetta)*, genet *(Genetta genetta)*, and leopard. Throughout all four sampling occasions, a total of 97 animals were photographed, with 45 of these animals being recaptures.

4.1 Abundance and sex structure of leopards.

The study identified 52 leopards (32 females and 20 males) at 69 cameras visited (Table 1). The population size of leopards at Malilangwe Wildlife Reserve (MWR) was estimated at 59 (95% CI = 55–70) animals [density = 12 leopards per 100 km^2] with a leopard sex ratio of 1 male to 1.6 females.

Table 1: The cumulative capture results for the leopards at MWR. M_{t+1} denotes the total marked individuals.

Sampling Occasion	**1**	**2**	**3**	**4**	$\boldsymbol{M_{t+1}}$
Cameras visited	15	17	19	18	
Animals caught	17	23	29	28	
Individuals marked	0	17	30	44	52
Newly caught	17	13	14	8	

Previous studies of leopard abundance, sex structure, and density using the Baited Camera-Traps at MWR for the years (2010, 2014, and 2017) are shown in Table 2, including the data for the current study. The rosette patterns that are as unique as human fingerprints made it possible to individually identify these target species because no two leopards have the same pattern. Through visual scrutiny, individual leopards were identified from the photographs by their rosette patterns. Male and female distinction was made based on whether or not a scrotal sac was visible on the photographs (thus determining the sex structure), and the population statistics over the four separate survey years are given (Table 2).

Table 2: Population statistics derived from baited camera trapping data for the four survey years.

Survey-year	**Population size (95% Cl)**	**Adult sex ratio (male: female)**	**Density (per 100 km^2)**
2010	41 (36-62)	1: 2.4	10.3
2014	46 (33-59)	1: 3.2	11.6
2017	61 (61-67)	1: 1.4	12.4
2022	59 (55-70)	1: 1.6	12.0

4.1.1 A comparison of sampling density and duration.

Table 3: The overall results for the sampling events of the Malilangwe Wildlife Reserve baited camera trap survey for 2017 (Source: Tarugara et al., 2019).

Occasion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	M_{t+1}
Animals caught	26	23	34	35	29	25	22	
Total marked	0	26	36	49	55	57	59	61
Newly caught	26	10	13	6	2	2	2	

The 2017 survey produced the highest number of captured leopards owing to factors like a higher cumulative sampling effort of (0.43 cameras per km^2), a sampling duration of seven sampling occasions, and running for a 14-day period each (i.e., a 98-day period of total sampling effort) (Table 3). The study produced 61 leopards (M_{t+1}) (33 were females, and 23 were males, with 5 sub-adults), which were recorded (Table 3), and among these, 50 animals were captured two or more times. The adult sex ratio of leopards was set at 1 male to 1.4 females. A total population size of 61 (95% CI =61-67) leopards, was estimated by the CAPTURE software (Tarugara et al., 2019).

4.2 Spatial distribution of leopards.

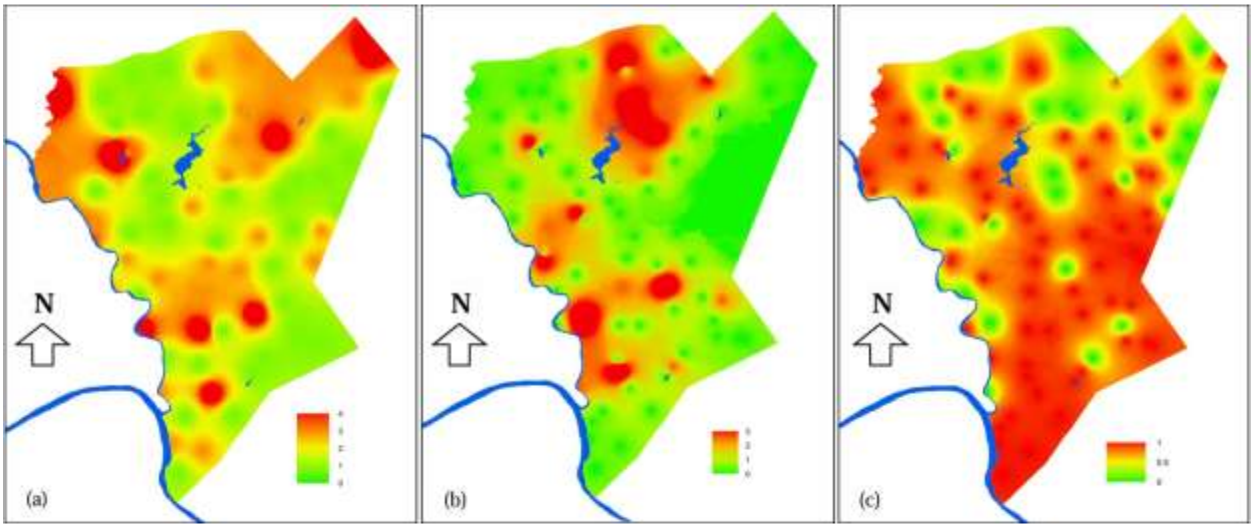

Figure 7: Distributions of leopards (a), lions (b), and spotted hyenas (c), during the survey period. Scale for leopards (0 - 4) and lions (0 - 3) shows the number of recorded individuals, while 0 represents the absence and 1 represents spotted hyena presence at the bait sites (Source: Tarugara, 2016).

The spatial distribution of leopards at MWR in previous surveys showed almost a similar pattern to this study. Leopards were found in areas where lions were not present, showing a spatial avoidance (Figure 7). Leopards seem to have maintained their previous territories as they continue to be found in the Northern half of the reserve (Figure 8). Spotted hyenas are distributed across the reserve, showing that they spatially co-existed with both these species (Figure 7 and Figure 10). The same pattern has been maintained, as can be seen in the study (Figure 9 and Figure 10).

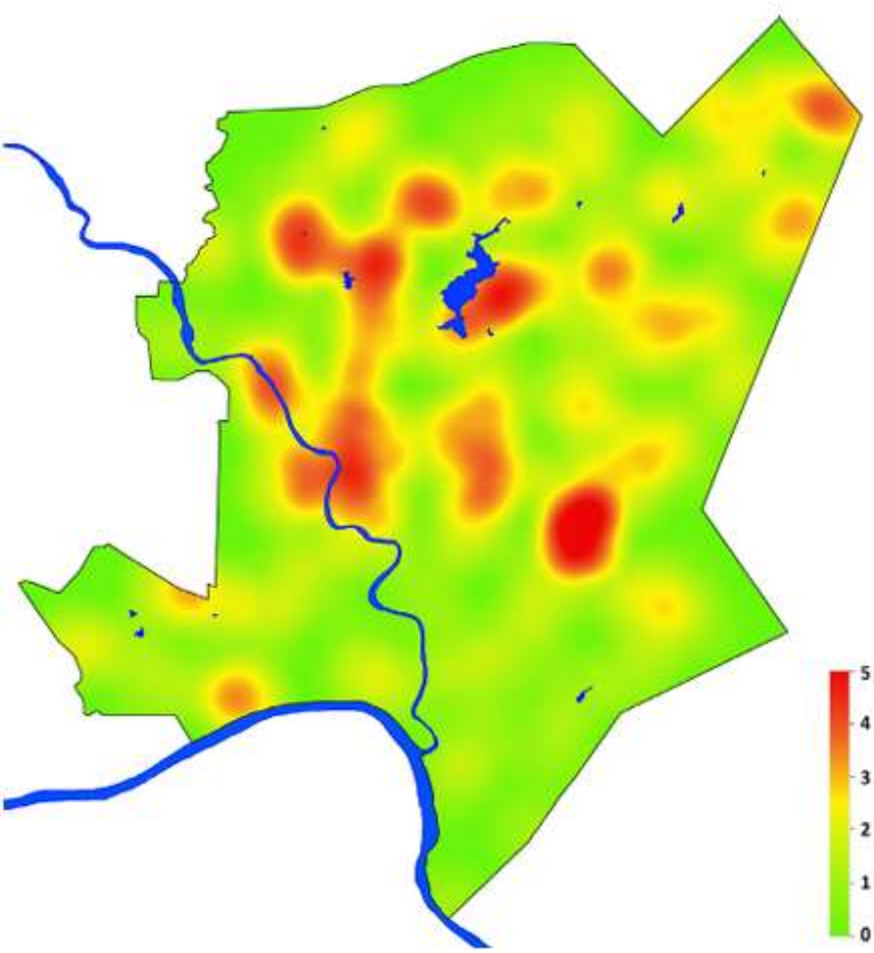

Figure 8: The data from baited-camera trapping at Malilangwe Wildlife Reserve is used to simulate space use. The geographical distribution of leopards throughout the study region. The range of scale is 0-5 leopards (Source: Joubert et al., 2020).

In this study, the leopard spatial distribution is shown at Figure 4, and that of spotted hyenas and lions in Figure 10. As seen from previous studies, the leopards at MWR are predominantly found in the Northern part of the reserve, and this might be influenced by several factors like more suitable habitat due to the presence of rocky landscapes, dense bush, and riverine forests (Figure 9). This area might also provide the necessary cover and prey for leopards to survive.

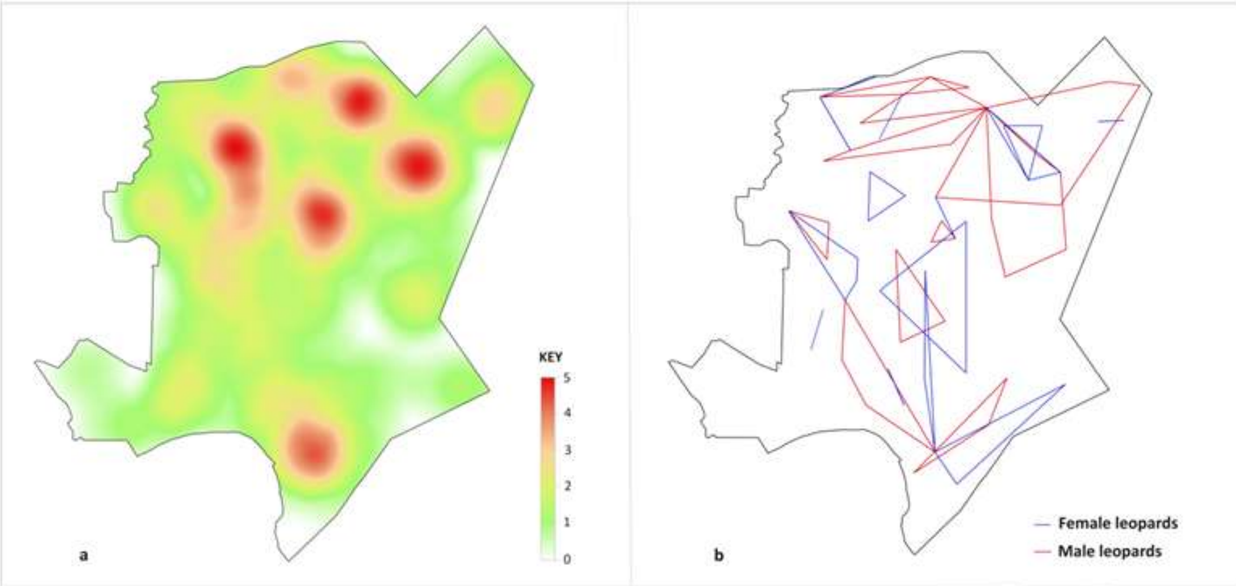

Figure 9: Spatial distribution of leopards during the study (a), scale (0-5) represents the number of leopards that visited a camera station. Space use of individual leopards (b), lines represent 2 stations visited, while polygons represent ≥ 2 points.

4.3 The applicability of baited camera trapping for inventorying other carnivores.

The method was able to show other larger carnivore species, particularly lions and spotted hyenas, that visited the bait sites at MWR (Table 4). A study by Tarugara and Clegg (2022) recorded 74 spotted hyenas, at BCT stations. The same study produced a density estimate of spotted hyenas at 25.1 per 100 km^2, which was higher than recorded in other studies. The results showed spatial avoidance between leopards and lions, and spotted hyenas were evenly distributed all over the property. Besides leopards, other species that were recorded throughout the study included lions, spotted hyenas, and genets. Of these species, spotted hyenas were captured the most, with animals caught totaling 268, followed by Genets at 67, and lions at 41. A total of other animals captured, not including leopards, summed up to 376.

Table 4: A record of other carnivores that visited the bait sites.

Other Animals Caught	SO1	SO2	SO3	SO4	Total
Lions	12	11	10	8	41
Spotted Hyenas	94	53	47	74	268
Genet	29	17	13	8	67
					376

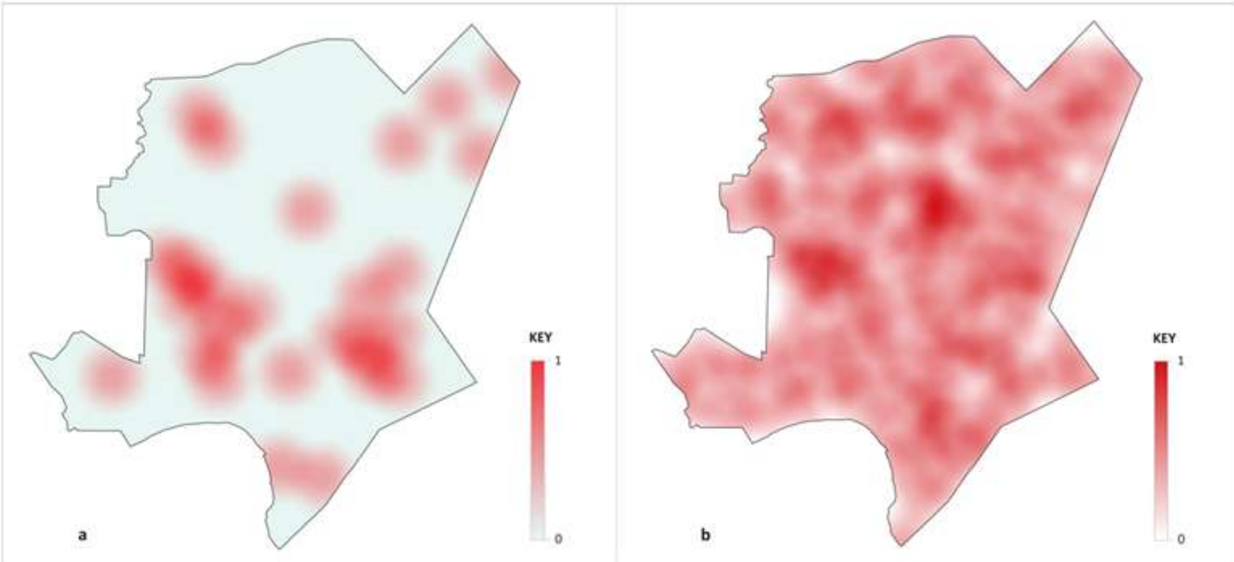

Figure 10: Spatial distribution of lions (a) and spotted hyenas (b) during the study (0 denotes absence and 1 represents presence).

Chapter 5 DISCUSSION

5.1 Population size.

The population size of leopards at MWR was estimated at 59 (95% Cl = 55-70) animals [density = 12 leopards per 100 km^2]. The study was able to photograph and identify 52 leopards in the reserve. This was higher than estimates from 2010 and 2014 which was set at 41 (95% Cl = 36-62) and 46 (95% Cl = 33-59) respectively, but lower than the estimate from 2017 which was set at 61 (95% Cl = 61-67) (Table 2). A slight difference between the population estimates of the 2017 study, comparing it to this study, showed a stable population. Similar to this study, a survey carried out in Nepal, Chitwan National Park, showed a stable leopard population size estimate, the study showed a stable population size with a small decline from 58 (33-77) in the year 2013 to 48 (34-66) for the study carried out in 2022 in the national park (Shrestha et al., 2025). Where the population size is stable, this may indicate a balanced ecosystem, where predators and prey coexist in a healthy dynamic, and it can be a sign of effective conservation efforts.

5.2 Sex structure.

At the 69 cameras that were visited by the animals, 52 leopards were captured, 32 of these were females and 20 were males. The sex ratio at MWR of 1.6 females to 1 male (32 females and 20 males) suggests a potentially healthy breeding population because females play a crucial role in maintaining the population by bearing cubs and raising them, while males' roles are more focused on defending territories and mating (Balme et al., 2013). A high male proportion, such as the case of MWR, requires a dynamic breeding environment with potential benefits of population growth compared to a low male proportion (e.g., 1 male to 9 females in hunting areas such as Save Valley Conservancy (SVC) (Clegg and Joubert, 2010). The sex ratio in the current study had a higher female to male ratio than that for 2017 (1 male to 1.4 females), but lower compared to the studies conducted in 2010 and 2014, which were set at (1: 2.4) and (1: 3.2), respectively (Table 2). There was marginal change when the sex ratio dropped from one male to 2.4 females (2010 study) to 1: 3.2 for the 2014 study because the sex ratio was still regarded as high comparing to neighbouring conservancies where leopards are hunted, the Save Valley Conservancy which had a sex ratio of 1: 9 (Clegg and Joubert, 2010; Tarugara, 2016).

If we compare the findings of the study conducted in 2017 and in this study, it showed that the change in sex ratio is relatively small, indicating a trend towards a higher female population relative to males. This is almost similar to observations by (Friedmann and Taylor-Holzer, 2008), the adult sex ratio was estimated at 1.6 females per adult male, which was considered a reasonable representation of wild leopard populations (Friedmann et al., 2008). These observations were also different from a study on snow leopards *(Panthera uncia)*, which showed an adult sex-ratio change from a male-biased to a female-biased (from 1.67 to 0.38 males per female), illustrating how sex ratios can change within a population (Sharma et al., 2014). For instance, in a study of leopards in the Western Cape, South Africa, it was noted that the dynamics of population growth are influenced by the availability of females for breeding (Müller et al., 2022).

5.3 Spatial distribution.

The study showed that leopards were mostly found in the North of Malilangwe (Figure 9). The possible explanation for this distribution pattern may be because the area has suitable environmental conditions which leopards prefer *(Brachystegia torrei – Androstachys johnsonii)* (Clegg, 2008). This area is also a suitable hunting ground for leopards because (1) the area supports diverse prey species (Clark et al., 2017), and (2) the area has dense canopy cover which leopards use as camouflage. The 2014 data showed that leopards were mostly found in the North, with a patchy distribution along the Western boundary (Figure 7). The 2017 data showed that leopards were mostly found in the central part of the reserve (Figure 8). The leopards at Malilangwe seemed to exhibit a similar distribution pattern as they are mainly found in the Northern region as shown by the data in 2014, 2017, and 2022 (Figure 7, 8, and 9), respectively. The same pattern has been shown over a prolonged period of time, owing to factors like leopard adaptability and minimal habitat disturbances, in these environments. The spatial distribution of lions in 2014 data is almost the same as that of leopards (Figure 7), but this is different compared to the results of this study (Figure 10). The spatial distribution of spotted hyenas in 2014 data showed a patchy distribution in the North (Figure 7). This study showed an even spatial distribution of spotted hyenas, and a patchy distribution for lions (Figure 10). Understanding the spatial distribution of these species help to determine their ecological needs, and measuring the effectiveness of conservation efforts at Malilangwe.

5.4 The applicability of baited camera trapping for inventorying other carnivores.

The use of baits has been demonstrated as an effective method for capturing photographs of carnivore species, such as leopards (du Preez et al., 2014; Randler et al., 2020; Tarugara et al., 2020). While the primary focus was on leopards, the data collected also provided valuable insights into the presence and relative abundance of other carnivore species within the reserve. The baits used to attract leopards also attracted other carnivore species, such as lions and spotted hyenas, thereby increasing the probability of detecting these species compared to the conventional un-baited camera trapping method. A total of 41 and 268 photographs were collected for lions and spotted hyenas, respectively. This showed how the BCT method proved cost-effective, as the same camera trap setup for leopard research was used to collect additional data on other carnivores, which came at a relatively low cost.

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions.

The BCT method was successfully used at Malilangwe to get insights on leopards in the reserve. The survey proved to be an effective method when it comes to determining the population size, sex structure, spatial distribution of these species. Data on spatial distribution as well as the population size of other carnivore species like lions and spotted hyenas was also collected as ancillary information. The results of this study help to understand the leopard population size, and the new information collected can be used to inform the necessary management and conservation efforts at the Malilangwe Wildlife Reserve.

6.2 Recommendations.

- A bigger study that better explains carnivore ecology and the carrying capacity of leopards, lions, spotted hyenas, and wild dogs carried out at Malilangwe to inform conservation strategies.
- The estimation of leopard population size is necessary to better understand their population dynamics, and it is recommended that the survey be conducted every five years to provide updated information.

REFERENCES

Balme, G.A., Batchelor, A., de Woronin Britz, N., Seymour, G., Grover, M., Hes, L., Macdonald, D.W. and Hunter, L.T., 2013. Reproductive success of female leopards P anthera pardus: the importance of top-down processes. Mammal Review, 43(3), pp.221-237.

Balme, G.A., Hunter, L.T.B. and Slotow, R., (2007). Feeding habitat selection by hunting leopards (Panthera pardus) in a woodland savanna: Prey catchability versus abundance. Animal Behaviour. 74: 589–598.

Balme, G.A., Slotow, R. and Hunter, L.T.B. (2009). Impact of conservation interventions on the dynamics and persistence of a persecuted leopard (Panthera pardus) population. Biological Conservation, 142(11), pp.2681–2690.

Birks, J., Messenger, J., Braithwaite, T., Davison, A., Brookes, R. and Strachan, C., 2005. Are scat surveys a reliable method for assessing distribution and population status of pine martens?. In Martens and fishers (Martes) in human-altered environments: an international perspective (pp. 235-252).

Boston, MA: Springer US., R., Ali, H., Kabir, M., Hameed, S., & Nawaz, M. A. (2014). Being the underdog: An elusive small carnivore uses space with prey and time without enemies. Journal of Zoology, 293, 40–48.

Borregaard, M.K., Hendrichsen, D.K. and Nachman, G. (2008) 'Spatial Distribution', in Fath, B. (ed.) Encyclopedia of Ecology. 2nd edn. Elsevier, pp. 589-596.

Braczkowski, A.R., Balme, G.A., Dickman, A., Fattebert, J., Johnson, P., Dickerson, T., Macdonald, D.W. and Hunter, L., 2016. Scent lure effect on camera-trap based leopard density estimates. PloS one, 11(4), p.e0151033.

Braczkowski, A., Gopalaswamy, A.M., Fattebert, J., Isoke, S., Bezzina, A. and Maron, M., 2022. Spatially explicit population estimates of African leopards and spotted hyenas in the Queen Elizabeth Conservation Area of southwestern Uganda. Mammalian Biology, 102(4), pp.1199-1213.

Chapman, S. and Balme, G., 2010. An estimate of leopard population density in a private reserve in KwaZulu-Natal, South Africa, using camera-traps and capture-recapture models. South African Journal of Wildlife Research-24-month delayed open access, 40(2), pp.114-120.

Clark, V.R., Timberlake, J.R., Hyde, M.A., Mapaura, A., Palgrave, M.C., Wursten, B.T., Ballings, P., Burrows, J.E., Linder, H.P., McGregor, G.K. and Chapano, C., 2017. A first comprehensive account of floristic diversity and endemism on the Nyanga Massif, Manica Highlands (Zimbabwe–Mozambique). Kirkia, 19(1), pp.1-53.

Clegg B.W. and Joubert D. (2010). A leopard survey at Malilangwe Wildlife Reserve between March 2009 and August 2010. Internal management report for the Malilangwe Trust.

Clegg, B. and O'Connor, T. (2012). The vegetation of Malilangwe Wildlife Reserve, south eastern Zimbabwe. African Journal of Range & Forage Science, 29(3), pp.109–131.

Clegg, B. W., Wenham, C. M., Clegg, S. B., & Hywood, L. (2013). The re-introduction of Lichtenstein's Hartebeest to Malilangwe Wildlife Reserve, south-eastern Zimbabwe. In: Soorae P. S., ed. Global Re-Introduction Perspectives: 2013. Further Case Studies from Around the Globe. Gland, Switzerland, 148-151.

Clegg, B.W., 2008. Habitat and diet selection by the African elephant at the landscape level: a functional integration of multi-scale foraging process. University of the Witwatersrand, Johannesburg (South Africa).

Clegg, B.W., 2010. Habitat and Diet Selection by the African Elephant at the Landscape Level: a Functional Integration of Multi-Scale Foraging Processes. University of the Witwatersrand, p. 180.

Clegg, B.W., 2017. Large Mammal Population Estimates for Malilangwe Wildlife Reserve: 5th- 14th October 2017. Internal Management Report for the Malilangwe Trust, p. 41.

Crall, J.P., Stewart, C.V., Berger-Wolf, T.Y., Rubenstein, D.I. and Sundaresan, S.R. (2013). HotSpotter — Patterned species instance recognition. [online] IEEE Xplore.

Davison, A., Birks, J.D., Brookes, R.C., Braithwaite, T.C. and Messenger, J.E., 2002. On the origin of faeces: morphological versus molecular methods for surveying rare carnivores from their scats. Journal of Zoology, 257(2), pp.141-143.

de Oliveira, T.G., Lima, B.C., Fox-Rosales, L., Pereira, R.S., Pontes-Araujo, E. and de Sousa, A.L., 2020. A refined population and conservation assessment of the elusive and endangered northern tiger cat (Leopardus tigrinus) in its key worldwide conservation area in Brazil. Global Ecology and Conservation, 22, p.e00927.

du Preez, B. D., Loveridge, A. J., & Macdonald, D. W. (2014). To bait or not to bait: a comparison of camera-trapping methods for estimating leopard Panthera pardus density. Biological Conservation, 176, 153-161.

Efford, M.G. (2014). Estimation of population density by spatially explicit capture–recapture analysis of data from area searches. Ecology, 92(12), pp.2202–2207.

Friedmann, Y. and Traylor-Holzer, K., 2008. Leopard (Panthera pardus) case study. NDF Work Case Stud, 29.

Gese, E.M., 2001. (17) Monitoring of terrestrial carnivore populations ERIC M. GESE. Carnivore conservation, 5, p.372.

Government of Zimbabwe (1982). Parks and Wildlife Act. Government Printer, Harare. (pp. 103).

Grant, T.-L. (2012). Leopard population density, home range size and movement patterns in a mixed landuse area of the Mangwe District of Zimbabwe. Rhodes University. Grahamstown, South Africa.

Henschel, P., Hunter, L., Breitenmoser, U., Purchase, N., Packer, C., Khorozyan, I., Bauer, H., Marker, L., Sogbo hossou, E., & Breitenmoser-Wursten, C. (2008). Panthera pardus. The IUCN Red List of Threatened Species 2008.

IUCN (2008). International Union for Conservation of Nature: Red Data List.

Jacobson, A. P., Gerngross, P., Lemeris Jr, J. R., Schoonover, R. F., Anco, C., BreitenmoserW¨ursten, C., Durant, S. M., Farhadinia, M. S., Henschel, P., Kamler, J. F., Laguardia, A., Rostro-Garcia, S., Stein, A. B., & Dollar, L. (2016). Leopard (Panthera pardus) status, distribution, and the research efforts across its range. PeerJ, 4, e1974.

Janecka, J.E., Jackson, R., Yuquang, Z., Diqian, L., Munkhtsog, B., Buckley-Beason, V., & Murphy, W.J. (2008). Population monitoring of snow leopards using noninvasive collection of scat samples: a pilot study. Animal Conservation, 11, 401-411.

Joubert, C. J., Tarugara, A., Clegg, B. W., Gandiwa, E., & Muposhi, V. K. (2020). A baited-camera trapping method for estimating the size and sex structure of African leopard (Panthera pardus) populations. MethodsX, 101042.

Karanth, K.U., & Nichols, J.D. (1998). Estimation of tiger densities in India using photographic captures and recaptures. Ecology, 79, 2852-2862.

LeFlore, E.G., Fuller, T.K., Tomeletso, M., Dimbindo, T.C. and Stein, A.B., 2020. Human dimensions of human–lion conflict: a pre-and post-assessment of a lion conservation programme in the Okavango Delta, Botswana. Environmental Conservation, 47(3), pp.182-189.

Long, R.A, MacKay, P., & Zielinski, W.J. (2008). Noninvasive survey methods for carnivores. Ray, J.C. (eds) Island Press, Washington.

Manning, J.A., Edwards, T., Clemons, J., Leavitt, D.J., Goldberg, C.S. and Culver, M., 2022. Scat as a source of DNA for population monitoring. Ecology and Evolution, 12(11), p.e9415.

Müller, L., Briers-Louw, W.D., Seele, B.C., Stefanus Lochner, C. and Amin, R., 2022. Population size, density, and ranging behaviour in a key leopard population in the Western Cape, South Africa. PLoS One, 17(5), p.e0254507.

Negroes, N., Sollmann, R., Fonseca, C., Jacomo, A. T., Revilla, E., & Silveira, L. (2012). One or two cameras per station? Monitoring jaguars and other mammals in the Amazon. Ecological Research, 27(3), 639-648.

O'Connor, K.M., Nathan, L.R., Liberati, M.R., Tingley, M.W., Vokoun, J.C., Rittenhouse, T.A., 2017. Camera trap arrays improve detection probability of wildlife: investigating study design considerations using an empirical dataset. PLoS One 12, e0175684.

Pirie, T.J., Thomas, R.L., Mark D. E., & Fellowes, M.D.E. (2016). Limitations to recording larger mammalian predators in savannah using camera traps and spoor. Wildlife Biology, 22, 13-21. doi: 10.2981/wlb.00129

Pitman, R.T., Mulvaney, J., Ramsay, P.M., Jooste, E. and Swanepoel, L.H., 2014. Global positioning system-located kills and faecal samples: a comparison of leopard dietary estimates. Journal of Zoology, 292(1), pp.18-24.

Randler, C., Katzmaier, T., Kalb, J., Kalb, N. and Gottschalk, T.K., 2020. Baiting/luring improves detection probability and species identification—a case study of mustelids with camera traps. Animals, 10(11), p.2178.

Reed, J. E., & Hart, J. A. (2003). Scat analysis as a technique for monitoring carnivore populations. Animal Conservation, 6(2), 155-164. doi: 10.1017/S136943003003154

Rocha, D.G., Ramalho, E.E. and Magnusson, W.E., 2016. Baiting for carnivores might negatively affect capture rates of prey species in camera-trap studies. Journal of Zoology, 300(3), pp.205-212.

Rogers, L. M., & Elder, D. L. (2001). Identification of carnivore scats using morphological and molecular techniques. Wildlife Society Bulletin, 29(2), 347-355.

Schaller, G.B., 1996. Introduction: carnivores and conservation biology. Carnivore behavior, ecology, and evolution, 2, pp.1-10.

Searle, C.E., Smit, J., Strampelli, P., Mkuburo, L., Ikanda, D., Macdonald, D.W., Loveridge, A.J. and Dickman, A.J., 2021. Leopard population density varies across habitats and management strategies in a mixed-use Tanzania landscape. *Biological Conservation*, *257*, p. 109120.

Searle, C.E., Strampelli, P., Smit, J.B., Mkuburo, L., Mathews, F., Kiwango, H., Macdonald, D.W., Loveridge, A.J. and Dickman, A.J., 2024. Spotted hyaena population density across habitat and land use types in southern Tanzania. Journal of Zoology, 322(1), pp.89-100.

Sharma, K., Bayrakcismith, R., Tumursukh, L., Johansson, O., Sevger, P., McCarthy, T. and Mishra, C., 2014. Vigorous dynamics underlie a stable population of the endangered snow leopard Panthera uncia in Tost Mountains, South Gobi, Mongolia. PloS one, 9(7), p.e101319.

Shrestha, B.B., Lamichhane, B.R. and Amin, R., 2025. Population size, density, and ranging behaviour of a key leopard population in Nepal. Journal for Nature Conservation, 86, p.126920.

Si, X., Kays, R., Ding, P., 2014. How long is enough to detect terrestrial animals? Estimating the minimum trapping effort on camera traps. PeerJ 2 e374.

Sinclair, A.R.E., Fryxell, J.M. and Caughley, G. (2006). Wildlife Ecology, Conservation, and Management. 2nd Edition, Blackwell Publishing Ltd, U.S.A.

Skinner, J.D., & Chimimba C.T. (2005). The Mammals of the Southern African Subregion, 3rd Edition. University of Pretoria, Pretoria.

Spong, G., Hellborg, L. and Creel, S. (2000).Sex ratio of leopards taken in trophy hunting: genetic data from Tanzania. Conservation Genetics. 1: 169 – 171.

Stein, A. B., Athreya, V., Gerngross, P., Balme, G., Henschel, P., Karanth, U., Miquelle, D., Rostro-Garcia, S., Kamler, J. F., Laguardia, A., Khorozyan, I. & Ghoddousi, A. (2020). Panthera pardus (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T15954A163991139.

Sunarto, S.R., Mohamed, A., & Marcella J.K. (2013). Camera Trapping for the Study and Conservation of Tropical Carnivores. The raffles bulletin of Zoology (Supl) 28, 21-42.

Swanepoel, L.H., Balme, G., Williams, S., Power, R.J., Snyman, A., Gaigher, I., Senekal, C., Martins, Q. and Child, M., 2016. A conservation assessment of Panthera pardus. The red list of mammals of South Africa, Swaziland and Lesotho, pp.1-13.

Tarugara, A. (2016) *THE DYNAMICS OF THE AFRICAN LEOPARD (Panthera pardus) IN SOUTHEASTERN ZIMBABWE, AS REVIEWED USING BAITED CAMERA TRAPS.* Unpublished Bsc thesis. National University of Science and Technology, Zimbabwe.

Tarugara, A., Clegg, B.W. and Clegg, S.B., 2024. Factors influencing space-use and kill distribution of sympatric lion prides in a semi-arid savanna landscape. PeerJ, 12, p.e16749.
Tarugara, A. and Clegg, B.W., 2022. Using by-catch camera trapping data for estimating the population size of spotted hyaenas (Crocuta crocuta). African Journal of Ecology, 60(4).

Tarugara, A., & Clegg, B.W. (2015). A leopard survey at Malilangwe Wildlife Reserve between September 2014 and April 2015. Unpublished. Internal management report for the Malilangwe Trust.

Tarugara, A., Clegg, B.W., Gandiwa, E. and Muposhi, V.K., 2019. Cost-benefit analysis of increasing sampling effort in a baited-camera trap survey of an African leopard (Panthera pardus) population. Global Ecology and Conservation, 18, p.e00627.

Tarugara, A., Clegg, B.W., Gandiwa, E. and Muposhi, V.K., 2021. The effect of competing carnivores on the feeding behaviour of leopards (Panthera pardus) in an African savanna. Ecology and Evolution, 11(12), pp.7743-7753.

Tarugara, A., Joubert, C., Clegg, B., Gandiwa, E. and Muposhi, V., 2020. A Baited-Camera Trapping Method for Estimating the Size and Sex Structure of African Leopard (Panthera Pardus) Populations. Joubert CJ, Tarugara A, Clegg BW, Gandiwa E and Muposhi VK (2020). A Baited-Camera Trapping Method for Estimating the Size and Sex Structure of African Leopard (Panther Pardus) Populations. MethodsX. doi, 10.

Traill, L.W., & Bigalke, R.C. (2007). A presence-only habitat suitability model for large grazing African ungulates and its utility for wildlife management. African Journal of Ecology, 45, 347-354.

Wang, S.W. and Macdonald, D.W., 2009. The use of camera traps for estimating tiger and leopard populations in the high altitude mountains of Bhutan. Biological Conservation, 142(3), pp.606-613.

Weber, W. & Rabinowitz, A. (1996). A global perspective on large carnivore conservation. Conservation Biology 10: 1046-1055.

Wegge, P., Pokheral, C.P., Jnawali, S.R., 2004. Effects of trapping effort and trap shyness on estimates of tiger abundance from camera trap studies. Anim. Conserv. 7, 251e256.

Williams, B.K., Nichols, J.D. and Conroy, M.J. (2002). Analysis and management of animal populations. Academic Press, San Diego.

APPENDIX

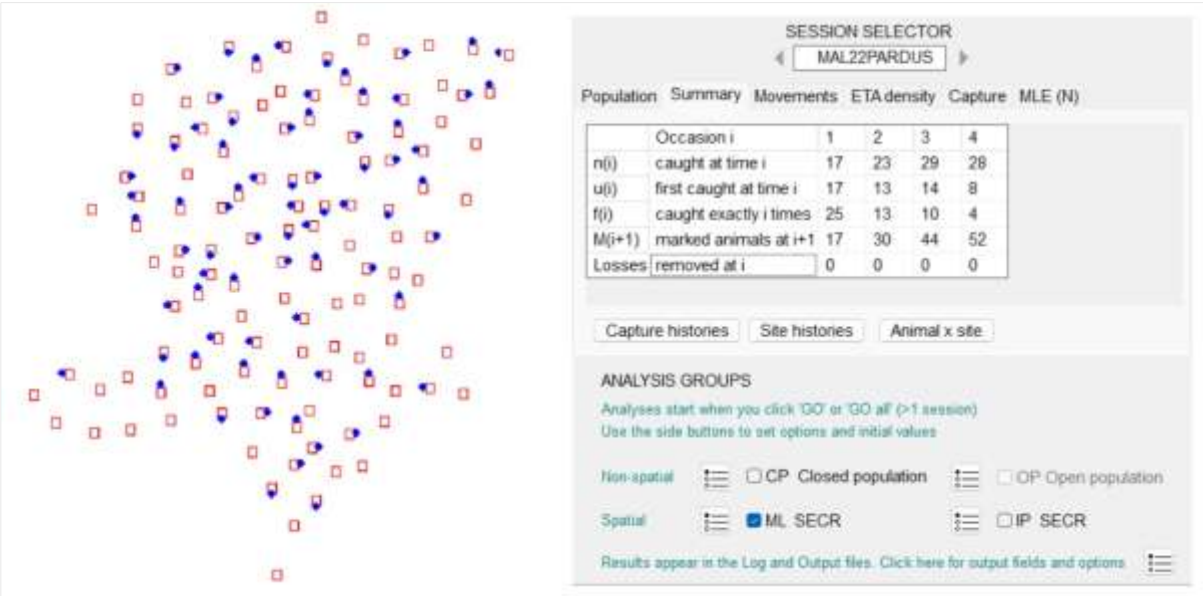

Figure A1. Map on the left represents the location of bait sites across the Malilangwe Wildlife Reserve (red squares) and locations where leopards were photographed (blue dots). Table on the right depicts encounter history information derived from the analysis of capture data.

Female leopard **Male leopard**

Figure A2. Photographs of two individual leopards. The unique spot patterns are marked in red. Males were marked by a visible scrotum under the tail.