University of Salford MANCHESTER

MSc by Research in Environmental Studies

# Abundance, Distribution, and Threats of Mammals and Trees within the Lingadzi Namilomba Forest Reserve within Lilongwe, Malawi, and a Conservation Action Plan for the Protection of the Reserve.

**Charlotte Long**

**2020**

School of Environment & Life Sciences

MSc by Research Thesis

# Contents

# List of Tables

# List of Figures

# List of Appendices

# Acknowledgements

I would like to thank my supervisor Professor Jean Boubli for his ongoing support, understanding and advice, as well as helping me to shape this project. I would also like to thank Lydia Fletcher and Tommy Burch for their help and support with learning DISTANCE 7.3 and QGIS.

I would like to thank Lilongwe Wildlife Trust for enabling me to conduct my research within the Lingadzi Namilomba Forest Reserve. I would also like to give a special thanks to Alma van Dorenmalen and Bright Mbangalah for their support and guidance whilst living within Malawi.

Lastly, I would like to thank my family for their support and to Sean Baker who travelled to Malawi with me to support my research and to help create my transects.

# Abstract

Lingadzi Namilomba Forest Reserve is one of the last remaining wildlife reserves situated within Malawi's capital city Lilongwe. The purpose of this study was to conduct the first systematic assessment of mammal and forest cover within the reserve. Abundance and distribution data was collected, and direct threats were assessed, using Miradi adaptive management software, to create a conservation action plan. This was to provide a baseline study that can be used by local authorities to monitor and manage the park rationally. A systematic line transect census was used to survey the mammals within the reserve, whilst belt transects and 10x10 quadrats were used to carry out a botanical inventory. DISTANCE software was used to assess the abundance and distribution of the mammals and trees, whilst Miradi was used to evaluate the threats damaging the biodiversity using viability assessments and threat ratings.

A major finding was that the invasive *Gmelina arborea* was a significant threat that comprised over 50% of the forest cover, causing fragmentation, reducing the native tree population, thus diminishing natural resources. The distribution results displayed that the mammals preferring the native tree areas, were isolated into smaller fragmented sections of the forest. This drives human-wildlife conflict, which is escalating, as mammals such as the vervet monkey (*Chlorocebus pygerythrus*) raid neighbouring farms to survive, due to a lack of natural food sources. The main threat identified was habitat fragmentation and degradation through factors such as infrastructure, agriculture, invasive trees, and illegal logging. The conservation status of the reserve is critical with the threat of local extinction. The main aim is to build a relationship with the surrounding communities, implement a habitat management plan, remove the invasive species and provide education and research on wildlife and how to preserve and protect it together.

# Chapter One: Introduction

## 1. Introduction to the Lingadzi Namilomba Forest Reserve

Global threats such as environmental degradation, global warming, famine, extinction of species, non-sustainable agriculture and human overpopulation all connect to drive the 6$^{th}$ mass extinction. This is also known as the Anthropocene extinction because of human activity. There is an urgency worldwide to reduce climate change, support billions of citizens and preserve wildlife (Nunez, 2019). Nonetheless, the mass devastation to forests worldwide, including deforestation and degradation, increases each day (IUCN, 2020), despite the fact trees are one of the key ingredients to preventing a mass extinction. Deforestation is the permanent removal of trees to replace forest with something else , such as land for construction, grazing or agriculture (Derouin, 2019). Farming, mining, grazing of livestock, forest practices, wildfires and urbanization are the main drivers of all deforestation worldwide (Nunez, 2019).

With few regions of undisturbed forest remaining, it is estimated that around 30% of forests within Sub-Saharan Africa will disappear by 2030 (WWF, 2019). Forest degradation has already transformed forest areas within West and Central Africa into degraded savannas and savanna grasslands. East Africa has one of the continent's most biologically diverse areas, however it also has one of the highest poverty rates in the world (WWF, 2019). Mozambique, Tanzania and Zambia have seen significant forest loss. For example, Tanzania and Kenya's coastal forests have been reduced to 10% of their original area (Kideghesho, 2015). These countries all border and surround Malawi. Malawi itself has also suffered loss, although specifically how much is unknown due to lack of research within the country. Although there is a general agreement that deforestation is a problem throughout Africa with an estimated two million hectares of forest lost each year, there is no consensus to develop a solution (Youmatter, 2020). The combination of unsustainable management, unsustainable resource extraction and intensified climate change threatens to disrupt the continent's development and natural resource support.

Malawi is a highly biologically diverse country with areas such as Nyika National Park and Lake Malawi, which have been classified as one of Africa's hubs for plant diversity due to the thriving flora having a huge impact in sustaining habitats for endangered animals (Mgoola & Msiska, 2017). Lake Malawi is globally important for biodiversity conservation due to its endemic freshwater fish diversity. There are 350 species of cichlid fish, 345 of these are endemic to the lake. (UNESCO, 2020). Typically, conservation or environmental studies are conducted in more established countries such as Kenya or South Africa. However, very few studies have been conducted or published from Malawi. Malawi, a habitat for endemic and potential new species yet to be discovered is the perfect location for a study to take place. With imminent threats that currently have no solutions or management plans, Malawi is worthy of preservation.

Malawi is the fourth poorest country in the world with a total area of 119,140km² (Office,2018) and a population of 18.14 million. The livelihood of Malawians is highly dependent on biological resources. The continuous growth in the human population has created increased demand for settlements and agriculture (NationalReport, 2014). This has led to a correspondingly high demand for natural resource extraction, resulting in loss of species diversity and habitats (NationalReport, 2014).

Lilongwe is the largest city in Malawi and, with an annual growth rate of 4.3%, the city has seen a high urbanization rate since it became the capital city in 1975 (UN-Habitat, 2011). 16% of the city's population is unemployed with 25% living in poverty and 76% of the population living in informal settlements (UN-Habitat, 2011). 84% of the employed are involved in forestry, fishing, and agriculture (NSO, 2009), therefore indicating a dependence on natural resources for income and survival (EAD, 2010). United Nations Human Settlements Programme stated in their 2011 Lilongwe Urban Report that ‘rapid population growth, weak legal frameworks, inadequate resource capacity, and inadequate resources have led to environmental degradation, pollution, deforestation, and uncontrolled development on fragile land. Thus the status of biodiversity within Lilongwe and Malawi is decreasing due to the unsustainable use of natural resources (NationalReport, 2014).

Lingadzi Namilomba Forest Reserve is the only natural protected area found in urban Lilongwe. It has a total area of 0.619km² and is situated within the center of Lilongwe at Lilongwe Wildlife Trust. The forest is split into two sections by the Namanthanga River and is home to various wild fauna and flora species, such as antelope, primates, crocodiles, and hyena, which all roam freely. The original size of the forest is unknown due to lack of research, however it has been subjected to deforestation with its surroundings being converted into human settlements, infrastructure and for agricultural use (EAD, 2014). This is a growing concern for the Lingadzi Namilomba Forest, as the deforestation has caused isolation and habitat loss, including loss of food and shelter resources. This is detrimental to the wildlife within the reserve (UN-Habitat, 2011). Unfortunately, very few research studies have been carried out within the area. There is a need to assess the status of wildlife and the overall state of the habitat in terms of human pressures and invasive plant species. The dwindling forest of Lingadzi Namilomba Forest Reserve holds some of the last remnants of wildlife and forest within the city. Therefore it is essential the area be preserved, not only for the wildlife, but also for the human population . The forest is isolated and surrounded by Lilongwe Wildlife Trust, roads, agricultural structures, and settlements. Malawi’s largest city is rapidly encroaching upon the wilderness reserve. Multiple threats such as human settlement expansion, logging, hunting, invasive species, human-wildlife conflict, and habitat loss are all factors that are affecting the flora and fauna that inhabit the Lingadzi Namilomba Forest Reserve.

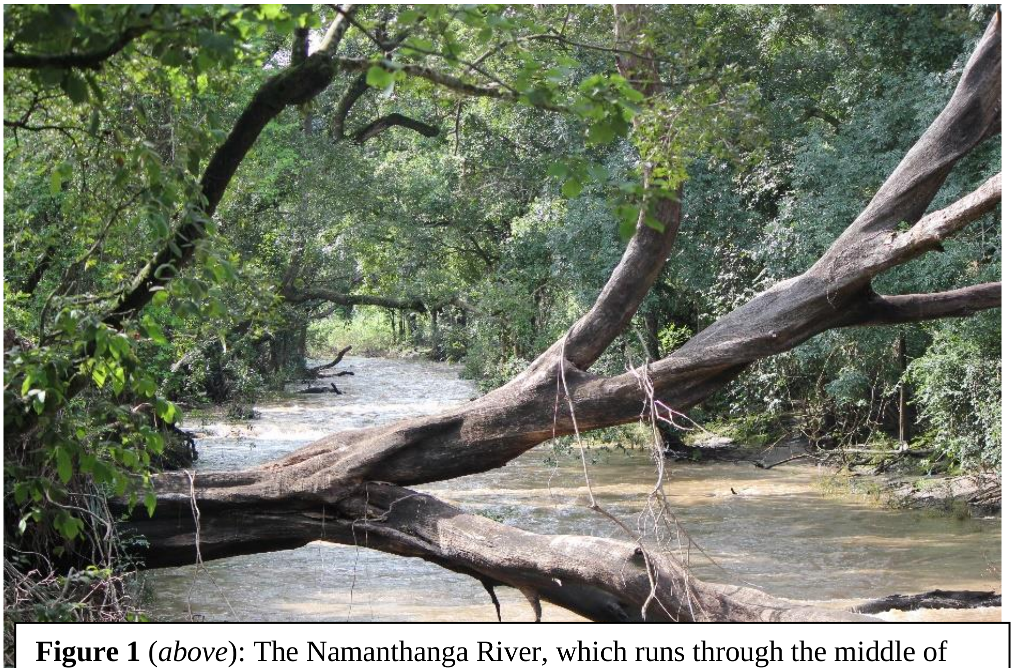

**Figure 1** (*above*): The Namanthanga River, which runs through the middle of the Lingadzi Namilomba Forest Reserve.

The objective of this study was thus, to conduct the first systematic assessment of wildlife and forest cover of the nature reserve. This was to provide a baseline study that can be used by local authorities to rationally monitor and manage the reserve. The current threats were also assessed in order to prepare an Action Plan to mitigate these threats.

The future stability of the reserve, the wildlife within and the surrounding inhabitants are dependent on the success of the research being conducted for this study.

## 1.1 Background

With a growing population of 18.4 million people and a large variety of habitats and biodiversity, human wildlife conflict exists in many forms within Malawi. Human-wildlife conflict occurs when wildlife poses an immediate and recurring threat to humans safety and livelihood, which typically leads to retaliation and persecution of that species, thus leading to further conflict on how the situation should be managed (IUCN, 2020b). The need to protect and conserve wild areas and species is receiving growing attention. However, the people who are facing the impact of the conflict are often disregarded (Ali, 2015). The conflict is often overlooked until irreversible damage has been done to the wildlife. There is, therefore, an urgent need to research the existing issues within Lingadzi Namilomba Forest Reserve to mitigate the conflicts to benefit both humans and wildlife (Ali, 2015). Urbanization is occurring at an excessive rate within Lilongwe, and has negative implications for the natural ecosystems that exist within the city (Ramkissoon, 2005). The growth is having a significant effect on the natural habitats such as Lingadzi Namilomba Forest Reserve, which is now being shaped by habitat destruction, fragmentation and modification (Ramkissoon, 2005), thus increasing the human-wildlife conflict within the reserve. The reserve has become completely isolated, as it is surrounded by human activity.

Fragmentation is the transition of forest areas into agricultural lands as the land is converted into a built up urban environment (Ramkissoon, 2005). This process can convert a once thriving ecosystem into an unstable environment due to decreased resilience, interbreeding of wildlife populations, confinement and conflict (Thompson, 2003). This can also cause faunal and floral species to be unable to cope with the vast changes, causing them to struggle to survive and decline in population numbers, resulting in endangerment or extinction (Ramkissoon, 2005).

However, some species, such as vervet monkeys (*Chlorocebus pygerythrus),* can adapt and thrive within these modified environments. This can be due to several factors, including a year round food supply from the neighboring maize farms or the absence of natural predators (Ramkissoon, 2005). Although a thriving species may appear to be a positive result of the new modified environment, it can cause irreversible damage, such as an over-population in a small isolated space, leading to an increase of human-wildlife conflict, interbreeding and outcompeting other species. This ultimately leads to a loss in biodiversity.

Within this study the most abundant mammal species was the vervet monkey, common duiker (*Sylvicapra grimmia*) and Cape bushbuck (*Tragelaphus sylvaticus*). There was also significant evidence that spotted the presence of hyena (*Crocuta crocuta)*. Mammals such as hyena and vervet monkeys are regarded as pests or vermin and a threat to human livelihoods, thus are killed by farmers and face human retaliation (Mikula et al, 2018). Primates, hyena and bushpigs (*Potamochoerus larvatus*) are widely identified as a problem animal in Malawi and across Africa (Anthony & Wasambo, 2009) due to livestock and crop raiding. One of the key forms of human-wildlife conflict is crop raiding, which has been perceived as the most important disadvantage of farming close to natural wildlife areas (Archabald & Naughton-Treves, 2001). This is due to a wide range of species being able to have a destructive effect on agriculture (Chiyo & Cochrance, 2005), which creates a huge issue for farmers trying to make a living and feed their communities. This results in conflict between the farmers and the wildlife.

With the human and primate population increasing, these conflicts are escalating rapidly within the reserve. There are some measures in place aimed to reduce the human-wildlife conflict such as fencing, guarding and noise (Woodroffe, Thirgood, & Rabinowitz, 2005). However, these procedures aren’t as effective as desired. The fences between the reserve and the farms are damaged and the animals have a reduced fear of humans. There is a need for new measures to be introduced to mitigate these building conflicts. Damaged fences are also a result of human activity due to illegal logging and poaching, which regularly occurs within the reserve, as people cut holes in the perimeter fence to gain unauthorized access to the reserve. The logged trees are used for firewood and charcoal, which is used for cooking in the rural settlements surrounding the reserve (UN-Habitat, 2011), therefore adding to the fragmentation pressures that are already present.

Human-wildlife conflict in densely populated, low-income countries is an increasing challenge for conservation initiatives (McGuinness & Taylor, 2014), authorities and local communities (Hill, 2014). The task of meeting development goals and mitigating conflict is repeatedly associated with natural resource pressures (McGuinness & Taylor, 2014). There is a lack of locally suitable and efficient ways of reducing the conflict, which has led to a mutual feeling of alienation and a lack of care, which is typically the view among rural African populations that are situated adjacent to natural wildlife areas (Hill, 2014). Thus, in-depth research would be extremely beneficial for the wildlife within the Lingadzi Namilomba Forest Reserve and the locals that have settled adjacent, to find solutions and mitigate further conflict and distress to both factions.

As previously mentioned, Malawi is known for its plant biodiversity. However, Lilongwe's human growth expansion is causing Lilongwe's only biodiversity hotspot to become an isolated, dwindling pocket of wildlife within Malawi's capital city. Only recently has there been a few taxonomic revisions of African tree genera being published, thus it is of high importance to research floral biodiverse hotspots such as Lingadzi Namilomba Forest Reserve (Versteegh & Sosef, 2007; Botermans, Sosef, Chatrou & Couvreur, 2011). The reserve's native species forest cover consists of *Brachystegia* sp. woodland and pockets of evergreen forest (Overton & Overton, 2007). However, the native trees within the reserve face several threats including deforestation, habitat degradation, illegal logging, and invasive species. The invasive *Gmelina arborea* poses a threat to the forest, as it currently occupies more than 50% of the forest cover. This tree has been logged for firewood and charcoal, however it has also been known to be toxic to the wildlife, fast growing and nutrient absorbing, thus taking vital resources away from native trees, which the wildlife currently depend on for survival.

Invasive alien species and illegal logging are now recognized as a serious problem within Malawi, which need to be addressed. Both major drivers of deforestation are imposing a direct threat to Lingadzi Namilomba Forest Reserve. Therefore, the research conducted within this study produce the first systematic assessment of the rate of devastation these major international and national threats are having on one of the only pockets of wildlife remaining within the capital city.

## 1.2 Objectives

As the forest is split into two sections, due to accessibility, the area of $0.366km^2$ situated within the Lilongwe Wildlife Trust's wilderness trails is the area being studied. This study begins by assessing the abundance and distribution of the tree and mammal species present within the reserve. It then assesses the extent and magnitude of the threats and ecological factors within and surrounding the area. This is then evaluated with the aim of creating measures and a management plan aimed to mitigate further threats to the reserve and the neighboring inhabitants.

The aims are to assess the threats and ecological factors that are affecting the abundance and distribution of free ranging mammals within the Lingadzi Namilomba Forest Reserve within Lilongwe, Malawi. Using the line transect sampling method, belt transects and 10x10 quadrats, data was collected and processed to create a management and conservation action plan to ensure the long-term protection of the forest reserve and the wildlife within. The main objectives are thus:

1) To collect data on the abundance and distribution of mammals using the line transect method.
2) To carry out a botanical inventory of trees within the reserve.
3) To determine the abundance and distribution of the invasive *Gmelina arborea* tree.
4) To assess the main threats and contributing factors affecting the mammals within the reserve using the Miradi software.
5) To devise a long-term management and action plan, which benefits the local people surrounding the area, in addition to the wildlife to mitigate any further conflict.

The main goal of this study is to explore the native trees associated within the Lingadzi Namilomba Forest Reserve's ecosystem and to consider the links between the tree life, wildlife, and their threats. Objective one and two are achieved by using the line and belt transecting method to examine which mammal and tree species are present within the reserve, whilst recording data on quantity and location to create the ecological profile and tree inventory (Overton & Overton, 2007), which results in reliable data to manage the reserve. This technique can also show the progressive succession between the native tree species, the invasive species and where the two ecosystems merge into each other (Overton & Overton, 2007). This is used to achieve objective three.

The animals within the reserve depend on the different native trees for food, shelter, territory, raising their young and safety. Therefore, it is important to understand the relationship between the wildlife and trees to understand which species of tree is thriving and supporting the wildlife to be able to encourage a healthy ecosystem.. Knowing which trees are being used by which mammals species  helps to locate and monitor these animals efficiently (Overton & Overton, 2007). Objective four uses the Miradi adaptive management software for conservation projects to assess the threats being observed during the line transect field study. These threats are assessed using a target viability assessment and threat ratings. This helps to determine the main factors affecting the mammals and trees within the reserve and how to create the most effective strategies to reduce them. This results in the accomplishment of objective five as the Miradi software is used as a tool to create a conceptual model to generate a management and conservation action plan for Lingadzi Namilomba Forest Reserve.

# Chapter Two: Methods

Lingadzi Namilomba Forest Reserve does not have a management plan, or any previous research conducted within the forest. In this study we used line transect census to survey the local wildlife and carry a botanical inventory using belt transects and 10x10 quadrats. With these methods we fully assessed the abundance and distribution of mammals and trees, as well as evaluated the threats damaging the biodiversity within the reserve using viability assessments and threat ratings within the Miradi software.

## 2.1 Study site

From the 4th February until the 9th April 2019 line transects were created and data was collected from the Lingadzi Namilomba Forest Reserve. Lingadzi Namilomba Forest Reserve is situated along Kenyatta Drive and comprises the wilderness trails at Lilongwe Wildlife Trust in Lilongwe, Malawi (see **Fig.2**.). The Namanthanga river runs through the middle of the forest creating the two sections. However the wilderness trails located within the Lilongwe Wildlife Trust was the area sampled with an area of 0.366km2 (see **Fig.2**.).


**Figure 2** (*above*): A birds eye view of the city of Lilongwe and the Lingadzi Namilomba Forest Reserve to demonstrate the isolated pocket of forest. The red outline indicates the area of the reserve used within this study (GoogleEarth, 2020).

## 2.2 Preparation of transects

The line transect sampling method was used to collect data for this study. Prior to data collection, the transects were created and cleared to enable the observer to conduct research effectively without being detected or causing disturbance to the wildlife. The area studied within the wilderness trail section of the reserve within Lilongwe Wildlife Trust consists of four trails: Blue, Yellow, Red and the perimeter trail. The section of the forest across the river was inaccessible.

The main trail in the observation area started at the beginning of the wilderness trails (see **Fig.3** and **Fig.4**.) and followed the river to the other side of the forest. This trail was named Transect A and was used to plot the starting points of each transect. A systematic line transect sampling method was used for this study. Starting from the beginning of the main trail with Transect A, the transects were plotted every 100m using a 100m measuring tape. There were 14 transects across 1400m, which is displayed in **Figure 3**. White string and GPS co-ordinates were used to locate and plot the transects onto google maps to indicate where each transect begins.

Once the starting point for each transect was determined, each transect was created and cleared. Using a compass and a measuring tape each transect was plotted. A straight line was walked to the bearing of 240’SW (south-west) at all times to ensure a straight line for equal transect lines. A machete was used to create a small path to allow the observer to pass through the vegetation without causing disturbance. Tall grass and branches were cut down to create a path for each transect. However when encountering anything bigger, such as a tree or shrub, the transect would then go around these objects and then continue back on track following the bearing of 240’SW on a compass. Transect 10 was a small transect of 50m due to inaccessibility with a thick thicket and no way around. The measuring tape and a DISTANCE tracker app was used to calculate the length of each transect. Along each transect line white string was tied in a bow around the trees to indicate the path.

There were three additional transects that were also used to plot data. Transects A, B and C. As mentioned, Transect A was the main trail. Transect B was the trail that ran through the middle of the forest from start to end. Transect C was the perimeter trail, which began alongside Transect B and then looped around the perimeter of the forest to join Transect 14 at the end of the trails. These Transects were already made and had clear paths already in place as they are used as wilderness trails for the public (See **Fig.3.**).

Once the transects were created they were left untouched for at least 24 hours to ensure the wildlife activity returned to normal.


**Figure 3** (*above*): This map displays the transects within Lingadzi Namilomba Forest Reserve (QGIS, 2020).
**Key:** T: Transect, : Main transects 1-14 that were created, : Transect A, : Transect B and : Transect C.
Transects A, B and C were already existing paths.


**Figure 4** (*above*): The start of the wilderness trails within the Lingadzi Namilomba Forest Reserve and the starting point at 0m of Transect A and B.

## 2.3 Mammal data collection methods

Abundance and distribution data of the mammal species within Lingadzi Namilomba Forest Reserve was collected using the 14 transects during the same time as stated previously. Estimating abundance and distribution of mammals within the forest included species such as primates, antelope, and other large mammals. These mammals were sampled using the line transect DISTANCE sampling method.

The transects were walked and surveyed every day by a single observer. Surveys began between 6am-11am and 2pm-6pm. There were no surveys conducted at midday due to midday heat, as the wildlife was less active during that time. Transects were surveyed in the morning or in the afternoon. The reserve is a small area, therefore once observations had been conducted for four hours in the morning the forest had been disturbed. Therefore, if observations were conducted in the afternoon in the same day, the data could be corrupt due to the disturbance in the morning. A system was used to choose which transects to sample each day. Either the odd transects were observed or the even, in numerical order. For example, on day one Transect 1,3 and 5 were observed in the morning. Day two Transect 7, 9, 11 and 13 were also observed in the morning. Then on day three the same was repeated for Transect 2, 4 and 6, then day four 8, 10, 12 and 14. Trails A, B and C were then walked the following day. The following day this system was repeated, but in the afternoon. This was repeated continuously until the end of the data collection period.

The Chi-Square Goodness of Fit was used for the data analysis using the DISTANCE software to estimate the abundance and density of mammals using the data collected within Lingadzi Namilomba Forest Reserve (see **Appendix**).

### 2.3.1 Methods for species inventory

At the start of each transect walk the start time, weather, transect number and the identification of the observer was recorded. The distance tracker 'GPS-Tracker Pro' was started at 0m when the observer began to walk the trail. Transects were walked at a slow pace of 1km per hour and there were regular stops every 20m to increase detection of wildlife. When an animal was detected, the distance measuring app 'Easy Measure' was used to determine the distance the animal was from the observer. The perpendicular distance (distance from the animal to the transect line) and position (position in the canopy or on the ground) of the animal was recorded. The iPhone SE's camera using the distance measuring app was pointed at the center of the 'cluster' when a group of animals were detected to get an accurate perpendicular distance. The distance measuring app and the distance tracker app were both tested using a 100m measuring tape at the beginning of each day before any surveys were conducted to assess the accuracy of the app. Both apps were downloaded to an iPhone SE. This method was used due to lack of resources and funds.

When possible, binoculars were used to collect other essential data during a sighting such as species, age, gender, and the number of individuals seen. The position on the census was also recorded (where on the transect the animal was seen) using the distance tracker, as well as the GPS co-ordinates and the altitude. Data was only collected when the animal was physically seen. A maximum of 15 minutes was spent collecting this data. Once all the data was collected for each sighting the observer continued along the transect and repeated the procedure each time a mammal was detected and seen.

### 2.3.2 Methods for evidence data collection

Whilst collecting data on the transects for mammals, other data collections for evidence of the mammals were also collected. For example, if a track (hoof or paw print), feces, fur or a dead animal was found, it was also recorded as evidence that a certain species of mammal was present within the area. The date, time, transect, location on the transect, the type of evidence found, what species it was from, perpendicular distance, GPS co-ordinates, altitude and any additional notes were recorded into a data sheet, which was then inserted into an excel spreadsheet with all of the other data collections. A picture was taken using a canon 550D camera of each item found to ensure the correct identification was made. Certain food types were also recorded, such as corn (maize) from the neighboring farms as it was evidence that vervet moneys had been present and it gave an indication of troop size. Once all the data had been collected the observer continued along the transect and repeated the procedure upon each sighting.

**Figure 5** (*above*): Female Cape bushbuck that was observed during a sighting along transect 9, whilst crossing trail B.

## 2.4 Threats data collection

During the field observations different threats were identified, including, human-wildlife conflicts, infrastructure fragmentation, including vehicle-wildlife collisions from the adjacent roads and the invasive tree species affecting the mammal's distribution. The information on these threats were collected through observations during the study period, for example, when the farmers were seen chasing vervet monkeys or using slingshots to deter them from stealing their corn, the time, date, transect and the number of individual vervet monkeys spotted was documented. The threats were then discussed with the Lilongwe Wildlife Trust's personnel on the effects of these threats and the rate of occurrence. After the fieldwork had been completed, the threats observed were analysed using the Miradi adaptive management software for conservation projects. The Miradi tool assessed the threat ratings and created a viability assessment to establish the overall severity of the threats on the reserve. See **Chapter Five: Action Plan, Section 5.3. Threats** for the results of this method.


**Figure 6** (*above*)*:* These animals are some of the mammals observed whilst transecting during this study. **A**: Vervet monkey (*Chlorocebus pygerythrus*)*;* **B**: Spotted hyena *(Crocuta Crocuta)* (Poeticpenguin, 2019)*;* **C**: Common duiker *(Sylvicapra grimmia)*; **D**: Male Cape bushbuck *(Tragelaphus sylvaticus)* (Naizgi Ethiopia Tours, 2019); **E**: Female Cape bushbuck *(Tragelaphus sylvaticus)* (Sharp, 2018); **F**: Mohol bushbaby (*Galago moholi*) (Doyle, 2008); **G**: Bushpig *(Potamochoerus larvatus)* (Sloviak, 2020); **H**: African civet *(Civettictis civetta)* (Ando di, 2010); **I**: Serval *(Leptailurus serval)* (Dlamini, 2018) and J: Cape porcupine *(Hystrix africaea)* (Chester Zoo, 2020).

## 2.5 Tree data collection methods

The same starting process as the species data collection was applied for the tree data collection. Whilst walking along the transects, the observer also looked for fruit trees to establish natural food sources. Each time a fruit tree was spotted, the observer logged the following: date and time; the transect they were on; the location on the census; the species of the tree; a scan of how many there were in that area; perpendicular distance from the trail; the height and diameter of the tree; GPS and the altitude of where the tree was situated. A picture of the tree was also taken, so the observer could clarify exactly what species of tree it was. A maximum of 15 minutes was spent collecting these data. Once all the data had been collected, the observer continued along the transect and then repeated the procedure each time a tree was observed.

### 2.5.1 Tree inventory data collection

A tree inventory was created from the tree data collection using the belt transect sampling method to establish the native tree species within the reserve (Krebs, 1989). The size of the sample area for the tree inventory data collection was 303.104m. Transects 1, 3, 5, 7, 9, 11, and 13 were chosen for the data collection process. Any tree that was visually seen within five metres either side of the transect and had a DBH (diameter at breast height) more than 10cm, data was collected. A picture was taken of the tree using a canon 550D, the transect was noted, the location along the transect, distance from the transect, the species of tree, the DBH, height (estimation), altitude the tree is situated and the GPS was taken for each tree observed. A 100m measuring tape was used to take the tree and distance measurements.

### 2.5.2 Invasive species

The invasive tree species *Gmelina arborea* (see **Fig.7.**) comprised over 50% of the forest reserve. Therefore, a separate data collection survey was conducted to assess the densities of the invasive species using 10m by 10m quadrats. These data collection methods were necessary to establish the presence and the distribution of the *G. arborea.*

Once the transects were plotted and prior to the data collection process, the *Gmelina arborea* density was calculated. Starting from 0m and thereafter every 50m on each transect a density estimate was recorded until the end of the transect. A scale was made prior to the estimations in accordance with the concentration of *G. arborea* within the forest. Every 50m a scan was conducted to count the *G. arborea* in sight from the position of the observer. If there were less than 10 trees, it was classed as a low density zone. If there were between 10 and 100 trees, it was classed as a medium density zone, and if there were more than 100 trees it was classed as a high density zone. Once the *G. arborea* data collection had been conducted on every transect, the quadrat study was then conducted for a precise density and distribution determination.

Prior to the *G. arborea* density data collection the quadrats needed to be created. Different areas within the forest were assessed for areas the *G. arborea* were thought to be in low, medium, and high densities. 10mx10m quadrats using a 100m measuring tape were then placed in these areas. The position, distance from the transects and GPS co-ordinates of each quadrat was noted. Once the quadrats had been placed a count was conducted to examine how many *G. arborea* trees were within each quadrat. The DBH (diameter breast height) was taken for every tree within the quadrat to keep track of each tree counted. This study was repeated multiple times along different and random transects in various areas of low, medium, and high-density areas to get an accurate measurement of the distribution and density of the *G. arborea.* After the *G. arborea* evaluations were conducted the reserve was left undisturbed for at least 24 hours to ensure the wildlife activity returned to normal after being disturbed.

L

M

N

**Figure 7 (*above*):** Images **L, M and N** display the invasive *Gmelina arborea* tree, which is the invasive species that is a threat to the ecosystem within the Lingadzi Namilomba Forest Reserve. **L**: *Gmelina arborea* leaf (Churi, 2020); **M**: Multiple *Gmelina arborea* trees (Morad, 2019); and **N**: *Gmelina arborea* trunk of tree growing at Kahanu Gardens (Starr and Starr, 2019).

# Chapter Three: Results

## 3 Mammal results

### 3.1 Transects

During the duration of this study each transect was walked a total of eight times, which is displayed in **Table 1**.

**Table 1** *(below):* This table displays the transects length and the total effort (distance covered) walked throughout mammal data collection process.

| Transect | Length of Transect (m) | Total Effort (Distance Covered) (m) |
|---|---|---|
| 1 | 90 | 720 |
| 2 | 140 | 1,120 |
| 3 | 110 | 880 |
| 4 | 640 | 5,120 |
| 5 | 510 | 4,080 |
| 6 | 580 | 4,640 |
| 7 | 650 | 5,200 |
| 8 | 540 | 4,320 |
| 9 | 360 | 2,880 |
| 10 | 50 | 400 |
| 11 | 310 | 2,480 |
| 12 | 210 | 1,680 |
| 13 | 240 | 1,920 |
| 14 | 306 | 2,448 |
| A | 1400 | 11,200 |
| B | 1883 | 15,064 |
| C | 1207 | 9,656 |

### 3.2 Mammal Surveys

**Table 2** shows the 11 mammal species found whilst using the line transect sampling method. The main mammals observed can be seen in **Figure 6**. 199 individual mammals across 62 different encounters occurred within the line transect sampling method survey, which is displayed in **Table 2**. For example, 142 vervet monkeys were counted across 20 encounters, therefore vervet monkeys were presently seen 20 times during the study. However, during the majority of these encounters there were more than one vervet present, typically between 5 and 20 individuals and occasionally higher. Thus, one encounter could result in 20 different individuals being seen. There were two different vervet monkey troops identified. The Lilongwe Wildlife Trust had identified the two troops before the study had begun. It is possible that there was one large troop, however they were often split into two locations when observations took place with one troop occupying the observation area and the other troop living across the river, but frequently crossing into the observation area in search for food. Therefore, more studies into the troops and individual vervet monkeys would be needed to confirm the number of troops and troop size.

Tracks, feces, hair, and corn were also recorded for evidence of the animal's movements and presence. **Table 2** shows that 159 pieces of corn was found across 20 different encounters, thus showing evidence of vervet monkeys being present, as they would take the corn from the neighboring farms daily. This was important data to collect as it indicated the troop size for the amount of corn pieces found in one area, it revealed the rate at which the corn was being taken and it displayed the human-wildlife conflict occurring within the reserve.

**Table 2** also displays the Mohol bushbaby (*Galago moholi*) within the table, however there were no sightings recorded for the species during the study. The bushbaby was included as it was spotted outside the study hours, for example during a night walk. A regular night walk occurred through the reserve to gain insight into other mammals that may live within the reserve. Although, possible feces were found for the bushbaby during the surveys and due to seeing more than 20 individual bush babies during the study period, but not within the actual survey, it was important to note their presence for the conservation action plan.

**Table 2** *(below):* This table displays the mammals that were observed during the study. It shows the individuals counted, the amount of encounters, tracks, feces, hair and corn, which was evidence of the species presence within the reserve.

| Mammal Species | Individuals seen | Transect Encounters | Tracks | Feaces | Hair | Corn | Corn Encounters |
|---|---|---|---|---|---|---|---|
| Vervet monkey (*Chlorocebus pygerythrus)* | 142 | 20 | 3 | 3 | 0 | 159 | 20 |
| Common Duiker *(Sylvicapra grimmia)* | 38 | 27 | 191 | 20 | 1 | 0 | 0 |
| Cape Bushbuck *(Tragelaphus sylvaticus)* | 15 | 13 | 60 | 19 | 0 | 0 | 0 |
| Serval *(Leptailurus serval)* | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Spotted Hyena *(Crocuta crocuta)* | 1 | 1 | 2 | 5 | 0 | 0 | 0 |
| Bushpig *(Potamochoerus larvatus)* | 3 | 1 | 8 | 1 | 1 | 0 | 0 |
| African Civet *(Civettictis civetta)* | 0 | 0 | 3 | 1 | 0 | 0 | 0 |
| Black backed Jackal *(Canis mesomelas)* | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| Crested Porcupine *(Hystrix cristata)* | 0 | 0 | 4 | 2 | 2 | 0 | 0 |
| Common Genet *(Genetta genetta)* | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Mohol bushbaby *(Galago moholi)* | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **199** | **62** | **276** | **53** | **4** | **159** | **20** |

The vervet monkey was the mammal that recorded the most sightings and encounters (see **Table.2. and Fig.8.**). **Figure 8** shows that the vervet monkey, common duiker and the cape bushbuck were the most prevalent mammal species within the reserve, which is why their data has been used within the DISTANCE software and Miradi, to be used as representation of the mammals species within the reserve to create a viable action and habitat management plan.

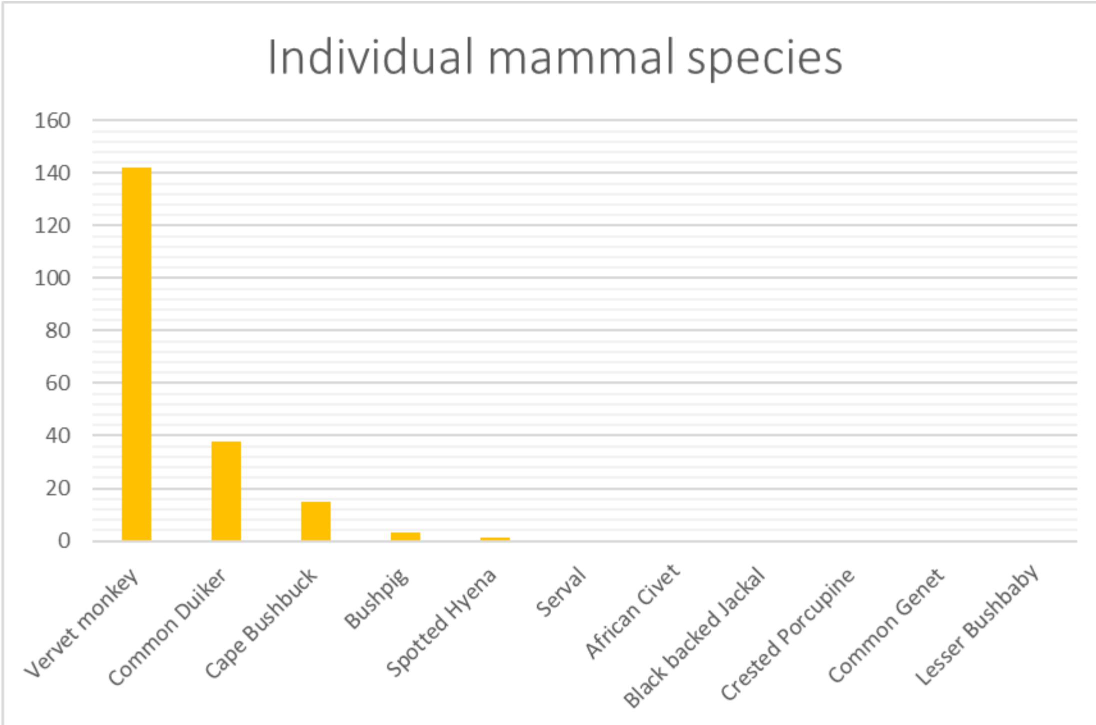


**Figure 8** (*above):* This bar chart displays the quantity of individual mammal species sightings' that occurred during the study.

## 3.3 Distribution of mammals

**Figure 9** displays the distribution of the mammals that were observed along the transects within Lingadzi Namilomba Forest Reserve. **Figure 9** also indicates the distribution of native and invasive trees within the reserve. The map within **Figure 9** signifies that most of the mammals reside within the areas where the native trees are situated, thus with only a few mammals observed within the invasive tree areas. The most common species observed within the invasive tree areas were the vervet monkey, which is also where the corn taken from the adjacent farms were observed (see **Table.2.**). **Figure 9** shows that the invasive tree species *Gmelina arborea* is the most prominent species along Transect C (the perimeter fence), in addition the vervet monkeys were observed in locomotion through the invasive tree area to reach the cornfields adjacent to the reserve. However, the vervet monkeys observed within the native tree areas were a larger troop size, resting and eating, suggesting they occupy within the native tree areas and use the invasive tree areas as a route to the corn fields. **Figure 9** also suggests the vervet monkeys reside within the native tree areas due to the troop populations sizes observed, as the population within the native tree sections show individuals of more than seven. Though, most of the sightings within the invasive tree sections contained two to six individuals. Therefore, indicating a smaller group of individuals leaving the troop to find food.


**Figure 9** (*above*): This map displays the distribution of mammals within Lingadzi Namilomba Forest Reserve that were observed within this study (QGIS, 2020).

**Key:** *Mammals:* Vervet monkey: ● , Common duiker: ● , Cape bushbuck: ● , Spotted Hyena: ● , Bush pig: ● .

*Number of individuals:* 1 individual: ● , 2-3 individuals: ● , 4-6 individuals: ● , 7+ individuals: ●

*visual representation on how the animals and the number of individual species is displayed within the map and not to scale.

*Trees:* Native: ▬ and Invasive: ▬ .

## 3.4 DISTANCE results

The vervet monkey, common duiker and cape bushbuck data was entered into DISTANCE 7.3 and analysed to estimate the species population size within the Lingadzi Namilomba Reserve to represent all mammals within the reserve. **Appendix I** displays the methods used to achieve these results.

### 3.4.1 Vervet monkey

**Figure 10** displays the detection probability, which indicates how likely it is for mammal detection the closer or further away to the transect the observer is. **Figure 10** indicates that the detection rate is higher closer to the transect, therefore there is a gradual line of fit to show that detection is less likely away from the transect. The figure shows a high 99% probability of vervet detection within 3m of the transect, with only a 20% chance of detection between 9m and 12m away from the transect. **Table 3** shows the results of the Chi-square Goodness of Fit results with a p-value of 0.71505 and a Goodness of Fit of 0.6708, therefore this test accepts the null hypothesis.

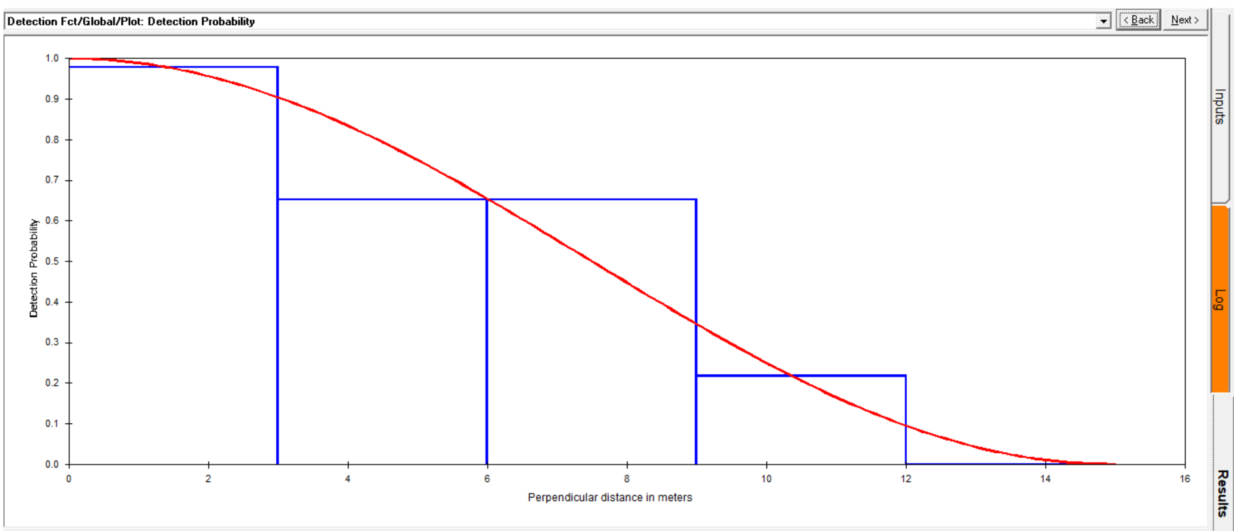


**Figure 10** *(above):* This graph displays the DISTANCE detection probability for the vervet monkeys, which shows the detection probability of observing vervet monkeys against the perpendicular distance in metres (distance from the transect to the animal).

**Table 3** shows that the Uniform Cosine model definition was the best fit for the vervet monkey data, with a high P-value of 0.71505 and a low AIC of 62.12. **Table 3** indicates the results of the test showing an estimated total number of 154.814 individual vervet monkeys within the Lingadzi Namilomba Forest Reserve. **Table 3** also provides an estimation of the lowest number of individuals within the forest with 84.412 and the highest possible density of 283.932. The truncation of 15m means that data was only taken if the animal was within 15m of the transect, therefore any animals further than 15m the data has been erased for that test. During this truncation only five units of data were erased due to being 15m, for example one was 200m and two were 50m as they were across a river and were insignificant to this test.

**Table 3** (*below):* This table displayed the estimated DISTANCE P-value, Goodness of Fit and the density results of the Uniform Cosine with 5 intervals and 15m truncation, which was thought to be the best fit with the vervet monkey data.

| Model definition | Intervals | Truncation | Total number of individuals | Number of individuals analytic lower | Number of individuals analytic high | Density of individuals analytic coeff of variation | P-Value | Goodness of Fit |
|---|---|---|---|---|---|---|---|---|
| Uniform Cosine | 5 | 15m | 154.814 | 84.412 | 283.932 | 0.306 | 0.71505 | 0.6708 |

### 3.4.2 Common duiker

**Figure 11** displays the DISTANCE detection probability for the common duiker. The figure shows a 95% chance of detecting a duiker within 4m of the transect versus a 5% chance of seeing a duiker between 16m and 20m from the transect. This is a good line of fit due to the observation taking place in high foliage with thick bush and forest cover, therefore it would be difficult to observe animals too far away from the transect, which results in a higher probability in seeing animals close to the transects.

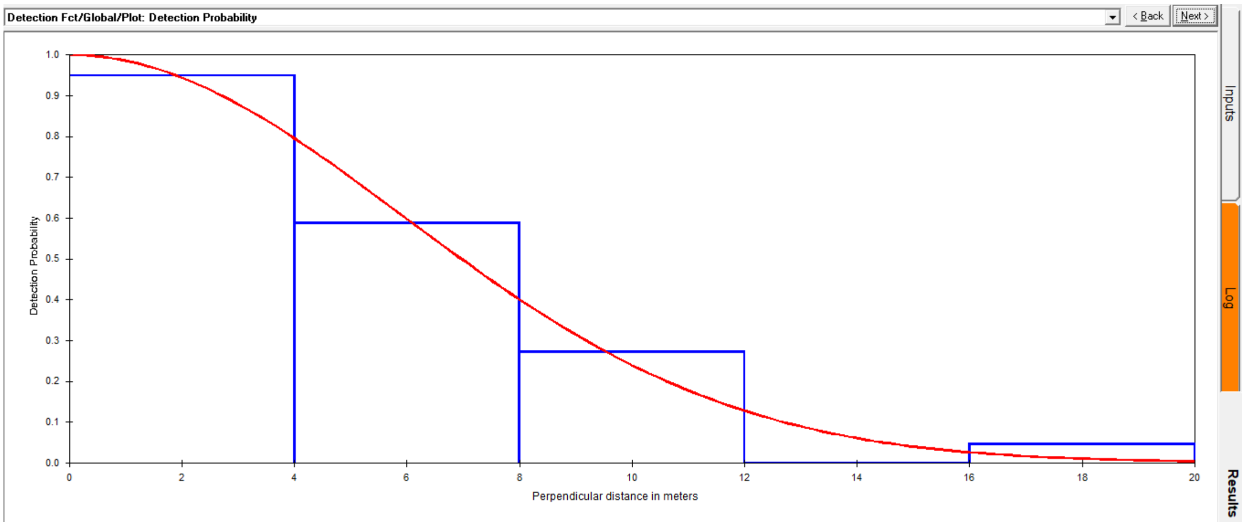


**Figure 11** *(above):* This graph displays the DISTANCE detection probability for the common duiker, which shows the detection probability of observing duikers against the perpendicular distance in metres (distance from the transect to the animal).

**Table 4** shows a high P-Value of 0.88790 and a Goodness of Fit of 0.0199 using the Chi-square Goodness of Fitness Test. The models Half Normal Cosine and Half Normal Hermite Polynomial both received the same results when run with 5 intervals at 20m truncations. It is also important to note that there were no data units over 20m, therefore all the common duiker data was included within this test.

**Table 4** also indicates an estimated total number of 42.575 individual duikers within the Lingadzi Namilomba Forest Reserve. The table also shows a low density of 26.769 and a high density of 67.712 individuals living with the reserve. With 38 individuals observed during the study (see **Table.2.**) a density of 42.575 individuals is a reliable result.

**Table 4** *(below):* This table displayed the estimated DISTANCE density results of the Half Normal Cosine and the Half Normal Hermite Polynomial with 5 intervals and 20m truncation, which was thought to be the best fit for the

| Model definition | Intervals | Truncation | Total number of individuals | Number of individuals analytic lower | Number of individuals analytic high | Density of individuals analytic coeff of variation | P-Value | Goodness of Fit |
|---|---|---|---|---|---|---|---|---|
| Half Normal Cosine | 5 | 20m | 42.575 | 26.769 | 67.712 | 0.230 | 0.88790 | 0.0199 |
| Half Normal Hermite Polynomial | 5 | 20m | 42.575 | 26.769 | 67.712 | 0.230 | 0.88790 | 0.0199 |

### 3.4.3 Cape bushbuck

**Figure 12** displays the DISTANCE detection probability for the Cape bushbuck. The figure displays a good line of fit as it shows the best detection for the Cape bushbuck was at 0m on the transect, indicating the closer to the transect the higher the chance of detecting the animal. The Cape bushbuck were mostly observed in dense bush areas within the reserve, thus making it difficult to see away from the transect trail, therefore supporting the results found in **Figure 12.**

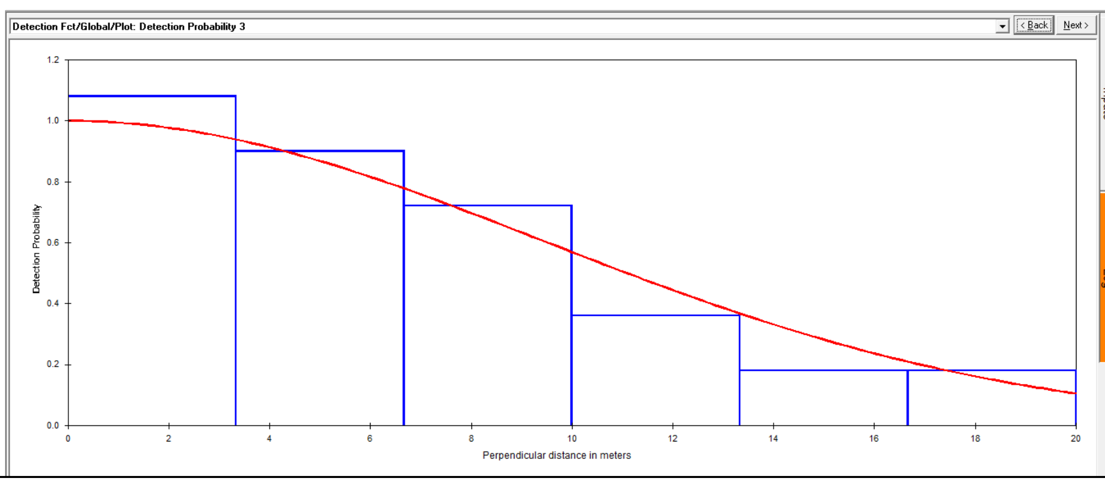


**Figure 12** *(above):* This graph displays the DISTANCE detection probability for the Cape bushbuck, which shows the detection probability of observing bushbuck against the perpendicular distance in metres (distance from the transect to the animal).

**Table 5** shows a high P-Value of 0.96161 and a Goodness of Fit of 0.2916 using the Chi-square Goodness of Fitness Test. The models Half Normal Cosine and Half Normal Hermite Polynomial received the same results when run with the default setting, therefore no set intervals or truncations were inserted. The default run resulted in six intervals and zero truncations, thus all the data collected for the Cape bushbuck from the line transect sampling method was included for these tests.

**Table 5** displays an estimated total number of 11.766 individual Cape bushbuck within the Lingadzi Namilomba Forest Reserve. The table also shows a low density of 5.216 and a high density of 26.543 individuals living within the reserve. 15 individual Cape bushbucks were observed during the study (see **Table.2.**), thus an estimation of 11.766 individuals is highly possible and a reliable result.

**Table 5** *(below):* This table displayed the estimated DISTANCE density results of the Half Normal Cosine and the Half Normal Hermite Polynomial with default setting, which was thought to be the best fit for the Cape bushbuck

| Model definition | Intervals | Truncation | Total number of individuals | Number of individuals analytic lower | Number of individuals analytic high | Density of individuals analytic coeff of variation | P-Value | Goodness of Fit |
|---|---|---|---|---|---|---|---|---|
| Half Normal Cosine | Default 6 | Default 0 | 11.766 | 5.216 | 26.543 | 0.41 | 0.96161 | 0.2916 |
| Half Normal Hermite Polynomial | Default 6 | Default 0 | 11.766 | 5.216 | 26.543 | 0.41 | 0.96161 | 0.2916 |

## 3.5 Tree Results

### 3.5.1 Transects

As previously mentioned, only the odd transects were walked for the native tree survey, although some trees were observed during the mammal observation process. **Table 6** displays the length of the transects walked for the tree inventory and the total effort for each transect.

**Table 6** *(below):* This table displays the transects length and the total effort (distance covered) walked throughout the tree inventory data collection process.

| Transect | Length of Transect (m) | Total Effort (Distance Covered) (m) |
|---|---|---|
| 1 | 90 | 90 |
| 3 | 110 | 110 |
| 5 | 510 | 510 |
| 7 | 650 | 650 |
| 9 | 360 | 360 |
| 11 | 310 | 310 |
| 13 | 240 | 240 |

### 3.5.2 Tree Inventory

**Table 7** displays the inventory of the tree species within the Lingadzi Namilomba Forest Reserve. There were 26 species found within the surveys, however 30 species are known to exist within the reserve. The table is also used to indicate which species are toxic, edible, and useful for human consumption, which can be used for the habitat management plan. These trees can be identified in **Figure 13.** The *Gmelina arborea* was the only invasive tree species identified within this study.

**Table 7a** (*below*)**:** This table displays the tree species and the number of each species recorded during the data collection process within Lingadzi Namilomba Forest Reserve. The table also illustrates whether the trees are hazardous, edible, good pollinators or used for human medicinal use. **Table 7b** (right)**:** This is the key to read **Table 7a**.

| **KEY:** | |
|---|---|
| Hazardous/Not Edible | Red |
| No Hazard/Edible | Green |
| Not Self Fertile | Orange |
| Insects Fertilize | Yellow |
| Useful Rating | /5 |

| **Tree Species** | **Count** | **Hazardous** | **Edible** | **Medicinal** | **Pollinators** |
|---|---|---|---|---|---|
| *Monotes africanus* | 33 | Green | Red | Red | Green |
| *Hexalobus monopetalus* | 14 | Green | Green | Green | Red |
| *Allophylus africanus* | 6 | Green | Green | Green | Green |
| *Ekebergia benguelenis* | 3 | Green | Green | Green | Orange |
| *Oldfieldia dactylophylla* | 6 | Green | Green | Green | Red |
| *Stychnos cocculoides* | 5 | Red | Red | Green | Red |
| *Pterocarpus sotundifolius* | 4 | Green | Red | Green | Green |
| *Flacourtia indica* | 1 | Green | Green | Green | Orange |
| *Bridelia duvigneaud* | 8 | Green | Red | Green | Red |
| *Ziziphus abyssinica* | 11 | Green | Green | Green | Green |
| *Zahna africana* | 11 | Red | Green | Green | Orange |
| *Brachystegia utillis* | 2 | Green | Red | Red | Red |
| *Schrebera trichoclada* | 15 | Green | Red | Green | Red |
| *Zanthoxylum capense* | 2 | Green | Green | Green | Red |
| *Acacia sieberana* | 11 | Green | Green | Green | Green |
| *Lantara camara* | 13 | Red | Green | Green | Green |
| *Colophospermum mopane* | 2 | Green | Green | Green | Red |
| *Xylopia odoratissima* | 3 | Green | Green | Red | Red |
| *Zylopia odoratissima* | 2 | Green | Green | Red | Red |
| *Pysychotria pumila* | 10 | Green | Green | Red | Red |
| *Grewia monticola* | 2 | Green | Green | Green | Red |
| *Pavetta lancelata* | 4 | Green | Green | Green | Green |
| *Solanum anguiri* | 1 | Red | Green | Green | Green |
| *Lilex mitis* | 2 | Green | Green | Green | Orange |
| *Feretia aeruginescens* | 5 | Green | Green | Red | Red |
| *Rhoitissus tomenesa* | 3 | Green | Green | Red | Red |
| *Gmelina arborea* | N/A | Red | Green | Green | Yellow |
| *Bridelia micirantha* | N/A | Green | Green | Green | Red |
| *Combretum molle* | N/A | Green | Red | Green | Green |
| *Combretum mossambicense* | N/A | Green | Red | Green | Green |

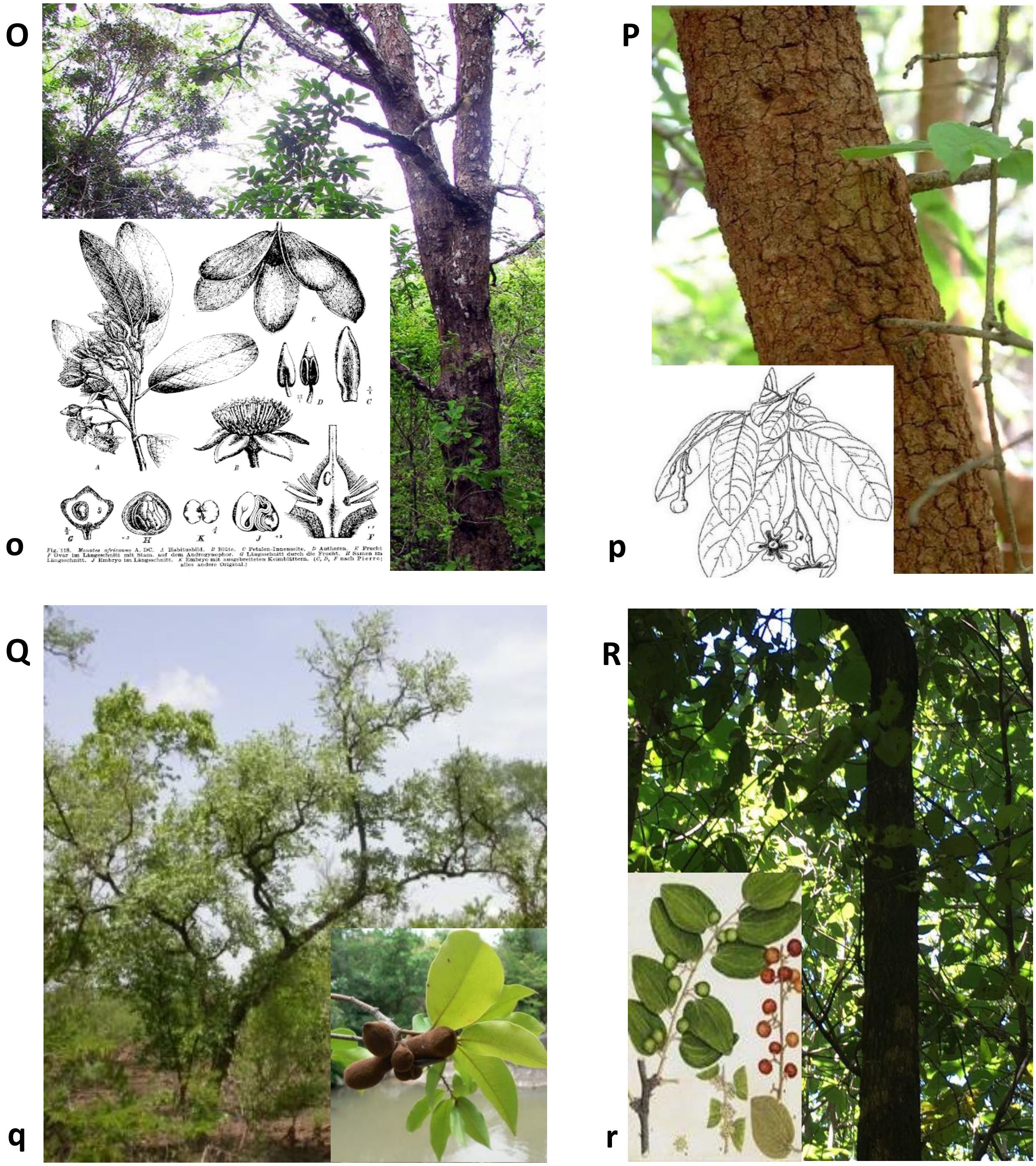


**Figure 13** (*above*): The images above display the most abundant native tree species within Lingadzi Namilomba Forest Reserve. **O:** *Monotes africanus* (Prota, 2020)**, o:** *Monotes africanus* (Prota, 2020)**, P:** *Schrebera trichoclada* (Burrett, 2020)**, p:** *Schrebera trichoclada* fruit and leaves drawing (Bingham, 1976)**, Q:** *Hexalobus monopetalus* (Birnbaum, 2019)**, q:** *Hexalobus monopetalus* ripening fruit (Baumann, 2019)**, R:** *Ziziphus abyssinica***, r:** *Ziziphus abyssinica drawing* (Burkill, 1985).

### 3.5.3 Tree Counts

**Table 7a** displays the trees found during the study. Due to the vast population of the *Gmelina arborea* a count would be too time consuming and difficult for a single observer with limited resources. Consequently, the 10x10 quadrat method was used to examine the abundance and distribution of *G. arborea*, which is displayed in section **3.5.5**.

**Figure 14** visually displays the tree species that are the most abundant in descending order. *Monotes africanus* had the highest abundance during this study with 33 individual trees observed (**Fig.14.**). The second most observed was *Schrebera trichoclada* with 15 individuals detected, therefore showing that *Monotes africanus* was more than double in abundance than the other native tree species. It was important to detect which native species are the most successful and abundant within the reserve for future habitat management plans.

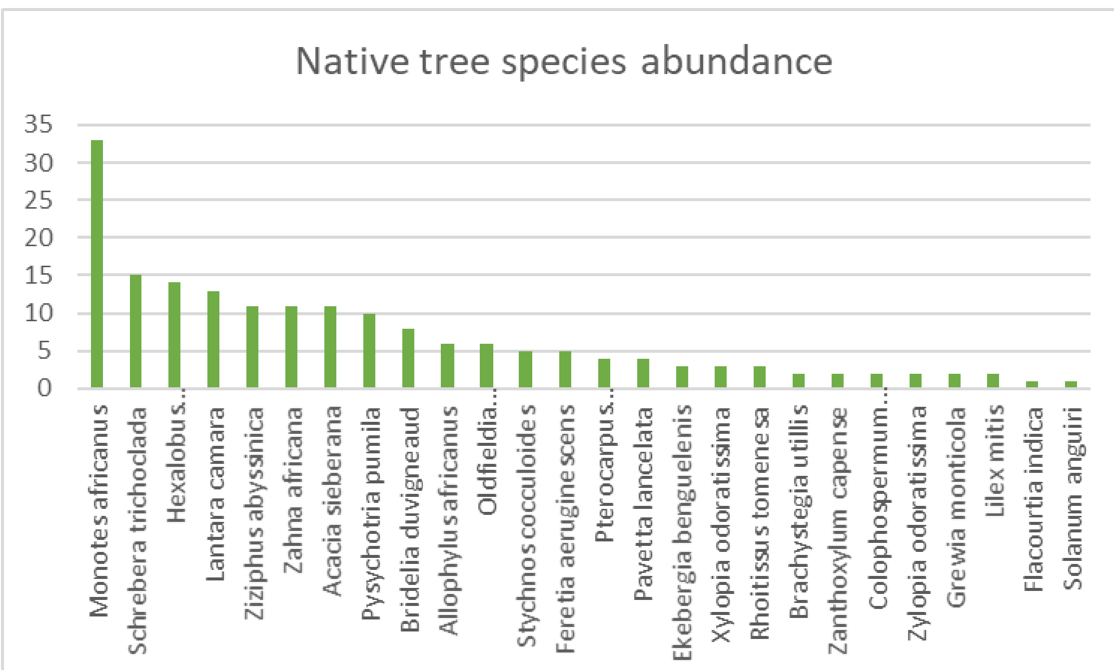


**Figure 14** *(above):* This graph displays the individual native tree species detected within the Lingadzi Namilomba Forest Reserve and the numbers of individuals observed.

### 3.5.4 Invasive Species Count

To calculate the abundance of the *Gmelina arborea* invasive tree the 10 by 10 quadrant sampling method was used due to the immense abundance of the species. **Appendix II** displays the results of the 10x10 quadrats tested in estimated low, medium, and high invasive tree areas. The DBH was taken from each counted invasive tree within each quadrant to keep count of the trees. The DBH data can also be used as reference in future studies to assess the basal area of the invasive species against the native tree species. **Table 19** within **Appendix II** indicates a low density of under 10 individual trees. The decision was made to only count the trees that were above the DBH of 10cm for a fair comparison with the native tree data collection process, thus making the counts and assessment reliable across both native and invasive species. **Table 19** indicates that there were no species observed within that quadrant. However there were a couple of trees present, but due to being below 10cm DBH they were not counted. It is important to note that if the trees below 10 DBH were counted the area was still a low-density zone. **Table 20** displays a medium density with a count between 11 and 49 invasive trees and **Table 21** shows a high density as the count was over 50 tree species. **Table 21** displays a high density 600m along transect 6 with a result of 165 *G. arborea* in one 10x10 quadrat ranging from 10cm DBH (diameter breast height) to 150cm DBH.

**Table 8** demonstrates the estimations of the *G. arborea* low, medium, and high densities along each transect and main trails throughout the reserve. **Table 8** shows that every 50m on each transect a scan was conducted to rate the densities into the high, medium, and low category. This table indicates that between 0m and under 150m the density of *G. arborea* is generally low, then between 150m and 250m the population of *G. arborea* is more spread out with a medium rating. However, above 250m there was a high rating of invasive trees. The *G. arborea* were observed

**Table 8** *(below):* This table displays the estimated results of the low, medium and high densities of *Gmelina arborea* observed within the Lingadzi Namilomba Forest Reserve on all 17 transects, which includes the main trails A, B and C.

| Transect | 0m | 50m | 100m | 150m | 200m | 250m | 300m | 350m | 400m | 450m | 500m | 550m | 600m | 650m | 700m | 750m | 800m | 850m | 900m | 950m | 1000m | 1050m | 1100m | 1150m | 1200m | 1250m | 1300m | 1350m | 1400m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Low | Low | 90m | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Low | Low | High | 140m | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Low | Low | High | 110m | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Low | Med | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | 640m | | | | | | | | | | | | | | | |
| 5 | Low | Low | High | High | High | High | High | High | High | High | High | 510m | | | | | | | | | | | | | | | | | |
| 6 | Low | Low | Low | High | High | High | High | High | High | High | High | High | 580m | | | | | | | | | | | | | | | | |
| 7 | Low | Low | Low | Med | Med | Med | Low | Low | Low | Low | Low | High | High | High | 650m | | | | | | | | | | | | | | |
| 8 | Low | Low | Low | Low | Low | High | High | High | High | High | High | 540m | | | | | | | | | | | | | | | | | |
| 9 | Low | Low | Low | Med | High | High | High | High | 360m | | | | | | | | | | | | | | | | | | | | |
| 10 | Low | 50m | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | Low | Low | Low | Med | Med | Med | Low | 310m | | | | | | | | | | | | | | | | | | | | | |
| 12 | Low | High | Low | Low | Low | 210m | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | High | Med | Low | Med | High | 240m | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | Med | Med | Med | Med | Med | Med | 300m | | | | | | | | | | | | | | | | | | | | | | |
| A- MT | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | Low | High | High | 1400m |
| B- MT | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | 1050m | | | | | | | |
| C- MT | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | Med | 1338m | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Key:** | | | No MT | MT | | | | | | | | | | | | | | | | | | | | | | | | | |
| Low Density | Low | >10 | 54 | 80 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Medium Density | Med | 11-49 | 17 | 67 | | | | | | | | | | | | | | | | | | | | | | | | | |
| High Density: | High | <50 | 44 | 46 | | | | | | | | | | | | | | | | | | | | | | | | | |
| MT | Main Trail | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

within one section of the reserve, with evidence of encroachment into the native tree species area, which can be observed within **Table 8** and **Figure 9**. **Table 8** shows the *G. arborea* densities on Transects A, B and C, which are the main wilderness trails that run through the other transects. This display is to show the comparison of the native and invasive trees, as it also displays where on the transects the native and invasive trees are situated.

### 3.5.5 Distribution of trees

**Figure 9** and **Table 9** display the comparison of abundance for native and invasive trees. **Table 9** displays the count of the invasive *Gmelina arborea* versus the most abundant native species discovered '*Monotes africanus'* and is a clear indication of a lack of habitat management and an alarming threat from the invasive species. The individual tree count of 27,050 for the *G. arborea* is an incredibly high number for a small forest, which is based on density estimations when walking the transects and 10x10 quadrant sampling. **Table 9** shows that there are 0.5718 individual invasive trees per $1m^2$ and these trees have been observed on all 14 transects, compared to *Monotes africanus*, which has 0.0182 individuals' trees per $1m^2$ and has been observed on only three transects.

Most of the species seen in **Table 9** have been found on all the transects throughout the forest during the mammal observations, thus 100% of the forest was covered for the observation of those species. If the native trees were observed outside of the tree survey, during the mammal observations, they were noted as being present where they were found. Therefore, some of the trees had been tested on all the transects, thus showing that 100% of the forest being tested. However, most of the species, such as the most abundant *Monotes africanus,* was only physically surveyed in 50% of the forest along the odd transects during the tree inventory data collection process. During the transect creation stage, most of the trees were full of fruits, therefore the edible tree data was collected on each transect before the season finished and the fruits disappeared. The native trees within **Table 7a** were noted as a part of that data collection and were also noted during the native tree inventory data collection.

**Table 9** (below)**:** This table exhibits the abundance comparisons between the native and invasive trees. Only the five most abundant native species were selected to demonstrate the comparison data. The table displays the species of tree, native or invasive, how many trees were found during the survey, the calculated number of trees per $1m^2$ within the forest, how many transects the trees were identified on and the percentage of the forest that was surveyed for each individual tree species.

**The count for the Gmelina arborea is an estimation established from the 10x10 quadrat surveys and using the low, medium and high ratings seen in **Table 8**.*

| Tree Species | Native/Invasive | Count | Tree per $1m^2$ | No. Transects Species identified | % of forest tested |
|---|---|---|---|---|---|
| *Gmelina arborea* | Invasive | 27,050* | 0.5718 | 14 | 100% |
| *Monotes africanus* | Native | 33 | 0.0182 | 3 | 50% |
| *Schrebera trichoclada* | Native | 15 | 0.0082 | 2 | 50% |
| *Hexalobus monopetalus* | Native | 14 | 0.0029 | 3 | 100% |
| *Lantana camara* | Introduced | 13 | 0.0027 | 5 | 100% |
| *Ziziphus abyssinica* | Native | 11 | 0.0023 | 2 | 100% |

# Chapter Four: Discussion

Our results show that Lingadzi Namilomba Forest Reserve is an isolated pocket of forest with plentiful wildlife. Eleven different mammal species were observed during this study, which was conducted during daylight, and included an estimation of 154.814 individual vervet monkeys (see **Table.3.**), 42.575 individual common duikers (see **Table.4.**) and 12 individual cape bushbucks (see **Table.5.**). Our surveys did not account for nocturnal species that may inhabit the reserve. Lingadzi Namilomba Forest Reserve is home to many reptiles, birds, insects and other mammals that were seen, but not observed during the study, therefore many more species and individuals are living within this small isolated pocket of forest of just 0.336km$^2$.

Lingadzi Namilomba Forest Reserve's wildlife is under severe threat due to many factors, including the fragmentation of the forest and urbanization within Lilongwe. The reserve is surrounded by human activity being situated in the center of the capital city. The main threats to the mammals are the main road that surround half of the reserve, farming, infrastructure and the Lilongwe Wildlife Trust, which involves many visitors each day to tour the sanctuary, walk along the trails or to visit the bar and restaurant that is situated on the edge of the reserve. Other threats include illegal hunting and trapping for the illegal wildlife trade and litter pollution. Whether the threats are large or small, they all unite to create a serious problem for the Lingadzi Namilomba Forest Reserve and across the African continent.

Our botanical study revealed that there are at least 26 species of native trees in this reserve, some of which are important food sources to the mammals we recorded. The invasive tree species *Gmelina arborea* was observed within Lingadzi Namilomba Forest Reserve. The alien species comprised of over 50% of the forest with evidence of further encroachment (see **Figure 9** and **Table 8**), which could lead to native extinction within the reserve. This invasive species is seen as an opportunist and a long-lived pioneer, as it is highly adaptable, highly mobile and benefits from cultivation, browsing pressures and mutilation. Thus, it has the potential to disrupt and outcompete native vegetation. For example, it can alter the trophic levels, making the soils acidic, causing habitat alteration and damaging ecosystem services. The invasive tree can also modify successional patterns, introduce pest and disease transmission. It is immense competition (monopolizing resources and shading) and it reduces native biodiversity (IUCN, 2013).

Not only is the invasive species detrimental to the native tree species, it is also a threat to the wildlife inhabiting the reserve. The *G. arborea* is thought to be toxic to animals and their fruits can cause upset to stomachs or be damaging to health if eaten in excess (Razack, Awede & Adjagba, 2015). The tree offers no shelter or sufficient food for the wildlife, therefore the habitat the animals depend on has been degraded and reduced in size. This is supported in **Figure 9**, as, during the study, the majority of the mammals were observed within the small native tree areas. This also results in further human-wildlife conflict, as the animals begin to search for food outside of the reserve and within human settlements. *G. arborea* is native to Asia, though it was introduced into plantations across the globe for its rapid growth rate, in reforestation programs and used as a source of timber (USDA, 2016). It is now enlisted as an invasive species in nearly all of the countries into which it was introduced, such as Costa Rica, Ghana, Australia, Tanzania, Zambia and Malawi, as it has entered wild habitats and it is replacing the native trees species (IUCN, 2013). *G. arborea* can produce many fertile fruits, which is easily dispersed by animals, such as birds and bats, thus escaping the plantations and spreading across wild habitats, causing havoc to native species (IUCN, 2013; PROTA, 2016). These invasions are increasing due to land degradation through overgrazing, deforestation and climate change (Witt & Luke, 2017).

Lingadzi Namilomba Forest Reserve is an important area for natural wildlife and for the economy. The reserve is the last nature reserve remaining within Lilongwe and is one of the top hotspots of the capital city for tourists. Wildlife reserves are known to improve physical and psychological health, in conjunction with bringing communities together (Bratman, Hamilton & Daily, 2012). The wilderness reserve is a beautiful area, which provides jobs and revenue for the city. Although the reserve itself is free to visit, which is ideal for the locals, it provides customers for the sanctuary and the restaurant situated within Lilongwe Wildlife Trust. The reserve is also important for education, being within the city centre it can be used for schools, collages, university trips and multiple research projects. Thus, the reserve can be used to connect wildlife and humans to reduce the negative conflicts that are occurring. Although, Malawi is one of the poorest countries in the world, it is full of rich biodiversity, which deserves to be preserved and protected.

## 4.1 The Future

Research focusing on human-wildlife conflict often involves the examination of attitudes towards wildlife (Goswami, Karnad, Vasudev, & Krishna, 2013). Although, more research that identifies the fundamental tensions between wildlife and humans is also needed to distinguish the drivers of the conflict (Dickman, 2010). The conflict between humans and wildlife often occurs as a result of frustration. Wildlife are often targeted to release feelings of anger and powerlessness due to perceived inaction by government authorities, landowners and conservation agencies (Hemson, Maclennan, Mills, Johnson, & Macdonald, 2009). Peterson et al. (2010) argued that wildlife is presented as ‘’conscious human antagonists’ when using the term “human-wildlife conflict”, thus creating the persona that the wildlife is intentionally causing tensions and conflict against humans (Fraser-Celin, Hovorka, & Silver, 2018).

Little is known about the reserve regarding populations, abundance, ecology, and the seriousness of the threats pending within the reserve, which is why this study and a conservation action plan was created. Further research on human-wildlife conflict and invasive species must be conducted for the future of the reserve. Estimations can be drawn, however for a sustainable and successful management plan of the forest more research needs to be conducted. A repeat of this study each season or each year would be immensely beneficial to see the development of the species, ecology, and threats. This would help to guide an on-going successful management plan. If there is no plan put in place after this study, the reserve will soon experience local extinction for flora and fauna. With loss to natural resources the animals would become a threat to the public as they look for alternative food sources. This would result in an increase of conflicts as locals would begin to get angry and retaliate, whilst taking their frustrations out on the animals.

The phenomenon of deforestation is arising worldwide, for many different reasons, in different types of forest (Agyei, 1998). Forests are disappearing at an alarming rate and now only cover 30% of the world’s land mass (Nunez, 2019); (Derouin, 2019). Between 1990 and 2016, 502,000 square miles of forest was lost globally. This is an area larger than South Africa (Nunez, 2019), with a further 61,000 square miles lost in 2017 (Derouin, 2019). Most of the deforestation today is occurring within tropic regions- areas that were once inaccessible, but are now within reach due to newly constructed roads throughout the dense forests. Logging and deforestation are one of the main drivers of fragmentation within Lingadzi Namilomba Forest Reserve as the reserve is becoming an easily accessible target, thus the conservation action management plan must be put in place to give the reserve any chance of a future.

If there are no habitat management plans put into place for the invasive species, the native flora will in time be lost, resulting in the loss of native fauna. Lingadzi Namilomba Forest Reserve will soon become overrun by *Gmelina arborea* as it has already begun to encroach the native forest cover and it is quickly spreading. This will result in less food and shelter resources for the fauna and increase more detrimental human-wildlife conflict. Ultimately, it will result in Lilongwe and Malawi losing another pocket of nature for wildlife, biodiversity, locals and for tourists.

## 4.2 Complications of the study

There were multiple complications during this study within Lingadzi Namilomba Forest Reserve. As the reserve was not the original research subject, a considerable amount of time for data collection was lost due to the setup of the study. For example: creating the transects (planning the transects; making the paths; cutting foliage; tying the rope and plotting each transect on GPS); surveying the area and getting the correct equipment for the study.

There was also a language barrier as many of the local Malawians, whose native language is Chichewa, do not speak English . It was difficult, when approached during observations along the perimeter on Transect c, to explain why the research was being conducted and what was happening.

Funding was also an issue for resources and will continue to be an issue for management of the reserve. As this project was conducted by a solo observer, only limited data could be collected.

However if a team were to conduct the study, there could be a much richer database and more could be understood about the reserve.

One of the main complications when conducting the study was the weather. The study was conducted during the wet season within Malawi. Whilst conducting the study, there were two cyclones, therefore data collection had to be put on hold for a few days and sometimes for a week during the storms. This was detrimental to the study, as data collection could only take place for three months due to visa and funding restrictions, thus any time lost was disadvantageous. Animals also went into hiding during the storm and some of the transects had to be re-cleared due to flooding and tree damage.

Mammals such as the vervet monkey and the spotted hyena were also an issue as they were unafraid of humans, thus if they felt threatened, they could cause potential harm or life threatening injuries. If the vervet monkeys became too confident or a hyena was spotted, then the research would end for the day due to risk of safety. This resulted in loss of potential data and time, therefore multiple observers would significantly improve the study.

The spread of the *G. arborea* throughout the forest causes multiple complications. The tree is extremely fast growing and highly adaptable, thus it will be a big operation and costly to reduce and dispose of the invasive species. The species spreads as quickly as it grows and if it is not disposed of correctly it will double in growth. It will be a timely project for the disposal of the invasive trees followed by a reintroduction of the native species. To plant native species across half of the reserve will be a costly and timely plan. This has been taken into consideration within the action plan.

There have been several explanations for the cause of deforestation due to human activity. However, one explanation suggests that communal living and land tenure systems within Africa provide no incentives for individual investment or maintenance of the land (Agyei, 1998). Therefore, there is no motivation to protect and preserve the forest when land clearing, logging, or farming, as they provide a better investment for the communities. However, forests within these areas are seriously vulnerable to loss and degradation due to the colonization of settlers seeking employment, economic opportunities, and the alteration to agriculture (WWF, 2019). With no motivation or incentive to protect the forest, there will be complications when trying to restore it.

The lack of research conducted within the reserve, Lilongwe, and Malawi in general created some issues when trying to gain further insight, knowledge or evidence throughout the study, thus further research would be very beneficial. As mentioned, there is a lack of protection and management of the reserve, which is mainly due to lack of incentive and research. There is currently no real understanding of the pressures the reserve face. Therefore the insight provided by this study could facilitate a brighter future for Lingadzi Namilomba Forest Reserve.

## 4.3 Solutions and suggestions

Solutions must be drawn to improve the survival and future of Lingadzi Namilomba Forest Reserve. A conservation action plan and a habitat management plan has been created and must be implemented and developed further to tackle the threats impending on the reserve. This is important to track the success of the objectives and the threats that still pose a threat to the reserve. Education is key, working with the locals within Lilongwe will be hugely beneficial to the reserve. Simple strategies such as signage, for example, speed signs and road awareness campaigns could be beneficial and could help to deter some of the threats within the reserve. Additional surveys would also be beneficial, for example, roadkill ecology to examine the rating of the threats such as the roads that are affecting the reserve. Surveys on individual species would also be beneficial to get exact population size, distributions, and trends. Resource and habitat protection, area management, awareness and communication and research are all matters that must be taken into consideration to protect the species of Lingadzi Namilomba Forest Reserve. See Chapter Five for the further development of the conservation action and management plan.

A 10-year conservation and habitat management action plan has been created for the reserve to assess and reduce the threats. Strategies will be implemented to preserve and protect the reserve such as removal of the invasive species and reintroduction of native species, which can be seen in Chapter five. Forest restoration can reverse the effects of deforestation and degradation, and can provide 23% of climate mitigation that is needed to reduce the climate change impact (Derouin, 2019);(IUCN, 2020) and to restore the much needed natural resources for the wildlife to survive. More research on the invasive *G. arborea* and the other direct threats would be beneficial to help the management plan progress. Countries that have been affected by invasive species, such as the *G. arborea,* have urged the need for a database to assist in the identification, impacts and management of such species (Witt & Luke, 2017). This information is essential to enable countries of eastern Africa to develop effective strategies to control the invasive species and restore their native forests. These databases also help to enable these countries to meet their biodiversity targets, including the Convention on Biological Diversity (CBD) and Target 9 0f the 2020 Aichi Biodiversity Targets (Witt & Luke, 2017).

The solutions outlined within the action plan in Chapter Five will be of top priority when trying to reduce the threats within and surrounding Lingadzi Namilomba Forest Reserve. A repeat of this study should be conducted seasonally or annually to reassess the stability of the reserve, the population growth of the flora and fauna and the success of the management plan. The repetition of the study will help to assist the management plan with any changes that may need to be made and to track whether the targets are being achieved. Additional research needs to be conducted on the other section of the reserve on the other side of the Namanthanga River to fully assess the abundance and distribution of the mammal population, the forest cover, and the threats.

A connection needs to be established between the reserve and the locals, whether it is through education, employment, or pleasure. The isolation and human-wildlife conflict are a major threat to the reserve, yet the reserve is an essential asset to Lilongwe, thus solutions to reduce these conflicts and create a positive connection with the community is of upmost importance.

# Chapter Five: Conservation Action Plan

## 5.1 Introduction

Lingadzi Namilomba Forest Reserve is significant due to being one of the only wildlife nature reserves remaining within Lilongwe, Malawi's capital city. The reserve offers peace, tranquility, beauty and education to the local community, schools, and tourists. Lingadzi Namilomba Forest Reserve and Lilongwe Wildlife Trust are one of the top hotspots for tourists and locals to visit within Lilongwe. In addition to being a top tourist destination, the reserve is home to hundreds of flora and fauna species.

There is a growing concern for the Lingadzi Namilomba Forest Reserve's sustainability, as the forest is dwindling and becoming a biodiversity concern. The reserve is a species rich, albeit small area that is highly fragmented and isolated. Whilst there is a general acknowledgement that there must be change, and a recognition that there is an urgent need for the removal of the invasive tree species, *Gmelina arborea,* there are currently no specific management plans for the forest. Being a tourist attraction and a natural wildlife preserve with key stone species, it is the perfect place to generate attraction, jobs, and education. However, without proper management, the pocket of paradise will soon be inhabitable, which will affect all that are surrounding the reserve, not just the wildlife.

Here we propose an Action Plan to help local authorities with the management of the reserve. This action plan is based on the survey work presented in the previous chapters of this dissertation. We adopt the Open Standards methodology for strategic conservation planning (FOS, 2009), using the Miradi tool for conceptualizing the project (FOS, 2009). A conservation action plan using Miradi is a process used to fully assess the risks of the area, targets, and strategies to improve the status of the target being observed. Using steps of conceptualization, action planning and monitoring, Miradi helps to distinguish the key threats and the contributing factors to get a clear picture of what is putting pressure on the target. This is to successfully create a long-term plan to help mitigate these stresses and improve the welfare of the target. To begin, the project must be conceptualized, therefore the project's geographic scope (geographic range and where the project will affect) and the project vision must be established to set the ultimate desired state and condition of the project's future. The next step is to establish the projects focal conservation targets, which will assess the biodiversity of concern, discuss the selected focal targets and their geographic range, population status, habitat and ecology and any known current threats. This will help to set goals and actions to measure the conservation effectiveness.

The next stage is the target viability assessment, which assesses the current and future threats. This process defines the most important ecological requirements needed to achieve a healthy population and ecosystem. This step establishes what key ecological attributes and indicators will be used to assess whether the target is 'healthy' and how it will be measured. This will then give a current viability status and an impression of the reserve. The key critical threat will then be identified to determine the current conditions that the reserve is in, the meaning of the rating, what it affects and the rate of deterioration. Using this information, a conceptual model is created for the conservation situation analysis. This is a crucial planning process, as it displays the contributing factors for each direct threat, thus showing the relationship between biological, social, economic and political environments to find the root causes and implement the best strategies to mitigate the pressures.

Once these processes have been established the action planning and monitoring commences, goals are put into place to improve the Key Ecological Attributes and to advance the viability ratings. Then, the strategies are created as actions to put into place to reduce the threats and improve the status of the targets. Results chains are created on assumptions to display how the strategies in theory will affect and contribute to reduce the direct threats to achieve healthy targets. Step by step, the results chain will show the change in each contributing factor to reach the desired outcome, which will include objectives and measures to keep them on track. Ultimately, a monitoring plan will be established from these results to show the stages of action and to track the progress to achieve the specified goals and objectives.

## 5.2 Conceptualization

### 5.2.1 Project Geographic Scope

The geographic scope is the Lingadzi Namilomba Forest Reserve, which is situated within the grounds of Lilongwe Wildlife Trust within the centre Lilongwe, Malawi (see **Fig.15.**). Malawi is a small landlocked country in southeastern Africa, however it is defined as a biodiverse hotspot with highlands split by the Great Rift Valley and the vast Lake Malawi, which runs the length of the country. Lingadzi Namilomba Forest Reserve is one of the last pockets of wildlife remaining within the capital city Lilongwe. The reserve is a small isolated forest with a total area of

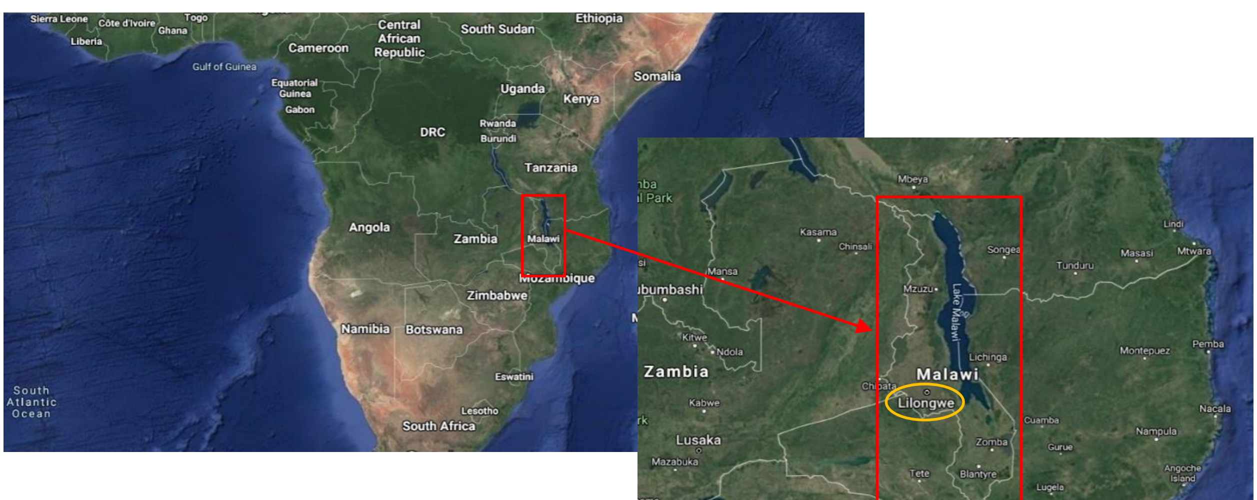


**Figure 15** (*above*): This map displays Lilongwe's position within Malawi (GoogleEarth, 2020b).

0.619km². The Namanthanga River splits the reserve into two sections, thus only 0.366km² was studied for this project.

The forest shares the same land as the Lilongwe Wildlife Trust (see **Fig.16.**). The Lilongwe Wildlife Trust is a rehabilitation sanctuary for wildlife. Zoos within Malawi are now illegal, thus when the neighboring zoo had to close the animals came to the sanctuary. The sanctuary also consists of animals that have been rescued from the illegal wildlife and pet trade, thus with hundreds of animal intakes each year there was a need to expand and build more enclosures. The enclosures within the sanctuary are large and contain the natural forest, which is used for preparation for when the animals are eventually released back into the wild. Consequently, Lingadzi Namilomba Forest Reserve has been driven smaller and smaller, as the sanctuary expands and the farmlands and infrastructure surrounding enclose, consequently creating the isolation it has today. The wilderness reserve is owned by the Lilongwe Wildlife Trust, however there are currently no habitat or conservation action plans in place to manage it. The wilderness trails were created to allow access to the public and visitors to the sanctuary, which invades the forest further, however, it does generate a value and incentive to the public. The section of forest on the other side of the river is currently untouched and inaccessible, however poachers and illegal loggers have been sighted on multiple occasions. This leads to the fear that soon the reserve will become uninhabitable for the wildlife within.

The flora is split into two sections: native trees and invasive trees (see.**Fig.8.**). The invasive *Gmelina arborea* has quickly spread throughout the reserve and is now encroaching further into the native tree’s land and resources. The positioning of the trees also appears have an impact on the distribution of mammals throughout the reserve, as the *G. arborea* gives little resources or protection and are known to have toxic traits.

Lingadzi Namilomba Forest Reserve is located at 1,100 metres above sea level and is mostly flat, with a few elevations towards the rear of the reserve. Lilongwe has mild temperatures that range from an average maximum of 30°C in November to an average low of 6°C in July (ClimatesToTravel, 2020). Lilongwe is subjected to a wet rainy season and a dry season. The rains occur from November to April, which amounts to 850 millimetres per year (ClimatesToTravel, 2020). The tropical rains are mainly in the form of thunderstorms and downpours, which can result in flooding (ClimatesToTravel, 2020). During the data collection period for this study Cyclone Idai occurred, which caused flooding to the southern parts of Malawi and disturbance to the forest (ClimatesToTravel, 2020).

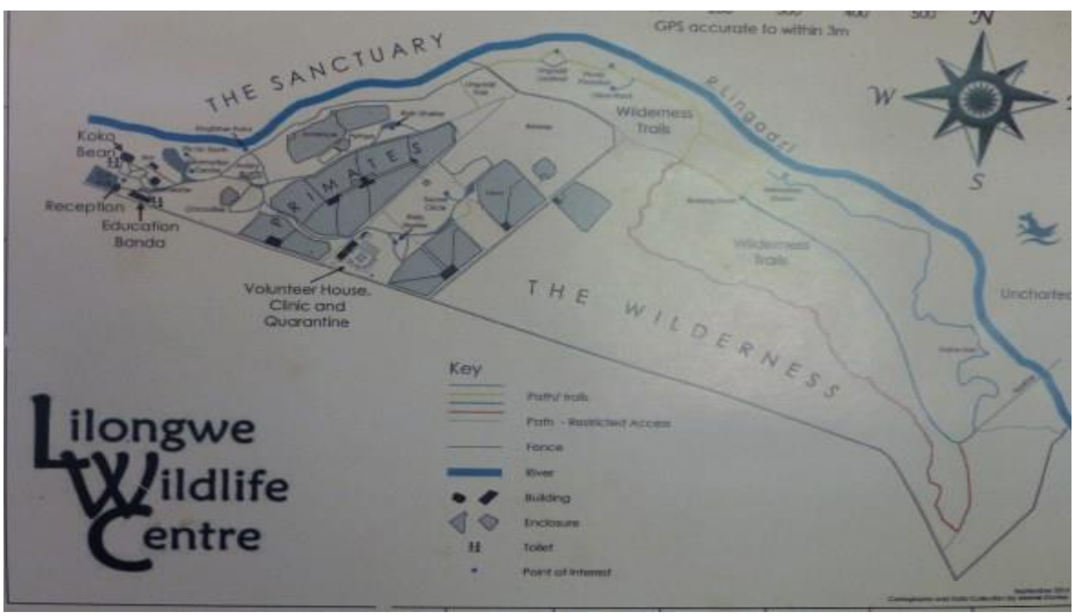


**Figure 16** (*above*): This is Lilongwe Wildlife Trusts (formally Centre) map of the area (Nartan, 2016).

There is little legal protection for the reserve, although security has been increased due to the rise in logging and poaching throughout the forest. Thus, human-wildlife conflict is high due to the human settlements surrounding the reserve. Due to lack of funding and research it has become difficult to successfully manage the reserve and reduce its current threats.

### 5.2.2 Project Vision

The vision is the ultimate desired state and condition the project aims to achieve for the reserve through the conservation management plan.

‘The vision is to restore, preserve and protect an ecological healthy ecosystem within Lingadzi Namilomba Forest Reserve, by managing and protecting the mammal population and reducing the threats by 75% by 2030. The vision is to allow the mammals to fulfil their ecological roles and thrive with reduced disruption from human activities. The park will also aim to meet the economic, cultural and spiritual needs of local communities, but without damaging or disrupting the reserve.’

### 5.2.3 Project Focal Conservation Targets

The focus point of this project are the mammals and trees of the Lingadzi Namilomba Forest Reserve. These targets were chosen as they are good indicators to assess how healthy the biodiversity and ecosystem are. The most abundant mammals observed were the vervet monkey, common duiker, and the Cape bushbuck, however the evidence of hyena being present is also a key factor to the study. The vervet monkey and the antelope are keystone species through seed dispersal, thus they are important to protect as they encourage natural forest succession. The spotted hyena is also a key species for the reserve to keep balance in the food chain. Without the hyena there are no large top predators, thus without their presence the vervet monkey, which is the most abundant species, would become even more overpopulated. This would result in an increase of human-wildlife conflict due to a reduction in natural resources, such as food and space. Hyenas also bring an element of fear, which is needed for the animals within Lingadzi

Namilomba Forest Reserve, for example, without fear of a natural predator the vervet monkeys would become over-confident and aggressive towards humans, which is already taking place. A balanced food chain gives order and success to the ecosystem.

**Table 10** describes the most abundant mammals in more detail showing their individual biodiversity concern, geographic range, population, habitat and ecology and threats. The mammals may be widespread across different parts of Africa and though decreasing in numbers are not at risk of extinction. However, the animals are at threat to local extinction and are highly important for Lingadzi Namilomba Forest Reserve's ecosystem. The reserve and the mammals within are also important for human welfare, as they provide a wild, peaceful space full of nature and wonder, which people need to escape from the bustling city.

There are many threats facing these animals, such as logging, hunting, deforestation and fragmentation, human-wildlife conflict, agriculture, settlements, roads, and invasive species. The main threat these factors accumulate to is habitat destruction and degradation. This includes factors such as restricted resources, risk of inbreeding, and human-wildlife conflict, resulting in the reduced probability of long-term survival. These animals need the reserve to survive, as they are an isolated population, thus without a healthy ecosystem these animals will shortly have restricted resources and protection, therefore they will begin to spread across the city. Most of the threats are from human activity, excluding the invasive tree species, which arguably is still a form of human activity, as they were introduced by humans. The habitat must be restored for progress to be made before irreversible damage is caused.

**Table 10** (*below*): This table displays a fact sheet for vervet monkey, common duiker, cape bushbuck and the spotted hyena exhibiting their biodiversity concern, geographic range, habitat and ecology.

| **Species** | Vervet monkey (*Chlorocebus pygerythrus*) | Common duiker (*Sylvicapra grimmia)* | Cape Bushbuck (*Tragelaphus scriptus*) | Spotted Hyena (*Crocuta Crocuta)* |
|---|---|---|---|---|
| **Biodiversity Concern** | Least concern, Decreasing. Isolated populations may be prone to local extinction (Isbell & Jaffe, 2013). | Least concern, decreasing (IUCN, 2016a) | Least concern, stable (decreasing in densely settled regions) (IUCN, 2016b) | Least Concern, decreasing (Bohn & Honer, 2015). |
| **Geographic Range** | 14 countries across Africa. | 37 countries across Africa. | 40 countries across Africa. | 37 countries across Africa. |
| **Population (worldwide)** | 9-104 individuals/km² (Isbell & Jaffe, 2013). | 1,660,000. Decreasing in areas of high hunting pressures. (IUCN, 2016a). | 1,000,000-1,500,000 (IUCN, 2016b). | 27,000-47,000 (Bohn & Honer, 2015). |
| **Habitat** | Forest, savanna and shrubland, (Butynski & de Jong, 2019) | Forest, savanna, shrubland, grassland, desert and terrestrial (IUCN, 2016). | Forest, savanna, shrubland, grassland and terrestrial (IUCN, 2016b). | Forest, savanna, grassland and terrestrial (Bohn & Honer, 2015). |
| **Ecology** | Medium-sized, semi-terrestrial primate. Adaptable in fragmented habitats. Home ranges vary from 5-103ha. (Butynski & de Jong, 2019). They are omnivores. | Varied diet of foliage, herbs, fruits, seeds, and cultivated crops (Wilson, 2013). High level of adaptability to habitat modifications caused by agricultural settlements (IUCN, 2016a). | Herbivorous. Primarily browsers, some areas they eat crops from agricultural fields (Plumptre & Wronksi, 2013). | Known for being scavengers but are effective and flexible hunters (Honer, Wachter, East, & Hofer, 2002). Fairly large carnivores, with large powerful jaws and sloping hind quarters (YPTEb, 2020). Matriarchy social system. |

| | | | | |
|---|---|---|---|---|
| **Threats** | Habitat degradation, fragmentation, and destruction (Isbell and Jaffe, 2013), bushmeat (de Jong *et al*. 2008), illegal pet trade and human-wildlife conflict. | Hunting and trapping (IUCN, 2016a). | Residential and commercial development, livestock farming, ranching and agriculture, habitat loss, hunting and trapping (bushmeat and skin) (AWF, 2020). | Hunting and trapping, poison, and culling (Bohn & Honer, 2015). |
| **Typical group size** | Multi-male and multi-female groups up to 38 individuals (YPTEa, 2020). | Solitary. (Sibyabona, 2020). | Solitary (AWF, 2020). | 6-100 members, hyenas live in clans and are highly social animals (Lyon, 2019). |
| **Gestation** | 165 days (YPTEa, 2020). | 182 days (Sibyabona, 2020). | 6-7 months. | 110 days (Lyon, 2019). |
| **Lifespan** | 7-12 years (YPTEa, 2020). | 8-11 years (Sibyabona, 2020). | 15 years (in captivity) (AWF, 2020). | 12 years (Lyon, 2019). |
| **Estimated population within Lingadzi** | 154.814 | 42.575 | 11.766 | N/A |

# 5.3 Threats

## 5.3.1 Target Viability Assessment

The target viability assessment on the Miradi software is used to define the most important ecological requirements to achieve a healthy population of mammals and a healthy ecosystem. Different attributes of the targets, including population, sex ratio, birth rates, reproduction, survival rate and movement will help to determine a 'healthy' population. Key Ecological Attributes (KEA) are used to assess the 'healthiness' of the forest reserve such as abundance, sex ratio, availability of resources, such as space and food. The assessment was performed with the data collected for this study from the native trees and the three most abundant mammal species: Cape bushbuck; common duiker and vervet monkey (see **Table.2.**). The key ecological attribute ‘abundance’ was used to assess the status of the population densities of each species. The indicator ‘population density within Lingadzi/km²’ was used to assess how many individual species there were per km within the reserve, to give an indication to space resources versus population ratio. The indicator ‘population density of mature individuals’ was also used to assess the KEA ‘abundance’, as it indicates whether a population is healthy with enough breeding individuals.

During the data collection process, the sex and age of the species identified were collected when possible. **Table 11** and **Table 12** display the KEA ‘Sex Ratio’, which used the indicator ‘Adult ratio of males to females’. This was used to assess the balance of the species sex within each population and the predictability of population growth. Typically, two-three females to one male is considered a great ratio, as there are more females for reproduction to increase the population and less males for intraspecific competition to mate. The KEA ‘Birth Rates’ was used to estimate the success of reproduction and population growth. The number of births during the study was used as an indicator, due to the study being conducted during and just after the birthday season. Finally, the KEA ‘Forest Fragmentation’ uses the indicator ‘area of occupancy/km²’, which indicates the area of which the mammals and native trees are inhabiting. The native trees also have the indicator of ‘percentage of native trees’ within the reserve to display the area of occupancy and how many trees within the reserve are actually native.

The targets are currently struggling, however with the correct management the status can improve. It is difficult to assess the status regarding official IUCN requirements, due to species over-population in comparison to the population density within Lingadzi/km². All the mammal species show an indication of an over population in comparison to space; however, it is due to the fact that the space they inhabit is less than 1km² and only 0.366km². It is also difficult to set future targets to increase the population, due to the lack of space resources, thus strategies such as increasing the space, possible corridors or translocation must be considered.

**Table 11** (below): This table displays the target viability analysis for the Cape bushbuck and the common duiker.

| Item | Viability Mode | Status | Future Status | Type | Poor | Fair | Good | Very Good | Source | Progres |
|---|---|---|---|---|---|---|---|---|---|---|
| Lingadzi Namilomba Forest Reserve | | Poor | Fair | | | | | | | |
| Cape Bushbuck | Key | Poor | Fair | | | | | | | |
| 1. Abundance | | Poor | Fair | Size | | | | | | |
| 1.1. Population density within Lingadzi/km² | | Poor | Poor | | <1.5 | 1-1.5 | 0.5-1 | 0-0.5 | Onsite / | Not Speci |
| 2020-04-24: 40.98 | | | | | 40.98 | | | | Intensive | |
| 2030-04-24 | | | | | 20 | | | | | |
| 1.2. Population density of mature individuals | | Poor | Fair | | <50 | <250 | <1,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 15 | | | | | 15 | | | | Intensive | |
| 2030-04-24 | | | | | | 51-100 | | | | |
| 2. Sex Ratio | | Good | Very Good | Size | | | | | | |
| 2.1. Adult ratio of males to females | | Good | Very Good | | >1 | 1-2 | 2-3 | <3 | Onsite / | Not Speci |
| 2020-04-24: 2:3 | | | | | | | 2:3 | | Rapid | |
| 2030-04-24 | | | | | | | | 1:3 | | |
| 3. Birth Rates | | Poor | Fair | Size | | | | | | |
| 3.1. Number of births during the study | | Poor | Fair | | >50 | 51-800 | 801-1,600 | 1,601-3,000 | Onsite / | Not Speci |
| 2020-04-24: 0 | | | | | 0 | | | | Rapid | |
| 2030-04-24 | | | | | | 51 | | | | |
| 4. Forest Fragmentation | | Poor | Poor | Landscape | | | | | | |
| 4.1. Area of occupancy/km² | | Poor | Poor | | <10 | <500 | <2,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 0.366 | | | | | 0.366 | | | | Intensive | |
| 2030-04-24 | | | | | 1.252 | | | | | |
| Common Duiker | Key | Poor | Fair | | | | | | | |
| 1. Abundance | | Poor | Fair | Size | | | | | | |
| 1.1. Population density within Lingadzi/km² | | Poor | Poor | | <1.5 | 1-1.5 | 0.5-1 | 0-0.5 | Onsite / | Not Speci |
| 2020-04-24: 103.8 | | | | | 103.8 | | | | Intensive | |
| 2030-04-24 | | | | | 40 | | | | | |
| 1.2. Population density of mature individuals | | Poor | Fair | | <50 | <250 | <1,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 33 | | | | | 33 | | | | Intensive | |
| 2030-04-24 | | | | | | 50-80 | | | | |
| 2. Sex Ratio | | Very Good | Very Good | Size | | | | | | |
| 2.1. Adult ratio of males to females | | Very Good | Very Good | | >1 | 1-2 | 2-3 | <3 | Onsite / | Not Speci |
| 2020-04-24: 1:4.4 | | | | | | | | 1:4.4 | Rapid | |
| 2025-04-24 | | | | | | | | 1:4 | | |
| 3. Birth Rates | | Poor | Fair | Size | | | | | | |
| 3.1. Number of births per year | | Poor | Fair | | >50 | 51-800 | 801-1,600 | 1,601-3,000 | Onsite / | Not Speci |
| 2020-04-24: 2 | | | | | 2 | | | | Rapid | |
| 4. Forest Fragmentation | | Poor | Poor | Landscape | | | | | | |
| 4.1. Area of occupancy/km² | | Poor | Poor | | <10 | <500 | <2,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 0.366 | | | | | 0.366 | | | | Intensive | |
| 2030-04-24 | | | | | 1.252 | | | | | |

**Table 12.**(below): This table demonstrates the target viability analysis for the vervet monkey and the native trees.

| Item | Viability Mode | Status | Future Status | Type | Poor | Fair | Good | Very Good | Source | Progres |
|---|---|---|---|---|---|---|---|---|---|---|
| Vervet Monkey | Key | Poor | Fair | | | | | | | |
| 1. Abundance | | Fair | Fair | Size | | | | | | |
| 1.1. Population density within Lingadzi/km² | | Poor | Poor | | <1.5 | 1-1.5 | 0.5-1 | 0-0.5 | Onsite / | Not Speci |
| 2020-04-24: 387.97 | | | | | 387.97 | | | | Intensive | |
| 2030-04-28 | | | | | 130 | | | | | |
| 1.2. Population density of mature individuals | | Fair | Fair | | <50 | <250 | <1,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 91 | | | | | | 91 | | | Intensive | |
| 2030-04-24 | | | | | | 120 | | | | |
| 2. Sex Ratio | | Poor | Good | Size | | | | | | |
| 2.1. Adult ratio of males to females | | Poor | Good | | >1 | 1-2 | 2-3 | <3 | Onsite / | Not Speci |
| 2020-04-24: 1.9:1 | | | | | 1.9:1 | | | | Rapid | |
| 2030-04-24 | | | | | | | 1:3 | | | |
| 3. Birth rates | | Poor | Fair | Size | | | | | | |
| 3.1. Number of births per year | | Poor | Fair | | >50 | 51-800 | 801-1,600 | 1,601-3,000 | Onsite / | Not Speci |
| 2020-04-24: 11 | | | | | 11 | | | | Rapid | |
| 2030-04-24 | | | | | | 51-80 | | | | |
| 4. Forest Fragmentation | | Poor | Poor | Landscape | | | | | | |
| 4.1. Area of occupancy/km² | | Poor | Poor | | <10 | <500 | <2,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 0.366 | | | | | 0.366 | | | | Intensive | |
| 2030-04-24 | | | | | 1.252 | | | | | |
| Native Trees | Key | Poor | Fair | | | | | | | |
| 1. Forest Fragmentation | | Poor | Fair | Landscape | | | | | | |
| 1.1. Area of occupancy/km² | | Poor | Poor | | <10 | <500 | <2,000 | >2,000 | Onsite / | Not Speci |
| 2020-04-24: 0.183 | | | | | 0.183 | | | | Intensive | |
| 2035-04-24 | | | | | 1.252 | | | | | |
| 1.2. % Native trees within Lingadzi | | Poor | Very Good | | >50 | 51-70 | 71-90 | 91-100 | Onsite / | Not Speci |
| 2020-04-24: 45 | | | | | 45 | | | | Intensive | |
| 2035-04-24 | | | | | | | | 91-100 | | |

### 5.3.2 Current Viability Status

**Table 13** shows that the Lingadzi Namilomba Forest Reserve is in a poor condition, resulting in the wildlife within to be critically endangered. The future status of the forest fragmentation within the reserve remain poor due to being unable to sufficiently expand the reserve. The reserve is surrounded by infrastructure, agriculture, and roads, although there is another small reserve unoccupied across the road, which could be joined using a wildlife corridor. However, this would be very expensive, and it would need extensive planning. The overall future status is to be 'Fair', thus allowing the reserve to repair and minimize further threats.

| Key | |
|---|---|
| **Status** | **Colour** |
| Poor | |
| Fair | |
| Good | |
| Very Good | |

**Table 13 (*below*)**: This displays the Key Ecological Attributes (KEA) and the current and future status of the Lingadzi Namilomba Forest Reserve and the targets within the reserve. This includes a Kev.

| Target | KEA | Current Status | Future Status |
|---|---|---|---|
| *Lingadzi Namilomba Forest Reserve* | All | | |
| *Cape Bushbuck* | All | | |
| | Abundance | | |
| | Sex Ratio | | |
| | Birth Rates | | |
| | Forest Fragmentation | | |
| *Common Duiker* | All | | |
| | Abundance | | |
| | Sex Ratio | | |
| | Birth Rates | | |
| | Forest Fragmentation | | |
| *Vervet Monkey* | All | | |
| | Abundance | | |
| | Sex Ratio | | |
| | Birth Rates | | |
| | Forest Fragmentation | | |
| *Native Tree* | Forest Fragmentation | | |

### 5.3.3 Impression

The assessment was a challenge due to the lack of present research and current resource limitations. The study that took place was focused on population densities rather than sex ratio and reproduction rates. However, when able to identify, the data was recorded during the study to give some indication. The results from DISTANCE 7.3., the original data collection notes and IUCN database was used to make these impressions. IUCN (IUCN Red List of Threatened Species) is a data base that displays research about each species status, geological range, population, ecology, and their current threats. IUCN allows the study to assess the real scale of endangerment and to derive a clear focus and goal to an achievable action plan to decrease the threats of the targets and the reserve.

## 5.4 Identifying the Critical Threats

Lingadzi Namilomba Forest Reserve faces multiple direct threats. The native trees and the three most abundant mammal species, which were used to represent the mammal species within the reserve, were assessed within the Miradi software against the four main direct threats that have been identified to estimate the severity of the situation. Though there are more threats than the four chosen, some are contributing factors that can be filtered into one main threat. For example, logging, agriculture, pollution, infrastructure, and human settlements are all direct threats affecting the reserve, however they are all contributing to habitat degradation, fragmentation, and destruction. The four main threats identified are invasive species, hunting and trapping, human wildlife conflict, habitat degradation and fragmentation.

The threat ratings shown in **Figure 17** display the threats as either high or very high, increasing the need for action to take place. The ratings are high due to most of the population being affected by these threats and it will be a long and potentially costly process to rectify them. The overall project rating is 'Very High', which is very concerning and immediate action must take place to restore and protect the reserve and the wildlife within.

| Threats \ Targets | Common Duiker | Cape Bushbuck | Native Trees | Vervet Monkey | Summary Threat Rating |
|---|---|---|---|---|---|
| Habitat Degradation | Very High | Very High | Very High | Very High | Very High |
| Human Wildlife | High | High | | High | High |
| Hunting and Trapping | High | High | | Not Specified | High |
| Invasive Species: | Not Specified | Not Specified | Very High | Not Specified | High |
| **Summary Target Ratings:** | High | High | Very High | High | **Overall Project Rating** Very High |

**Figure 17** (above): This table displays the threat ratings for the four main direct threats against the four targets. This gives the overall summary threat rating for each target and for the project.

## 5.4.1 Current critical threats

The four main critical threats to the Lingadzi Namilomba Forest Reserve are invasive species, hunting and trapping of wild animals, human wildlife conflict and habitat degradation and fragmentation. The reserve faces these threats due to poor management, lack of adequate zoning and lack of understanding and education. The overall project threat rating is very high with majority of the targets in poor condition, which means extensive management procedures need to be put in place to increase the stability of the reserve.

One of the main drivers to the demise of the reserve is invasive species. The invasive *Gmelina arborea* tree threatens more than 50% of the reserve and is encroaching further into the native trees space and resources. The current native tree threat rating is very high due to deforestation and invasive trees. *G. arborea* is native to Asia, though it was introduced into plantations across the globe for its rapid growth rate, reforestation programs and used as a source of timber (USDA, 2016). It is now enlisted as an invasive species in nearly all of the countries it was introduced, including Malawi, as it has entered wild habitats and it is replacing the native trees species (IUCN, 2013). *G. arborea* is a serious threat as it outcompetes native species, as well as being detrimental to the wildlife. The native trees provide natural healthy food, shelter, and the right resources the fauna of the reserve need to survive, thus with the *G. arborea* providing little shelter and toxins, they reduce the survival of wildlife with the reserve. This would also lead to further human-wildlife conflict. The 'invasive tree' threat has a summary of 'High', thus the threat is very serious, although, with the correct management and the removal of the species, there is a chance of reversing the damage that has been imposed.

'Hunting and Trapping' is a known direct threat to the species common duiker, Cape bushbuck and spotted hyena worldwide and within the reserve (IUCN, 2020). Hunting when conducted illegally is also known as poaching, which threatens many species with extinction when illegally killing or capturing animals from the wild for local or global consumption (Nunez, 2019). Hunting and trapping occurred whilst the study was taking place with at least two common duikers being illegally killed. The antelope are a main target due to their skins and are used as bushmeat for food or to sell for an income. Vervet monkeys are also trapped to be sold as pets in the illegal wildlife and pet trade. IUCN state the main reason for hyena decline is due to human persecution and poisoning (Evolution, 2010), thus they are often hunted and trapped, as they are perceived as grave robbers, witchcraft and a bad omen (Bohm & Honer, 2015). As mentioned, the reserve belongs to Lilongwe Wildlife Trust, which is a sanctuary that helps to rehabilitate animals that have been subjected to hunting, trapping, and poaching. There were around 300-400 animals of the same species living within the sanctuary during this study, which were pets, being sold by the side of the road or seized at the countries borders. This indicates that the threat is a serious problem not only for Lingadzi Namilomba Forest Reserve, but for Malawi, as it gives evidence that there is a national and international market for these animals. The threat summary rating for 'hunting and trapping' is currently 'high', which is a serious problem, however with adequate security and management zoning, the easy access for poachers can be significantly reduced and the threat can be managed.

Human wildlife conflict is one of the main drivers affecting the mammals within Lingadzi Namilomba Forest Reserve. The current summary threat rating is 'high', however with no action this will soon be 'very high' with difficulty to rectify. The locals living within the farmland and settlements surrounding the reserve (see **Fig.18.**) are becoming more anxious with the increasing crop raids. Primates, hyena and bushpigs (*Potamochoerus larvatus*) are identified as a widespread problem animal across Africa (Anthony & Wasambo, 2009). Vervet monkeys are perceived as a nuisance throughout its residency within Africa, as they are persecuted in response to their negative interactions within tourist facilities or due to their crop raiding (Isbell & Jaffe, 2013). Crop raiding is one of the main forms of human-wildlife conflict (Archabald & Naughton-Treves, 2001). Vervet monkeys and bushpigs are a frequent year-round problem, thus increasing the conflict with the farmers. The vervet monkeys raid the crops neighbouring the reserve daily, due to a gain in confidence and a lack of fear around humans (Mikula, Saffa, Nelson, & Tryjanowski, 2018). During the study, 159 pieces of corn were detected (see **Table.2.**) along the farmers fence line and within the forest. The farmers constantly patrol the fence line to deter the animals from entering the fields, using deterrents such as sling shots, fireworks, and loud noises. Crop raiding is a concern to farmers, as the animals can introduce potential diseases, decrease revenue from the crop damage, decrease in fertilization and an increase to the risk of starvation, due to no income or food (Anthony & Wasambo, 2009).

Due to lack of understanding some of the locals believe the animals belong to Lilongwe Wildlife Trust and are not wild, thus creating tension and disputes between the community and the centre. The vervet monkeys have also shown aggression towards customers at Lilongwe Wildlife Trust's restaurant, as they try to steal food from people's plates. The human-wildlife conflict is clear evidence that the wildlife is struggling and looking for alternative resources to survive, due to the lack of space, nutrients, and food within the reserve.

**Figure 18** (*above*): The perimeter of the Lingadzi Namilomba Forest Reserve along transect C. This illustrates how the forest has been fragmented and isolated due to encroaching farm fields than run along the reserve.

Habitat degradation and fragmentation is the most threatening driver with a consistent rating of 'very high' for all the targets and for the reserve. Multiple threats and factors filter into the habitat degradation causing destruction of the forest. Being surrounded by human activity has caused catastrophic isolation to the reserve as it has been reduced to a small area of 0.66km². The reserve is suffering inside and out, As it continues to decrease in size, the animals will soon be forced to find resources within the city, adding to the other pressures. Contributing factors such as the roads are an increasing pressure;  the infrastructure of countries such as Malawi is still under development. Thus, there is an increased encroachment into the wilderness areas (Nelson, 2013). Roads have an impact on wildlife due to habitat loss (Trombulak & Frissell, 2000), which leads to a decrease in habitat connectivity and potential changes in natural animal behaviour (D’Amico, Roman, Periquet & Revilla, 2015). Roads also cause direct mortality through vehicle collision, which has been regarded as one of the highest modern risks to wildlife (Periquet, Roxburgh, le Roux, & Collinson, 2018). Three mammals from the reserve collided with vehicles during this study: two vervet monkeys and one spotted hyena. Roads are a necessity for city development and to aid human productivity, however they cause direct habitat loss, mortality, isolation and introduce pollution, disturbance and increase easy access to the reserve.

Isolation can cause many problems for wildlife populations such as inbreeding and high intraspecific competition. Vervet monkeys are an adaptable and widespread species, however their main threats are habitat degradation and fragmentation (see **Table.10.**), which are all human-inflicted threats (Isbell & Jaffe, 2013). Though vervet monkeys within the reserve are currently a growing population with an estimated high of 283 individuals (see **Table.2.**), they are vulnerable to local decline and extinction (Isbell & Jaffe, 2013). This is applicable to all of the species within this study.

Threats such as logging and pollution are affecting the reserve from within. The fences are broken and weak due to people trespassing to illegally chop the trees for firewood and charcoal.

This is a huge problem throughout Malawi, causing mass deforestation and illegal crime. The illegal logging not only creates fragmentation within the reserve, but it also increases the pressures from the invasive *G. arborea*. The *G. arborea* is easy to log as it is plentiful, surrounds the border of the reserve, thus it is easy to get to and is known to be very good for timber and firewood. However, when logged incorrectly the invasive tree grows twice as fast allowing it to spread further into the reserve. With an estimated 90% of Africa's population using fuelwood for cooking (Agyei, 1998) and livelihoods, it is unsurprising that Africa's forests are disappearing. The pressures of population growth cause the unregulated and frequently illegal extraction of timber, which results in wildlife, local communities and the economies being at risk (WWF, 2019). Illegal logging is a major threat to the reserve and Malawi, with charcoal production being a main driver of deforestation (Vaughan, 2019). Wood is the main fuel in Malawi with 95% of homes still using wood and charcoal for cooking (RIPPLEAfrica, 2020). Therefore, illegal logging is powered by a growing urban demand within Malawi (Vaughan, 2019). With the current rates of deforestation is it estimated that Malawi could lose all its trees by 2079 (Vaughan, 2019). Deforestation can lead to catastrophic impacts on wildlife, ecosystems, biodiversity and even weather patterns.

The Namanthanga River that runs from the city through the reserve poses a threat to the wildlife due to litter pollution. Around 70% of waste within Malawi is indiscriminately disposed of (EnvironmentReport, 2010). Therefore, with a lack of waste management or disposal sites the waste is intoxicating the environment by polluting the animal's water supply and resources (EnvironmentReport, 2010). Crocodiles (*Crocodylinae* sp*)* live within the river and vervet monkeys have been observed living within the litter as it washes up on the forest's banks. Waste management needs to be considered within the reserve and Lilongwe, in addition education on litter and plastic needs to be enforced to help reduce the litter pollution throughout the reserve and the city. The threat for habitat fragmentation is very high as it will be extremely difficult, costly, and highly time consuming to repair. With Lilongwe's population growing and a lack of management, law enforcement and research the reserve faces a bleak future.

## 5.5 Conservation Situation Analysis: Conceptual Model

**Figure 19** illustrates the conceptual model, which is used to demonstrate the key direct threats and the factors that are contributing to the pressures. Human-Wildlife conflict, hunting and trapping, habitat degradation and fragmentation and the invasive species *Gmelina arborea* are the main direct threats affecting Lingadzi Namilomba Forest Reserve. The contributing factors are used as a step by step process to find the root causes of each threat. There are multiple factors that affect each threat, which is observed in **Figure 19**. For example, 'Habitat degradation and fragmentation', which affects each of the targets, is affected by illegal logging and the demand for land and informal settlements, which is due to high living costs within Lilongwe. This has led to a demand for wood and charcoal for an income and survival. Both contributing factors exist due to poverty pressures of high unemployment rates and a lack of education or awareness. Ultimately, these pressures and threats are due to a high human population growth within Lilongwe and a lack of support and regulation from the government or landowner bodies. Therefore, one of the root causes of the main threat 'Habitat degradation and fragmentation' is from a lack of regulation and support from the government and a high human population growth, which is causing poverty within Lilongwe. Thus, by introducing strategies such as 'training and employment' and 'education workshops', they can help to tackle the political and social pressures of poverty to reduce and mitigate these contributing factors such as logging and the demand for wood and charcoal.

Some contributing factors relate to more than one cause and threat. For instance, the invasive tree *Gmelina arborea* is a direct threat, but it also affects the threat 'habitat fragmentation and degradation'. This is due to outcompeting native flora and colonizing the wildlife reserve, whilst reducing space and food resources for the wildlife. The contributing factors indicate that one of the root causes for the threat 'Hunting and Trapping' to also be due to no government or landowner support, planning or regulation. This is due to no zoning management or security within and around the reserve. The reserve is situated within the middle of the capital city, which makes the wildlife, such as the targets common duiker and Cape bushbuck, easy targets. Therefore, the animals become an easy source of income, which is produced by the demand from international and national markets for the illegal pet and wildlife trade.

The targets vervet monkey, common duiker and the Cape bushbuck are all threatened by the human-wildlife conflict threat. The contributing factors within **Figure 19** suggests that the reserve being situated within the middle of the capital city and surrounded by human activity causes habitat isolation, therefore is a root cause for human-wildlife conflict. Due to the habitat isolation there are a lack of food and space resources for the wildlife within the reserve, which is also a result of the species over-populating within a small and isolated area. These contributing factors cause animals, such as the vervet monkey, to raid neighbouring farmer's crops, which affects the livelihoods of neighbouring communities. Ultimately leading to human retaliation and the belief that the wildlife are pests invading their communities, thus resulting in human-wildlife conflicts and also the threat of hunting and trapping. Identifying the root causes of the main threats using the Conceptual Model's contributing factors enables the correct strategies to be put into place to help reduce and eliminate the threats affecting the scope and the threats.

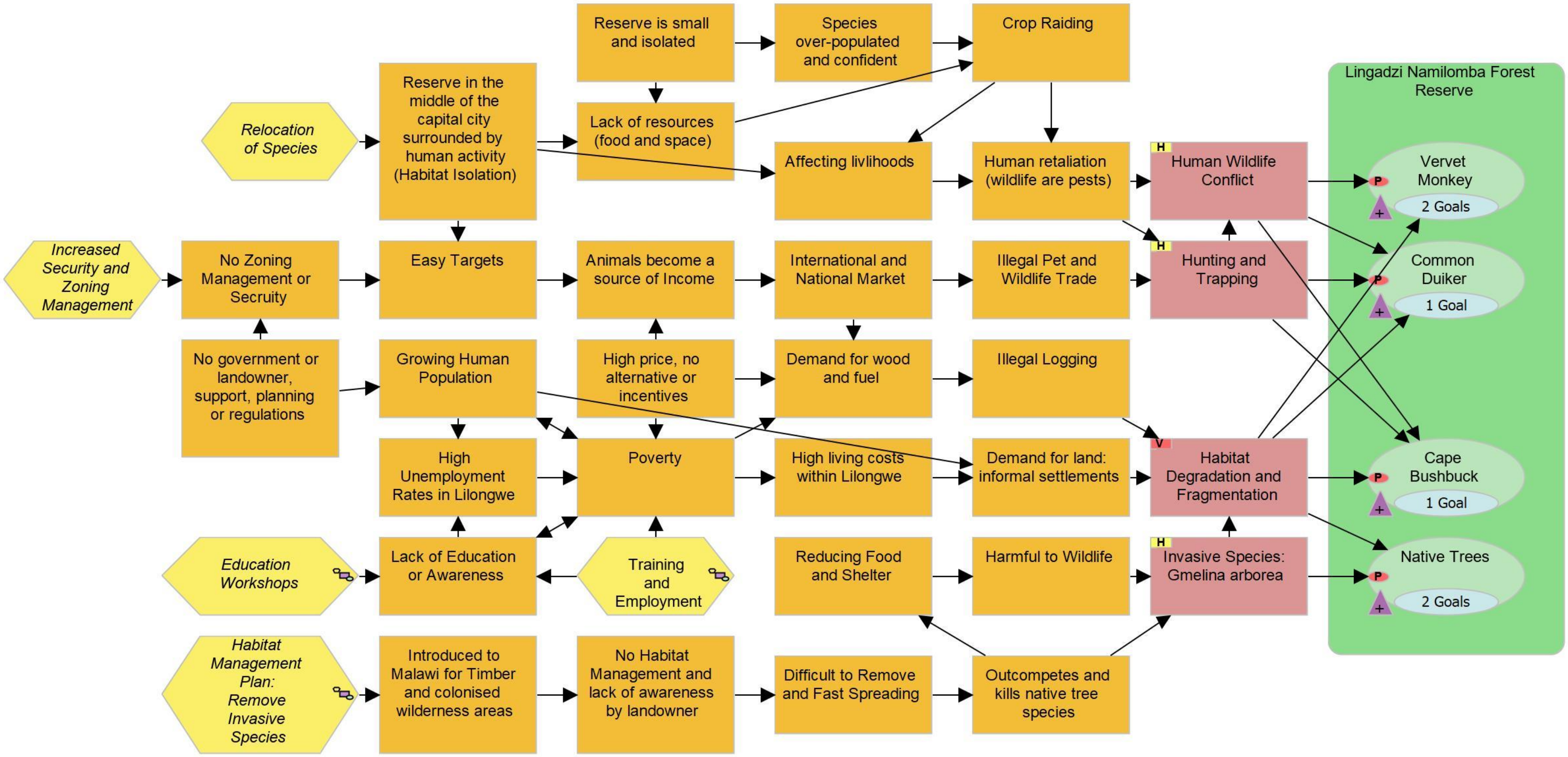


**Figure 19** (*above*): This conceptual model displays the contributing factors that add to the pressures of the direct threats to the scope and the targets. The model also presents the strategies that will be used to mitigate these pressures.

## 5.6 Action Planning and monitoring

### 5.6.1 Goals

**Table 14** displays the goals the project aims to achieve over the next 10 years. These goals will show the success of the project and help to keep the strategies on track and monitored. The goals are used to help achieve the ultimate desired state and vision for the reserve.

**Table 14** (below): The table shows the projects main goals for the next 10 years.

| | ***Goals*** |
|---|---|
| Goal One | By 2030, the population of vervet monkey within Lingadzi Namilomba Forest Reserve will have an average population density of 130 per km², with a male to female sex ratio of 1:3. |
| Goal Two | By 2030, the population of native trees will cover at least 90% of the reserve with the complete removal of the invasive *Gmelina arborea* species. |
| Goal Three | By 2030, the native tree species within Lingadzi Namilomba Forest Reserve will have a very good threat status rating. |
| Goal Four | By 2025, the successful translocation of at least one troop of male vervet monkeys will have been conducted, which will lead to an increase of space and food resources for the remaining individuals. |
| Goal Five | By 2030, the mammals within Lingadzi Namilomba Forest Reserve will have reduced threat ratings for all threats. |
| Goal Six | By 2030, the common duiker and cape bushbuck populations will have increased to a fair status threat rating with the reduction of hunting and trapping and increased security within the reserve. |

### 5.6.2 Strategies

#### 5.6.2.1 Strategy One: Habitat Management Plan: Remove Invasive Species

A habitat management plan for the removal of the invasive species is essential to the health and success of the reserve. With the correct step by step procedures to carefully remove the invasive species, the native species can flourish once again. The *Gmelina arborea* areas will be split into zones, then these zones will be removed one by one to ensure the correct procedures are followed. For example, within the first year the *G. arborea* within zone one with be removed, the following year the invasive species within zone two will be removed. The land and soil that used to have the invasive trees will then have the necessary treatment, so that those zones can be used as a nursery for reintroduced native species. The removal of the invasive species will be hugely beneficial for the ecosystem, as they take up vital resources and remove key food production and shelter needed for the wildlife's survival. With the invasive species removed and native trees replanted, the wildlife will have more food and shelter resources, giving them more space, less fragmentation and reducing the human-wildlife conflict due to the increased food supply. Strategy One will aid in achieving goals two and three, which are set out in **Table 14**, for the complete removal of the invasive species, to reduce the native species threat and to allow the space for native trees to cover 90% of the forest floor. The *G. arborea* that is removed can also be offered to the local communities for crafting, building, wood, and fuel, which can be an incentive for help and support.

#### 5.6.2.2. Strategy Two: School Trips and Workshops

Education is one of the key steps to Lingadzi Namilomba Forest Reserves success and to rebuild a connection with the surrounding community. Workshops can be held within the Lilongwe Trust's education centre or within schools to educate and raise awareness for wildlife conservation and ecology. These workshops can also help to educate about the consequences of the direct threats and contributing factors. Campaigns can also be made, as well as useful signage and Eco bricks to help the community. New methods of sustainable and ecofriendly living can be taught to help improve both the lives of the community and the wildlife.

Other threats such as pollution and roads are also a contributing factor towards habitat fragmentation and human-wildlife conflict, thus education workshops will also teach how to recycle properly and waste management. They can also help to raise road awareness and create signage for the roads surrounding the reserve to reduce wildlife-vehicle collisions.

#### 5.6.2.3 Strategy Three: Training and Employment

Training and offering employment are an important strategy to creating a connection with the community and helping the reserve. Training on security, waste management, habitat management, or basic skills to help with other employment opportunities. The sanctuary can offer employment to the farmers or locals for security, thus working with the locals to build a positive relationship. The management of the reserve will require a team, for example, the removal of the invasive *Gmelina arborea*, treating the soil and replanting native trees. This process will be a timely project. Hiring people from the local community will provide jobs and ensure the project is completed, ensuring the projects targets are met. This will ultimately increase job stability, create a new income source, an incentive to protect the reserve and the wildlife, decrease illegal activities within the reserve and create a partnership with the community. This will lead to a reduction in human-wildlife conflict, hunting and trapping and many contributing factors.

#### 5.6.2.4 Strategy Four: Increased Security and Zoning Management

Increasing the security on the borders of the reserve and daily walks through the forest will help to reduce the amount of illegal activities such as poaching, logging, hunting, and trapping. Creating a partnership with the surrounding farmers will also help to protect the reserve and have extra protection. Offering employment will give the farmers an incentive to help protect the reserve, thus reduce human-wildlife conflict, hunting and trapping. Zoning management will be introduced to keep visitors of the reserve to the footpaths and away from known animal settlements to reduce pressure to the wildlife and the reserve. This will also reduce habitat fragmentation and degradation as the habitat will be closely monitored and managed.

#### 5.6.2.5 Strategy Five: Relocation of Species

Relocation of over-populated species will help to increase the area of occupancy, space, and resources for the remaining animals, reduce human-wildlife conflicts, intraspecific competition, and habitat degradation. An over-populated species causing problems for the ecosystem, including over grazing, trampling, or using reducing food resources. The Lilongwe Wildlife Trust is in association with all national parks and most wildlife reserves within Malawi and frequently releases animals back into the wild. Thus, capturing one of the two troops of vervet monkeys or establishing a male troop to release into another reserve will be an achievable goal for the Lilongwe Wildlife Trust's team. The animals being translocated will be released into a much larger area of occupancy with unlimited resources, away from human settlements and infrastructure. These animals can also be monitored by the wildlife trust's research team to assess the success of the translocation.

A strategy to build a wildlife corridor or bridge to the forest across the road should be taken into consideration for the future if government planning, funding and access is granted. The forest across the road used to be an old zoo, however it is now empty and inaccessible, thus could offer more resources and space for the remaining wildlife, reducing isolation and increasing connectivity.

## 5.7 Results Chains

The results chains display the conceptual model's strategies, threats, and targets, with the estimated change the strategies are expected to have on the threats. The chain shows how the strategy will change the contributing factors to alter and decrease the threats to get the predicted progressive outcome the project is hoping to achieve. Different objectives, indicators and goals are used within each stage to set targets to achieve the progress needed to succeed.

### 5.7.1 Theory of Change for Results Chain One

Results chain one displays the strategy 'Habitat Management Plan: Remove Invasive Species' in **Figure 20**, which has the aim to remove the invasive species *Gmelina arborea* and replant native tree species with a step by step monitored action plan (see **Table.15.**). One of the first contributing factors that cause the threat of the invasive species and fragmented habitat, is that the invasive species was introduced to Malawi for timber, however the species quickly colonized native wilderness areas (see **Fig.19**). Thus with no habitat management plan or invasive species awareness from the landowners this has become a serious problem for the reserve. The first step within the results chain is to identify the areas within the reserve inhabited by the invasive species in order to successfully remove it. Additionally, efforts need to be made to ban future imports of the invasive species to stop the threat from occurring in the future. The next stage of the chain is to create a habitat management plan and begin to remove the invasive species and reintroduce native species. As the trees are fast growing and easily spread, especially if logged incorrectly, the next stage of the chain is to have the trees removed with the correct procedures and hired specialists. This will reduce the risk of the tree spreading and focus on the permanent removal of the species.

One of the main issues with *G. arborea* is that it is taking valuable resources away from the native trees and ultimately killing them. With the trees removed, the native trees will have more space and the resources they need, such as sunlight, nutritious soil and water, thus they can continue to grow and spread without competing against a much stronger invasive species. Once the invasive species have been removed, native trees will be replanted within each removal section to help with the forest's succession and growth. With the invasive species removed and native trees reintroduced, it will increase the resources for the animals living within the reserve and reduce the risk of harm the invasive trees pose to the wildlife. As a result, the invasive species will be permanently removed, reducing habitat degradation and fragmentation, as the reserve will occupy a native species forest cover.

**Table 15** (below): This table demonstrates the assumptions, objectives, indicators and desired outcome for the direct threats after the implementation of the strategy 'Habitat Management Plan: Remove Invasive Species', which is illustrated within **Figure 20.**

| Strategy | Assumptions | Objectives | Indicators | Direct Threats |
|---|---|---|---|---|
| Habitat Management Plan: Remove Invasive Species. | Zones established for removal of invasive species. | By 2021, all tree removal zones are established, and 15% of the invasive trees have been removed. | % of invasive trees removed. | Invasive Species removed. Habitat fragmentation reduced. |
| | Trees removed with the correct procedures to ensure it does not spread. | By 2025, all invasive species removed from the reserve. | 100% of the invasive trees have been removed. % of invasive trees left within the reserve. | Invasive Species removed. Habitat fragmentation reduced. |
| | Native trees have more space and the resources they need to flourish. | By 2027, native trees have regained their former land and are thriving. | Native tree area of occupancy /$km^2$. % native trees within the reserve. | Invasive Species Removed. |
| | The invasive species are banned from being imported into Malawi. | By 2030, the invasive species will be illegal to import into Malawi. | % of imports of *Gmelina arborea* within Malawi. | Future threat of reintroduction of the invasive species removed. |
| | Animals have more food and shelter. | By 2030, natural food, shelter and resources for animals has improved by 30%. | Rate of human wildlife conflict has reduced. | Reduced conflict. Invasive Species Removed. |

### 5.7.2. Theory of Change for Results Chain Two

Results chain two displays the strategy 'Training and Employment' in **Figure 21**, which has the aim to reduce the habitat degradation and fragmentation (see **Table.16.**). Poverty is a huge contributing factor towards the threats of Lingadzi Namilomba Forest Reserve with 16% unemployed and 25% of the population living in poverty within Lilongwe (UN-Habitat, 2011). Therefore, having a focus on educating and training the locals and the unemployed on the threats within the reserve, sustainable living, and key employment skills will help to build a community and give incentives to the population to provide a stable income, to ultimately protect and preserve the reserve. With the training in motion it would lead to better education and employment skills, which would lead to an increased employment rate within Lilongwe. The employment will bring in a new sustainable income to reduce poverty. This will then enhance the income within households to make the cost of living in Lilongwe achievable and affordable. This incentive and source of income will reduce the need for land and informal settlements and illegal logging. Reduced logging and need for land will ultimately lead to the reduction in habitat degradation and fragmentation, which could also lead to a land expansion in the future, due to reduced settlements.

**Table 16** (below): This table demonstrates the assumptions, objectives, indicators and desired outcome for the direct threats after the implementation of the strategy 'training and employment', which is illustrated within **Figure 21.**

| Strategy | Assumptions | Objectives | Indicators | Direct Threats |
|---|---|---|---|---|
| Training and Employment | Education and training on the threats, sustainable living, and key employment skills. | By 2025, 100 unemployed Lilongwe citizens will be trained in an employable skill. By 2025, 70% of the locals in the surrounding areas with be | Number of people that have taken the training per year.<br><br>Number of people who have taken the training and are now employed. | Reduction in Human-Wildlife Conflict.<br><br>Reduced habitat fragmentation and degradation. |

| | | | | |
|---|---|---|---|---|
| | | educated on sustainability, the threats of the reserve and the importance of protecting it. | | Habitat fragmentation reduced. |
| | Increased employment rates. | By 2030, at least 100 unemployed Lilongwe citizens will be employed.<br><br>By 2030, at least 20 locals will have been employed to protect and manage the reserve. | Number of people who have taken the training and are now employed.<br><br>Number of people employed by the reserve. | Reduction in Human-Wildlife Conflict.<br><br>No hunting or trapping within the reserve.<br><br>Habitat fragmentation reduced. |
| | New source of sustainable income and incentive to protect the reserve. | By 2025, hunting and trapping will have reduced by 95%.<br><br>By 2025, illegal logging will have reduced by 95%. | Number of animal deaths/injured or trapped from hunting and trapping per year.<br><br>Number of cases and trees illegally logged per year. | No hunting or trapping within the reserve.<br><br>Habitat fragmentation reduced. |
| | Illegal logging has significantly reduced. | By 2025, illegal logging will have reduced by 95%. | Number of cases and trees illegally logged per year. | Habitat fragmentation reduced. |

## 5.7.3 Results Chain One

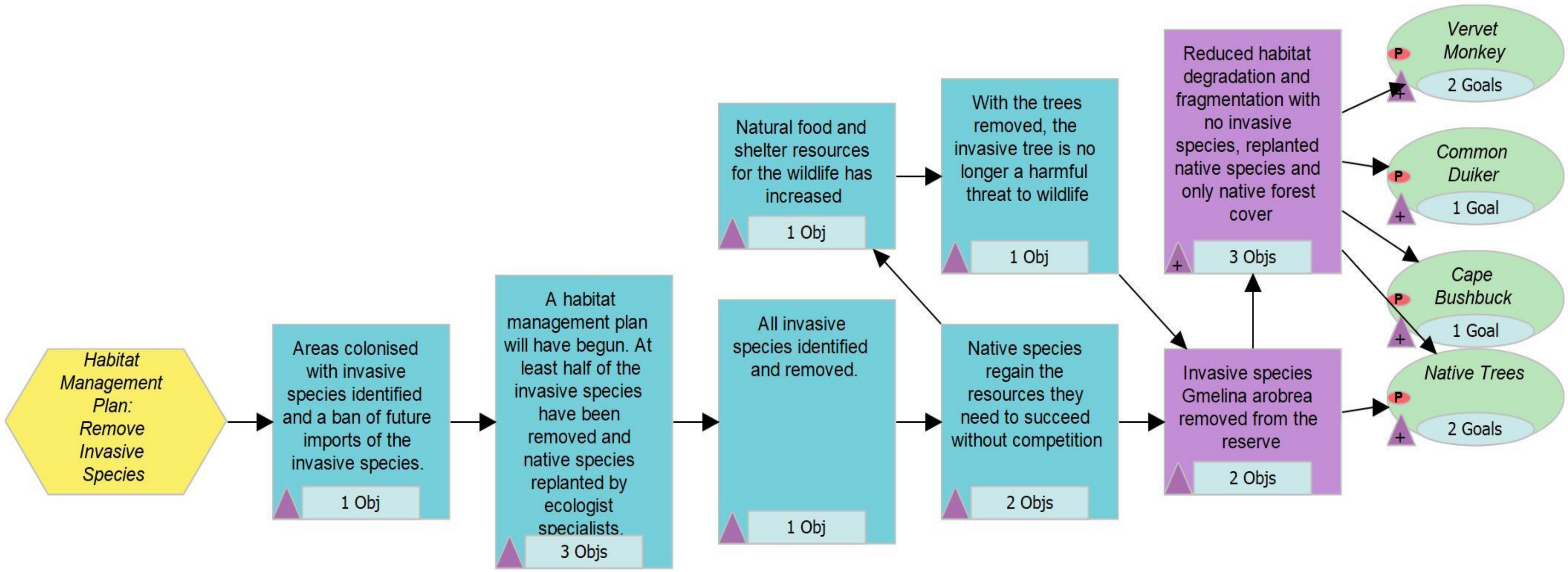


**Figure 20** (*above*): This diagram displays Results Chain One for 'Habitat Management Plan: Remove Invasive Species', with the step by step changing processes to improve the threats status.

### 5.7.4 Results Chain Two

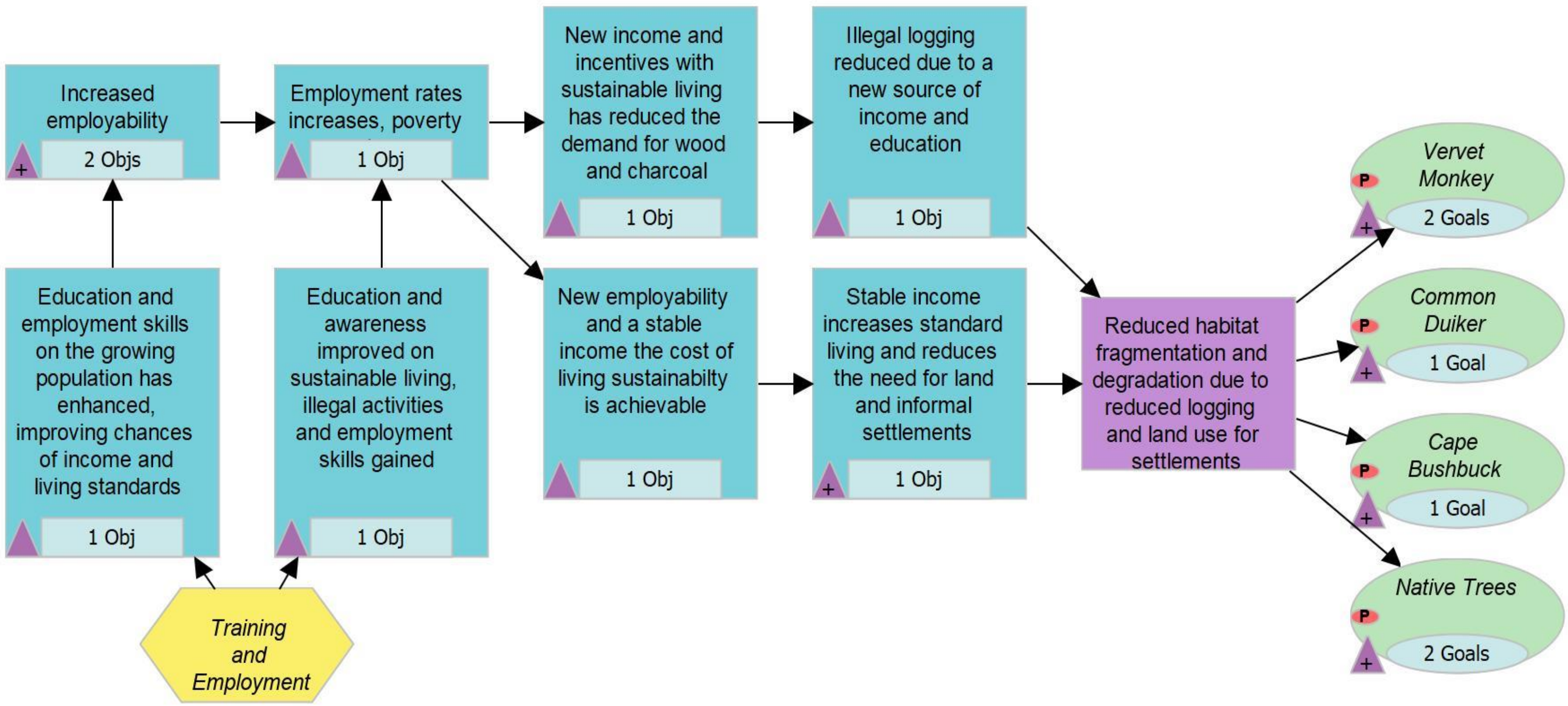


**Figure 21** (*above*): This diagram displays Results Chain Two for 'Training and Employment', with the step by step changing processes to improve the threats status.

## 5.8 Monitoring Plan

**Table 17** displays the monitoring plan, which is key for identifying the resources needed for implementation and analysis. This plan helps to monitor the project and to make sure it is on track. It is developed on core assumptions and adjusted through time using the indicators, to determine if the plan is on track to reaching the objectives and the project's main goals. **Table 17** exhibits each strategy with their main actions that will be implemented to achieve that strategy's aim. Each strategy and action has its own objectives and indicators to access the productivity of each process. For example, the first action to take place for the strategy 'Habitat Management Plan: Remove Invasive Species' is to establish where the *Gmelina arborea* is situated. The removal of the invasive species will not take place until all the invasive trees are accounted for and have their location marked. The objective will be to ensure that, by 2021, thorough research will be conducted to establish the exact locations of all the invasive trees. The objective is met by using the indicator to count and plot the invasive trees onto a map of the reserve. This will successfully identify the location of all the species. This will be measured by surveys and research using 10x10 quadrats, counts and GPS co-ordinates to successfully plot where all the invasive species are within the reserve. This will take place within Lingadzi Namilomba Reserve and carried out by employees of the Lilongwe Wildlife Trust, including the research manager, research assistants, research students and volunteers at the trust. There is a timeline of three to six months to complete this action, due to it being a small reserve with multiple people able to conduct the research. However, weather is unpredictable, and the sanctuary is incredibly busy, which could lead to this action taking longer than anticipated. This process is repeated with each action and strategy to be able to successfully stay on target to reach the projects goals and vision.

**Table 17** (*below*): This table displays the monitoring plan for the project, which shows the strategies and the brief actions that will take place with their objectives, indicators, indicator measurements, where, who and the timeline.

| ***Strategy/Action*** | ***Objectives*** | ***Indicator*** | ***How is the indicator measured?*** | ***Where?*** | ***Who?*** | ***Time*** |
|---|---|---|---|---|---|---|
| **1. Habitat Management Plan: Remove Invasive Species.** | **By 2025, all the invasive species have been removed from the reserve.**<br><br>**By 2030, the reserve will be 100% native species.** | **100% of the invasive trees have been removed.**<br><br>**% of invasive species still within the reserve.** | **Regular monthly surveys and counts for the invasive tree will be conducted within the reserve.** | **Lingadzi Namilomba Forest Reserve, Lilongwe Malawi.** | **Volunteers at Lilongwe Wildlife Trust.**<br><br>**Employees of the Trust.**<br><br>**School trips.** | **Within 10 years.** |
| 1.1 Establish where *Gmelina arborea* is situated. | By 2021, thorough research will be conducted to establish the exact locations of all the invasive trees. | No. invasive trees<br><br>A clear map of the reserve: native and invasive trees. | Surveys will be conducted using 10x10 quadrats, GPS mapping and counts to establish where the invasive species are. | Lingadzi Namilomba Forest Reserve. | Volunteers at Lilongwe Wildlife trust.<br><br>Employees of the trust. | 3-6 months. |
| Set up five invasive species zones. | By 2021, all the invasive species zones will have been established. | 5 zones have been established. | Once all the invasive trees are accounted for, separate zones will be created using the GPS co-ordinates. | Lingadzi Namilomba Forest Reserve. | Employees of the trust. | 2 months. |
| Zone by zone removal of the invasive species following a habitat | By 2025, all the invasive species will have been removed from the reserve. | No. invasive trees within the reserve. | Removal of the trees will happen one zone at a time. Each tree removed | Lingadzi Forest Reserve. | Employees of the trust.<br><br>Hired forest | 5 years. |

| | | | | | | |
|---|---|---|---|---|---|---|
| management plan. | | % of trees that have been removed. | will be documented. | | removal company. | |
| Treat and test the soil/land, where the invasive species where situated if needed. | By 2026, the soil will be ready for replanting native trees. | % of native trees within the reserve.<br><br>Soil Ph levels. | The soils Ph levels will be tested and treated accordingly. | Lingadzi Namilomba Forest Reserve. | Hired geologists or plant experts. | Within 1 year of each zone removal. |
| Plant native trees zone by zone. | By 2030, the reserve will contain 100% native trees.<br><br>By 2030, natural food, shelter and resources for animals has improved by 30%. | % of native trees within the reserve.<br><br>Human-wildlife conflict has reduced.<br><br>% of edible fruit trees | Human-wildlife conflict will be monitored to evaluate a reduction over time. Tree surveys will be conducted seasonally to assess the edible trees. | Lingadzi Namilomba Forest Reserve. | Volunteers at Lilongwe Wildlife Trust.<br><br>Employees of the trust. | 10 years.<br><br>Surveys annually. |
| **2. Education Workshops.** | **By 2030, 85% of schools in Lilongwe and surrounding towns will have participated in a workshop.**<br><br>**By 2030, 200 work forces will have participated in a workshop.** | **Number of schools and workplaces that have participated in a workshop or have had a trip to the reserve.** | **Each school and workplace will be recorded into a data protection file and logged.**<br><br>**This will be partnered with the current outreach projects.** | **At the schools and workplaces.**<br><br>**Lilongwe Wildlife Trust's education centre.**<br><br>**Lingadzi Namilomba Forest Reserve.** | **Education and outreach team at Lilongwe Wildlife Trust.**<br><br>**Lilongwe Wildlife Trust volunteers.** | **10 years.**<br><br>**On-going strategy/ project.** |
| Create workshops for schools and workplaces on nature, threats and co-existing. | By 2021, the workshop projects will be created.<br><br>By 2021, school trip lessons and | Progression of the projects. | The projects will be completed. | Lilongwe Wildlife Trust's Education Centre. | Education and outreach team at Lilongwe Wildlife Trust. | 1 year<br><br>On-going strategy/project. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | research projects will be created for the reserve. | | | Lingadzi Namilomba Forest Reserve. | | |
| School trips to the reserve. | By 2030, 75% of the schools within Lilongwe will have participated in a school trip to the reserve.<br><br>By 2030, 10 research projects from surrounding universities and colleges will have been conducted within Lingadzi Namilomba Forest Reserve. | Number of schools and classes that have participated in a trip to the reserve.<br><br>Number of research projects conducted and submitted to Lilongwe Wildlife Trust. | Each school and trip will be recorded into a data protection file and logged.<br><br>Each research project will be logged, filed, and used for future studies. | Lingadzi Namilomba Forest Reserve. | Education and outreach team at Lilongwe Wildlife Trust.<br><br>Lilongwe Wildlife Trust research team.<br><br>Research students. | 10 years.<br><br>On-going strategy/ project. |
| Workshops at Lilongwe Wildlife Trust, schools, and workplaces. | By 2030, 85% of schools in Lilongwe and surrounding towns will have participated in a workshop.<br><br>By 2030, 200 work forces will have participated in a workshop. | Number of schools and workplaces that have participated in a workshop or had a trip to the reserve. | Each school and workplace will be recorded into a data protection file and logged.<br><br>This will be partnered with the current outreach projects. | At the schools and workplaces. Lilongwe Wildlife Trust's education centre.<br><br>Lingadzi Namilomba Forest Reserve. | Education and outreach team at Lilongwe Wildlife Trust.<br><br>Lilongwe Wildlife Trust volunteers. | 10 years.<br><br>On-going strategy/ project. |
| **3. Training and Employment.** | **By 2025, 100 unemployed Lilongwe citizens will be trained in an employable skill.**<br><br>**By 2025, 70% of the locals in the surrounding** | **No. people that have taken the training per year.**<br><br>**No. people who have taken the training and** | **The number of training groups, individuals and sessions will all be documented.**<br><br>**The employment** | **Lilongwe Wildlife Trust education centre.** | **Employees of the trust.**<br><br>**Volunteers at Lilongwe Wildlife Trust can** | **5- 10 years.**<br><br>**This will be an ongoing strategy/ project.** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **areas will be educated on sustainable living.**<br><br>**By 2030, at least 20 locals will have been employed to protect and manage the reserve.** | **are now employed.**<br><br>**No. of people employed by the reserve.** | **rate as result of the training within Lilongwe Wildlife Trust and other areas.** | | **also take part.** | |
| Create training modules. | By 2021, the training modules on employable skills, sustainable living and living with wildlife will be complete. | Each modules completion date. | Completion of the modules. | Lilongwe Wildlife Trust's education centre. | Lilongwe Wildlife Trust's education and outreach team. | 1 year. |
| Training to be carried out on sustainable living, living with wildlife, illegal activities, and employment skills. | By 20205, 100 unemployed Lilongwe citizens will be trained in an employable skill.<br><br>By 2030, 70% of the locals in the surrounding areas will be educated on sustainability, living with wildlife and the damaging effects of illegal activities. | No. of people that have taken each training module per year.<br><br>No. of people who have taken the training and are now employed. | Each session that is completed, the number of people in participation documented.<br><br>There will be three separate training modules.<br><br>Each person employed after completing the modules will be documented. | Lilongwe Wildlife Trust's education centre. | Lilongwe Wildlife Trusts education and outreach team. | 10 years.<br><br>On-going project. |
| Employment. | By 2030, at least 100 unemployed Lilongwe citizens will be employed. | No. of people employed after taking the training courses. | Each person employed after the training will be documented. | Lilongwe Wildlife Trust's education centre. | Lilongwe Wildlife Trust's education and | 10 years.<br><br>On-going project. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | By 2030, at least 20 locals will be employed by Lilongwe Wildlife Trust. | No. of people employed by Lilongwe Wildlife Trust. | | | outreach team. | |
| **4. Increased Security and Zoning Management.** | By 2021, the vulnerable areas within the reserve will assessed and management will be put in place.<br><br>By 2022, the reserve will be fully fenced and secure.<br>By 2022, a fully trained security team will be patrolling the reserve. | % of the reserve fenced and secure.<br><br>No. of employed and trained security personnel.<br><br>No. patrols each day and night. | The fence and surroundings will be monitored daily to assess damage.<br><br>Security employees will clock in and out of each shift and will write a summary of each shift. | Lingadzi Namilomba Forest Reserve. | Lilongwe security team. | 1-5 years. |
| Train new and current employees on security of the reserve. | By 2021, a security training program will be established, and training will commence.<br><br>By 2022, a fully trained security team will be patrolling the reserve. | Number of people successfully trained for the security team. | An exam and in the field practical will take place, to assess whether the new and current employees are successfully trained. | Lilongwe Wildlife Trust.<br><br>Lingadzi Namilomba Forest Reserve. | Management at Lilongwe Wildlife Reserve.<br><br>Security professional. | 2 years. |
| Set up security zones, where the weakest links and entry points are. (Areas most threatened). | By 2021, vulnerable areas within the reserve will be assessed and management will be put in place.<br><br>By 2022, the reserve will be | % of the reserve fenced and secure. | The fence and the reserves surroundings will be closely monitored daily to assess damage or weaknesses. | Lingadzi Namilomba Forest Reserve | Lilongwe Wildlife Trusts employees. | 1-2 years. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | fully fenced and secure. | | | | | |
| Daily and Nightly security around and within the reserve. | By 2022, a fully trained security team will be patrolling the reserve. | No. patrols each day and night. | Security employees will clock in and out of each shift and will write a summary of each shift. | Lingadzi Namilomba Forest Reserve. | Lilongwe Wildlife Trust's security team. | 2 years<br><br>This will be a daily task. |
| **5. Relocation of Species.** | By 2025 the successful translocation of at least one troop of male vervet monkeys will have been conducted.<br><br>By 2030 the human wildlife conflict will have been mitigated by at least 75%. | No. of animals successfully translocated to another reserve.<br><br>No. of human-wildlife conflicts annually. | Each animal successfully translocated will be documented.<br><br>Human-wildlife conflict will be assessed over time. Annual surveys will be conducted to monitor the abundance and threats of the mammals. This will assess the population growth and resource availability. | Lingadzi Namilomba Forest Reserve.<br><br>National Parks and Reserves within Malawi, such as Kuti Wildlife Reserve or Vwaza National Park. | Lilongwe Wildlife Trust's rescue and vet team. | 5-10 years.<br><br>On-going project that will be assessed annually. |
| Surveys on the vervet monkeys to established which troop or males are best to relocate. | By 2023, there will be sufficient data on the vervet monkey troops to distinguish which individuals will be relocated. | No. individuals, troops, and their territories within the reserve.<br><br>No. males and females, | Line transect sampling method and behavioral observations will be conducted throughout the year. | Lingadzi Namilomba Forest Reserve.<br><br>Lilongwe Wildlife Trust. | Research manager and research assistants at Lilongwe Wildlife Trust. | 3 years.<br><br>This will be on-going research and data collection. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | adults, subadults and juveniles within the reserve. | | | Research students and volunteers. | |
| Survey duiker and bushbuck to evaluate whether any should be relocated. | By 2023, there will be sufficient data on the antelope to distinguish which individuals will be relocated. | No. individuals within the reserve.<br><br>No. males and females, adults, subadults and juveniles. | Line transect sampling method and behavioral observations will be conducted throughout the year. | Lingadzi Namilomba Forest Reserve.<br><br>Lilongwe Wildlife Trust. | Research manager and research assistants at Lilongwe Wildlife Trust.<br><br>Research students and volunteers. | 3 years.<br><br>This will be on-going research and data collection. |
| Prepare a relocation plan and discuss with wildlife reserves within Malawi. | By 2024, a relocation plan will have been developed and agreed with nature reserves within Malawi. | No. of reserves willing to have animals moved to their reserve.<br>-Kuti Wildlife Reserve<br>-Vwaza Marsh National Park<br>-Liwonde National Park<br>-Majete Wildlife Reserve<br>- Thuma Forest<br>% of relocation plan developed. | The relocation plan will be completed with the location, team, animals, vets, and dates ready for translocation. | Lingadzi Namilomba Forest Reserve.<br><br>Lilongwe Wildlife Centre<br><br>Nature Reserves in Malawi. | Research manager and research assistants at Lilongwe Wildlife Trust. | 4 years. |
| Relocate animals to their new reserves. | By 2025 the successful translocation of at least one troop of male vervet monkeys will | No. of animals successfully translocated to another reserve. | Each animal successfully translocated will be recorded and observed. | The nature reserves the animals are | Research manager and research assistants and Lilongwe | 5 years.<br><br>This will be an on-going project. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | have been conducted. | | A monitoring team will be established to observe the animals post release to assess their success back into the wild. | released into. | Wildlife Trust.<br><br>Research students. | |

## 5.9 Conclusion

Action plans typically have five sections, however this conservation action plan on the Lingadzi Namilomba Forest Reserve focuses on two: conceptualize, action plan and monitor. The purpose of the project was to define the key contributing factors and threats towards the scope Lingadzi Namilomba Forest Reserve and the targets; vervet monkeys, common duiker, cape bushbuck and the native trees. These targets were chosen due to being the most abundant species when data collecting and to represent the forest's mammal species and biodiversity. This project helps to define the planning purposes and the next steps needed to be taken after the initial baseline data collection has occurred.

The main threats to the reserve are human-wildlife conflict, hunting and trapping of animals, habitat degradation and fragmentation and invasive species, which is displayed in the conceptual model in **Figure 19**. The threat rating for the project is very high and in the red zone (see **Fig.17.**) with the highest threat being habitat degradation and fragmentation. This threat has contributing factors of agriculture, illegal logging, informal human settlements, infrastructure, roads, and pollution. Due to the reserve being so small, any contributing factor to the fragmentation and degradation to the reserve is critical.

The conservation status of the reserve is critical with the threat of local extinction if no action is taken. The main aim is to build a relationship with the community and together with Lilongwe

Wildlife Trust, the reserve can be respected and protected. The vision is to restore, preserve and protect an ecological healthy ecosystem within Lingadzi Namilomba Forest Reserve by managing and protecting the mammal population and reducing the threats by 75% by 2030. The vision is to allow the mammals to fulfil their ecological roles and thrive without disruption from human activities and to allow native tree species to flourish across the entire reserve. The park will also aim to meet the economic, cultural, and spiritual needs of local communities, but without damaging or disrupting the reserve. This conservation action plan will work towards making this vision a reality.

Lingadzi Namilomba Forest reserve is one of the only pockets of nature left within Lilongwe, thus is a hotspot for nature enthusiasts and a relaxing space to escape the bustling city. It would affect Lilongwe's tourism economy if the reserve is lost, as it is a major attraction on arrival into the country. Once the action plan is put into motion and the threats are being reduced, then the mammal population can become a focus to get the reserve to a healthy biodiverse state. More research is urgently needed to fully assess the animals and trees within the reserve and the conflicts they face. A recommendation to perform surveys and questionnaires to the locals surrounding and within Lilongwe, including the farmers bordering the reserve would be beneficial. It is crucial to listen to their suggestions, concerns and fears and to further understand their relationship with the reserve. Together, these surveys, this study, and the conservation action plan, will all help to build a positive future for the locals, the wildlife, and the ecosystem with Lingadzi Namilomba Forest Reserve.

# Appendices

## Appendix I: How to use DISTANCE 7.3.

DISTANCE 7.3. software was used to analyse the mammal data collected within Lingadzi Namilomba Forest Reserve. To begin the data was inserted into an excel spreadsheet. The type of habitat, area ($km^2$), which transect the animal was seen on, the total effort walked on each transect (m), perpendicular distance (m), number of individuals seen and the species were inputted. **Figure 22** exhibits how the data was inserted into a spreadsheet. Transects 1-14 and A, B, C were all inserted into the spreadsheet. All transects needed to be inserted to ensure the total effort from each transect was calculated, even if there were no animal sightings on the transect. Total effort was calculated by taking the length of each transect and multiplying it by the amount of times the transect was walked. For example, Transect 7 was 650m in length, which was walked 8 times during the data collection period. Therefore, 650 was multiplied by 8 to give the total effort of 5,200m (see **Table.1.**). If there was a transect with no mammal sightings it was still logged, because the effort was still put in for that transect. For example, there were no sightings along Transect 3 (see **Fig.22.**), therefore the effort still needed to be recorded, though the perpendicular distance, number of individuals and the species sections was left blank, as no data was collected. Once the data was inserted it was saved as 'Text (Tab delimited) (*.txt.)', so that it opened into the DISTANCE software. This process was done for each species separately. During this study, a file was made for the vervet monkey *(Chlorocebus pygerythrus*), common duiker (*Sylvicapra grimmia*) and the cape bushbuck (*Tragelaphus sylvaticus).*

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Type of Habitat | Area (km2 | Transect | Total (m) | Perpendicular (m) | Number of individuals | Species | |
| 2 | Forest | 0.336 | 1 | 720 | 7 | 3 | Vervet Monkey | |
| 3 | Forest | 0.336 | 2 | 1120 | 2 | 1 | Vervet Monkey | |
| 4 | Forest | 0.336 | 3 | 880 | | | | |
| 5 | Forest | 0.336 | 4 | 5120 | 7 | 7 | Vervet Monkey | |
| 6 | Forest | 0.336 | 4 | 5120 | 8.5 | 5 | Vervet Monkey | |
| 7 | Forest | 0.336 | 5 | 4080 | 3.7 | 6 | Vervet Monkey | |
| 8 | Forest | 0.336 | 5 | 4080 | *2.1* | 7 | Vervet Monkey | |
| 9 | Forest | 0.336 | 5 | 4080 | 7.5 | 5 | Vervet Monkey | |
| 10 | Forest | 0.336 | 5 | 4080 | 20 | 4 | Vervet Monkey | |
| 11 | Forest | 0.336 | 5 | 4080 | 0 | 17 | Vervet Monkey | |
| 12 | Forest | 0.336 | 6 | 4640 | 3 | 3 | Vervet Monkey | |
| 13 | Forest | 0.336 | 7 | 5200 | 5 | 3 | Vervet Monkey | |
| 14 | Forest | 0.336 | 7 | 5200 | 2 | 6.3 | Vervet Monkey | |
| 15 | Forest | 0.336 | 7 | 5200 | 10 | 3 | Vervet Monkey | |
| 16 | Forest | 0.336 | 8 | 4320 | 5.2 | 3 | Vervet Monkey | |
| 17 | Forest | 0.336 | 8 | 4320 | 50 | 2 | Vervet Monkey | |
| 18 | Forest | 0.336 | 8 | 4320 | 7.5 | 6 | Vervet Monkey | |
| 19 | forest | 0.336 | 8 | 4320 | 0 | 20 | Vervet Monkey | |
| 20 | Forest | 0.336 | 9 | 2880 | 200 | 3 | Vervet Monkey | |
| 21 | Forest | 0.336 | 10 | 400 | | | | |
| 22 | Forest | 0.336 | 11 | 2480 | | | | |
| 23 | Forest | 0.336 | 12 | 1680 | | | | |
| 24 | Forest | 0.336 | 13 | 1920 | | | | |
| 25 | Forest | 0.336 | 14 | 2448 | 0 | 6 | Vervet Monkey | |

Vervets | Duikers | Bushbuck

**Figure 22** *(above):* This excel spreadsheet displays the data input layout needed to analyse the data using DISTANCE 7.3.

DISTANCE 7.3 was uploaded to a Lenovo yoga laptop. DISTANCE 7.3 was then opened and a new project was created. A ‘New Project’ was selected on DISTANCE, then a file name was chosen and then the ‘Create’ tab was selected. The ‘Next’ tab was selected (Analyze a survey that has been completed), ‘Next’ again, then ‘line transect’, ‘single observer’ and ‘clusters of objects’ was chosen, then ‘Next’ was selected. The distance was then set to metres, transect to metres and area to square kilometer, then ‘Next’, ‘Next’, ‘Proceed to Data Import Wizard’ then ‘Finish’. ‘Next’ was selected again and then a file is uploaded (the file saved from excel created before) and ‘ok’ was selected. The tabs ‘Next’, then ‘tab’, ‘Do not import first row’ and ‘Use ‘’.’’’ was selected, then ‘Next’, select ‘Columns are in the same order as they will appear in the data sheet', then 'Next' and 'Finish'. The 'Observations' tab was then selected (see **Fig. 23**.) to see the results. This was repeated for all data sets 'Vervet', 'Duiker' and 'Bushbuck'.

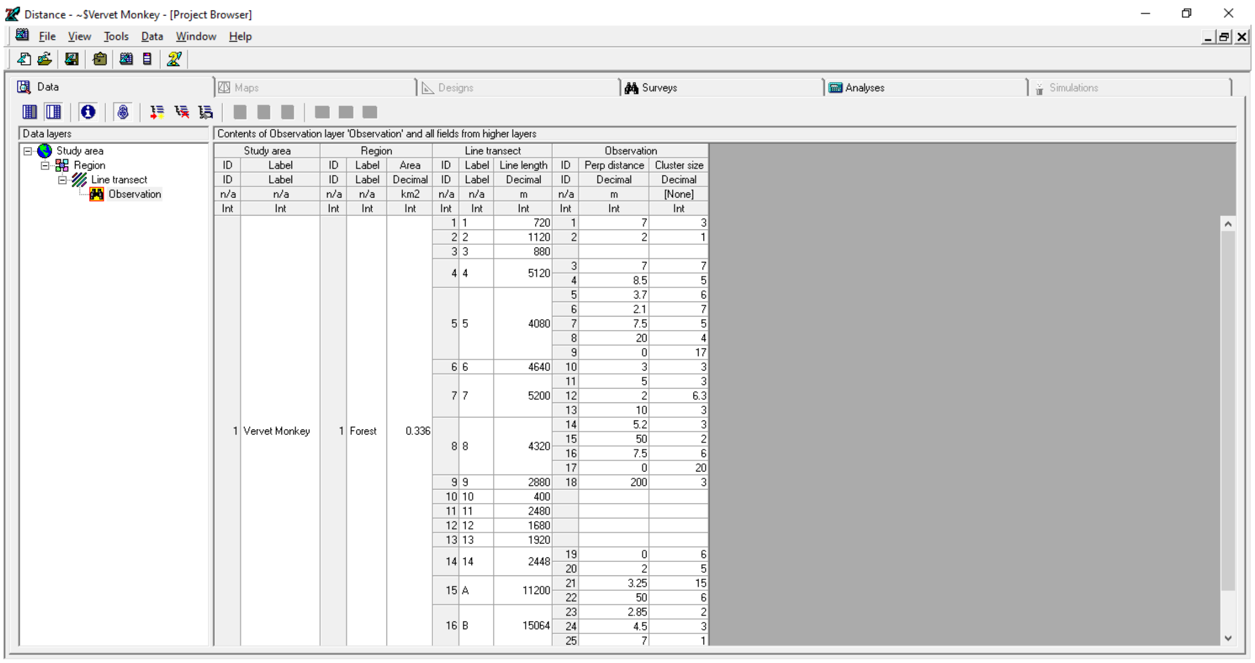


**Figure 23** *(above):* An example of how the data was displayed once a project is set up on DISTANCE 7.3.

Once the project was created on DISTANCE 7.3. the data was analysed to find the goodness of fit and P-Value. The goodness of fit measures the 'fit' between the data and the distribution that has been modeled by the program to best represent the data. P-value indicates a good fit to the model. The project that was being examined was then opened on DISTANCE 7.3 (see **Table.18.**).

**Table 18** *(below)*: This table displays the step by step process used to analyse the data using DISTANCE 7.3.

| | |
|---|---|
| **Step One** | The page began on the 'Data' tab, however the 'Analyses' tab was selected. |
| **Step Two** | The 'New analysis' icon was then selected (see **Fig.24.**). |
| **Step Three** | The new blank analysis that appeared in the section below was double clicked. |
| **Step Four** | Once the new analysis was opened the different tests are created and run. For this study four model definitions were used with three different intervals and four truncations. The model definitions used were 'Uniform Cosine', 'Half-Normal Cosine', 'Half-Normal with Hermite Polynomial' and 'Hazard-Rate Cosine', with 'Half-Normal Cosine' as the default. The three intervals were five, four and default. Finally, the four truncations were 25m, 20m, 15m and default. |
| **Step Five** | A 'Data Filter' was inserted to create the intervals and truncation. The tab 'New' or 'Properties' were selected on an existing filter within the 'Data Filter' section. Once this was opened, the 'Intervals' tab and the number of intervals wanted for the test were selected. Once the intervals had been inserted, they were seen on the right-hand side under 'Cut points. The truncations were set by selecting 'Manual' in the 'Interval cut point' section and then manually typed '25' or '20' into cut point '4'. The 'Automatic equal intervals' was selected, and the software equally divided the truncation distances into the intervals. The data filter was then renamed and then created, for example '25m 4 Intervals', thus the data will be truncated at 25 metres and divided into four intervals. The 'OK' tab was then selected to create the data filter. |
| **Step Six** | The model definition was created by selecting 'New' or 'Properties' like Step Five, but alongside 'Model Definition'. The models are adjusted using the drop-down tabs under 'Key function' and 'Series expansion'. The model being tested was selected and named with the model that was being used, for example, 'Uniform Cosine' was named 'UNcos'. The 'OK' tab was selected. |
| **Step Seven** | The data filter and model definition that was being tested was then selected, for example '25m 4 Intervals' and 'UNcos'. The analysis selected was then named, for example '4UNcos25, which meant 4 intervals, Uniform Cosine, 25m truncations. The analysis was then run by selecting 'Run'. |
| **Step Eight** | After the analysis had run, the three tabs along the side appeared: Inputs, Log and Results. Results was selected and then the 'Next' tab was selected until the 'Chi-sq. GOF Test' had appeared. The 'Chi-sq. GOF Test' was the Goodness of Fit test, which gave the 'Total Chi-square value' and the 'P-Value' (see **Fig.25.**). |
| **Step Nine** | Once the values were collected the tab 'Back' was selected until the 'Detection Probability' graph had appeared (see **Fig.26.**). This graph was used to visually see the test that had been conducted. |
| **Step Ten** | The 'X' to close the window was selected in the analysis tab to return to the main data set. This provided data such as the estimated density of individuals within the reserve. |
| **Step Eleven** | This process was repeated with the different intervals and truncations with all the model definitions. The data for each was then collected and inserted into a table such as **Figure 27** to assess which analysis had the best fit for the data. |

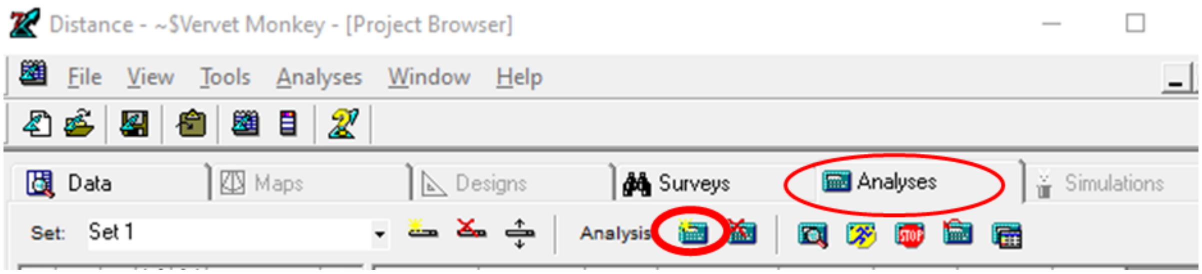


**Figure 24** (*above):* The red circles demonstrate the tabs to selected to create a new analysis using DISTANCE 7.3.

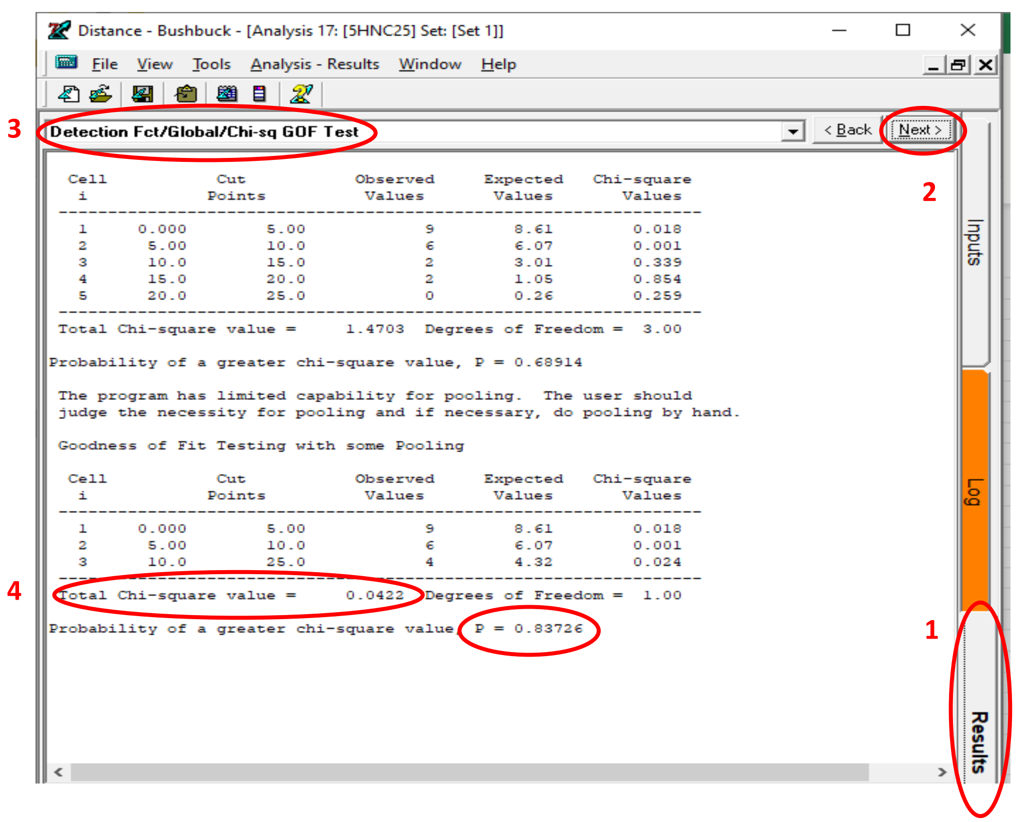


**Figure 25** (*above):* The red circles indicate the steps followed to access the ‘Goodness of Fit’ results on DISTANCE 7.3.

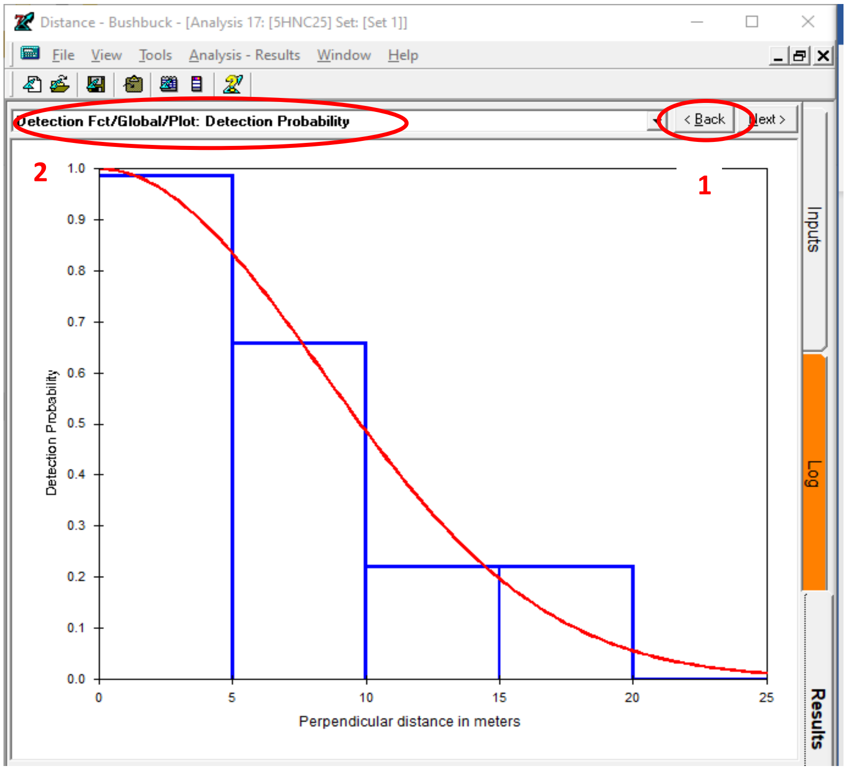


**Figure 26** *(above):* The red circles indicate the steps retrieved to reach the detection probability graph on DISTANCE 7.3.

**Vervets**

| | 4 Intervals | | | | | | | | | 5 Intervals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25m Truncation | | | 20m Truncation | | | 15m Truncation | | | 25m Truncation | | | 20m Truncation | | | 15m Truncation | | |
| | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF |
| Uniform Cosine | 0.06706 | 53.26 | 3.3537 | 0.39093 | 50.24 | 0.7361 | 0.41136 | 52.33 | 0.6749 | 0.49271 | 60.29 | 0.4706 | 0.42124 | 60.24 | 1.7291 | 0.71505 | 62.12 | 0.6708 |
| Half-Norm Cosine | | 53.03 | | 0.63162 | 49.03 | 0.2299 | 0.47114 | 51.95 | 0.5193 | 0.62302 | 58.72 | 0.9464 | 0.5126 | 59.54 | 0.4288 | 0.5655 | 63.09 | 1.1401 |
| Half-Norm with HP | 0.39088 | 53.53 | 0.7362 | 0.63162 | 49.03 | 0.2299 | 0.47114 | 51.95 | 0.5193 | 0.32593 | 60.23 | 0.965 | 0.5126 | 59.54 | 0.4288 | 0.5655 | 63.09 | 1.1401 |
| Hazard Rate | 0.05034 | 53.08 | 3.8302 | 0.40807 | 50.07 | 0.6844 | 0.61782 | 53.41 | 0.249 | 0.51307 | 59.18 | 1.2247 | 0.3852 | 60.21 | 1.908 | 0.64765 | 63.76 | 0.8688 |

**Duikers**

| | 4 Intervals | | | | | | | | | 5 Intervals | | | | | | | | | 0 Intervals: Default | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25m Truncation | | | 20m Truncation | | | 15m Truncation | | | 25m Truncation | | | 20m Truncation | | | 15m Truncation | | | 0m | | |
| | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF |
| Uniform Cosine | | 69.3 | | 0.1786 | 74.71 | 1.8093 | 0.59776 | 83.95 | 0.2784 | 0.29595 | 75.883 | 1.0923 | 0.38746 | 95.63 | 1.8963 | 0.41346 | 107.4 | 1.7664 | 0.18208 | 207.47 | 1.7806 |
| Half-Norm Cosine | 0.34308 | 68.2 | 0.8989 | 0.53476 | 72.98 | 0.3853 | 0.58848 | 84.44 | 0.2927 | 0.53839 | 73 | 0.3785 | 0.8879 | 94.71 | 0.0199 | 0.50441 | 108.46 | 1.3687 | 0.39013 | 208.87 | 1.8826 |
| Half-Norm with HP | 0.34308 | 68.2 | 0.8989 | 0.53476 | 72.98 | 0.3853 | 0.58848 | 84.44 | 0.2927 | 0.53839 | 73 | 0.3785 | 0.8879 | 94.71 | 0.0199 | 0.50441 | 108.46 | 1.3687 | 0.39013 | 208.87 | 1.8826 |
| Hazard Rate | 0.05838 | 67.82 | 3.5829 | 0.30238 | 73.43 | 1.0637 | 0.3011 | 84.97 | 1.0693 | 0.49807 | 73.72 | 1.394 | 0.19056 | 96.54 | 1.7133 | 0.02273 | 111.16 | 5.189 | 0.14186 | 210.79 | 3.9058 |

**Bushbuck**

| | 4 Intervals | | | | | | | | | 5 Intervals | | | | | | | | | 0 Intervals: Default | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25m Truncation | | | 20m Truncation | | | 15m Truncation | | | 25m Truncation | | | 20m Truncation | | | 15m Truncation | | | 0m | | |
| | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF | P-Value | AIC | GoF |
| Uniform Cosine | 0.36605 | 43.44 | 1.237 | 0.56926 | 48.24 | 0.3239 | 0.85251 | 45.69 | 0.0346 | 0.35692 | 49.25 | 0.8487 | 0.90925 | 54.69 | 0.1903 | 0.44004 | 52.7 | 1.6418 | 0.95647 | 109.46 | 0.3187 |
| Half-Norm Cosine | 0.32673 | 42.94 | 0.9618 | 0.69336 | 48.26 | 0.1555 | 0.82903 | 45.75 | 0.0466 | 0.83726 | 48.29 | 0.0422 | 0.92431 | 54.64 | 0.1574 | 0.62442 | 52.46 | 0.9419 | 0.96161 | 110.02 | 0.2916 |
| Half-Norm with HP | 0.32673 | 42.94 | 0.9618 | 0.69336 | 48.26 | 0.1555 | 0.82903 | 45.75 | 0.0466 | 0.83726 | 48.29 | 0.0422 | 0.92431 | 54.64 | 0.1574 | 0.62442 | 52.46 | 0.9419 | 0.96161 | 110.02 | 0.2916 |
| Hazard Rate | 0.32264 | 44.1 | 0.9782 | 0.55427 | 49.66 | 0.3487 | 0.84844 | 47.66 | 0.0365 | 0.48628 | 51.14 | 1.4419 | 0.72609 | 56.43 | 0.1227 | 0.28674 | 52.56 | 1.1349 | 0.44814 | 101.33 | 1.6053 |

**Figure 27** *(above):* This image displays the completed table after each test had been run for the ‘vervet monkey’, ‘duiker’ and ‘bushbuck’. The tables displays the species, intervals tested, truncations tested, model definitions tested and the P-value, AIC and GoF results.

## Appendix II: *Gmelina arborea* 10x10 quadrats results for low, medium, and high densities.

The *Gmelina arborea* was observed using 10x10 quadrats to identify the low, medium, and high-density zones to identify the invasive tree areas. **Table 19, 20** and **21** illustrate examples of data recorded for the low, medium, and high-density areas tested.

**Table 19** *(below):* This table shows the data collected from the 10 by 10 quadrat research. This particular quadrat was conducted in a low *Gmelina arborea* density area. It is important to note that trees were found within the low density areas, however their DBH were lower than 10, thus were not recorded. If the trees were counted it would still be a low density area, as there were fewer than 10 observed.

| Transect | Census | Points | GPS | Altitude | Scan | DBH (cm) | Density |
|---|---|---|---|---|---|---|---|
| 6 | 50m | | -13'58.338'S | 1027m | 0 | | Low |
| | | 1 | 033'47.566'E | | | | |
| | | | -13.58.334'S | 1028m | | | |
| | | 2 | 033'47.567'E | | | | |
| | | | -13'58.335'S | 1029m | | | |
| | | 3 | 033'47.575'E | | | | |
| | | | -13'58.340'S | 1030m | | | |
| | | 4 | 033'47.573'E | | | | |

**Table 20** *(below):* This table shows the data collected from the 10 by 10 quadrat research. This particular quadrat was conducted in a medium *Gmelina arborea* density area.

| Transect | Census | Points | GPS | Altitude | Scan | DBH (cm) | Density |
|---|---|---|---|---|---|---|---|
| 7 | 150m | | -13'58.379'S | 1035m | 12 | 104 | |
| | | 1 | 033'47.587'E | | | 200 | Medium |
| | | | -13'58.376'S | 1033m | | 95 | |
| | | 2 | 033'47.583'E | | | 42 | |
| | | | -13'58.380'S | 1032m | | 11 | |
| | | 3 | 033'47.586'E | | | 132 | |
| | | | -13.58.384'S | 1031m | | 160 | |
| | | 4 | 033.47.584'E | | | 160 | |
| | | | | | | 110 | |
| | | | | | | 167 | |
| | | | | | | 105 | |
| | | | | | | 267 | |

**Table 21** *(below):* This table shows the data collected from the 10 by 10 quadrat research. This particular quadrat was conducted in a high *Gmelina arborea* density area. There was a scan of 165 individual trees, however any tree with the DBH lower than 10cm was removed from the data, to create a reliable comparison with the native tree data.

| Transect | Census | Points | GPS | Altitude | Scan | DBH (cm) | | | | Density |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 400m | | -13'58.364 | 1032m | 145 | 42 | 17 | 28 | 25 | High |
| | | 1 | 033'47.529'E | | | 93 | 10 | 13 | 170 | |
| | | | -13'58.362 | 1034m | | 15 | 11 | 10 | 42 | |
| | | 2 | 033'47.526'E | | | 26 | 26 | 54 | 12 | |
| | | | -13'58.366 | 1036m | | 25 | 14 | 11 | 20 | |
| | | 3 | 033'47.520'E | | | 24 | 190 | 10 | 20 | |
| | | | -13'58.367 | 1037m | | 42 | 15 | 20 | 21 | |
| | | 4 | 033'47.523'E | | | 12 | 63 | 15 | 10 | |
| | | | | | | 29 | 15 | 30 | 49 | |
| | | | | | | 20 | 50 | 16 | 12 | |
| | | | | | | 30 | 12 | 63 | 35 | |
| | | | | | | 16 | 13 | 16 | 64 | |
| | | | | | | 10 | 10 | 28 | 49 | |
| | | | | | | 13 | 16 | 26 | 24 | |
| | | | | | | 18 | 150 | 11 | 23 | |
| | | | | | | 15 | 14 | 259 | 13 | |
| | | | | | | 90 | 13 | 26 | 25 | |
| | | | | | | 10 | 107 | 15 | 15 | |
| | | | | | | 18 | 33 | 12 | 12 | |
| | | | | | | 79 | 13 | 12 | 27 | |
| | | | | | | 40 | 12 | 36 | 78 | |
| | | | | | | 19 | 10 | 24 | 11 | |
| | | | | | | 25 | 12 | 14 | 20 | |
| | | | | | | 32 | 16 | 44 | 12 | |
| | | | | | | 63 | 32 | 62 | 33 | |
| | | | | | | 21 | 12 | 10 | 27 | |
| | | | | | | 12 | 13 | 13 | 19 | |
| | | | | | | 130 | 27 | 97 | 12 | |
| | | | | | | 12 | 20 | 44 | 17 | |
| | | | | | | 30 | 22 | 15 | 24 | |
| | | | | | | 15 | 127 | 25 | 20 | |
| | | | | | | 23 | 10 | 20 | 20 | |
| | | | | | | 45 | 46 | 38 | 35 | |
| | | | | | | 13 | 12 | 97 | 28 | |
| | | | | | | 50 | 12 | 12 | | |
| | | | | | | 19 | 10 | 29 | | |
| | | | | | | 60 | 17 | 11 | | |

# References

Agyei, Y. (1998). Deforestation in Sub-Saharan Africa. *African Technology Forum, Volume 8*.

Ali, I. (2015). *Investigation of Carnivore-human conflict in North-Eastern Kargil, India.* Dehradun: Forest Research Institure University .

Anthony, B. P., & Wasambo, J. (2009). *Human-wildlife conflict study report: Vwaza Marsh Wildlife Reserve, Malawi.* Budapest, Hungary: Malawi Department of National Parks and Wildlife.

Archabald, K., & Naughton-Treves, I. (2001). Tourism revenue-sharing around national parks in western Uganda: Early efforts to identify and reward local communities. *Environmental Conservation, 28*, 135-149.

AWF. (2020, April 16). *Bushbuck*. Retrieved from African Wildlife Foundation: https://www.awf.org/wildlife-conservation/bushbuck

Bohm, T., & Honer, O. R. (2015, March 30). *Spotted Hyaena*. Retrieved from IUCN Red List of Threatened Species 2015: https://dx.doi.org/10.2305/IUCN.UK.2015-2.RLTS.T5674A45194782.en

Botermans, M., Sosef, M. S., Chatrou, L. W., & Couvreur, T. L. (2011). Revision of the African Genus Hexalobus (Annonaceae). *Systematic Botany*, 33-48.

Bratman, G., Hamilton, P., & Daily, G. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences, The Year in Ecology and Conservation Biology*, 118-136.

Butynski, T.M. & de Jong, Y.A. (2019). *Chlorocebus pygerythrus*. *The IUCN Red List of Threatened Species* 2019: e.T136271A17957823. https://dx.doi.org/10.2305/IUCN.UK.2019-. 3.RLTS.T136271A17957823.en. Downloaded on 15 April 2020

Chiyo, P. I., & Cochrance, E. P. (2005). Population structure and behaviour of crop-raiding elephants in Kibale National Park, Uganda. *African Journal Ecology, 43*, 233-241.

ClimatesToTravel. (2020, April 14). *Climate - Malawi*. Retrieved from Climates To Travel; World Climate Guide: https://www.climatestotravel.com/climate/malawi

D'Amico, M., Roman, J., Periquet, S., & Revilla, E. (2015). Road avoidance responses determine the impact of heterogeneous road networks at a regional scale. *Journal of Applied Ecology 53*, 181-190.

Department, E. A. (2010). *Malawi State of Environment and Outlook Report; Environment for Sustaiable Economic Growth.* Lilongwe: Malawi Government; Ministry of Natural Resources, Energy and Environment.

Department, E. A. (2014). *Fifth National Report to the Convention on Biological Diversity.* Lilongwe: Government of Malawi.

Derouin, S. (2019). Deforestation: Facts, Causes & Effects. *Live Science*.

Dickman, A. J. (2010). Complexities of conflict: the importance of considering social factors for effectively resolving human-wildlife conflict. *Animal Conservation. Volume 13. Issue 5*.

Evolution. (2010). No Laughing Matter: Unlovable Hyenas Are Threatened in the Wild. *Scientific American*.

FAO. (2015). *Global Forest Resource Assessment 2015.* Rome: Food and Agriculture Oraganization of the United Nations.

FOS (Foundations of Success). (2009). *Conceptualizing and Planning Conservation Projects and Programs: A Training Manual*. Foundations of Success.

Fraser-Celin, V.-L., Hovorka, A. J., & Silver, J. J. (2018). Human conflict over wildlife: exploring social constructions of African wild dogs (Lycaon pictus) in Botswana. *Human Dimensions of Wildlife, 23:4*, 341-358.

Goswami, V., Karnad, D., Vasudev, D., & Krishna, C. (2013). Conflict of human-wildlife coexistence. *Proceedings of the National Academy of Sciences* , 110.

Hemson, G., Maclennan, S., Mills, G., Johnson, P., & Macdonald, D. (2009). Community, lions, livestock and money: A spatial and social analysis of attitudes to wildlife and the conservation value of tourism in a human-carnivore conflict in Botswana. *Biological Conservation*, *142*, 2718-2725.

Hill, C. M. (2014). Farmers' Perspectives of Conflict at the Wildlife- Agriculture Boundary: Some Lessons Learned From African Subsistence Farmers. *Human Dimensions of Wildlife*, 279- 286.

Honer, O. P., Wachter, B., East, M. L., & Hofer, H. (2002). The response of spotted hyaenas to long-term changes in prey populations: functional response and interspecific kleptoparasitism. *Journal of Animal Ecology*. *Volume 71, Issue 2*.

Isbell, L. A., & Jaffe, K. E. (2013). Chlorocebus pygerythrus Vervet Monkey. In J. Kalina, J. S. Kingdon, & T. M. Butynski, *The Mammals of Africa: Vol ll Primates* (pp. 277-283). London, UK: Bloomsbury Publishing.

IUCN, (2013). *Invasive plants affecting protected areas of West Africa. Management for reduction of risk for biodiversity.* Ouagadougou: IUCN/PACO.

IUCN, 2016a. IUCN SSC Antelope Specialist Group 2016. Sylvicapra grimmia. The IUCN Red List of

Threatened Species 2016: e.T21203A50194717. https://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T21203A50194717.en. Downloaded on 16 April 2020.

IUCN, 2016b. IUCN SSC Antelope Specialist Group 2016. Tragelaphus scriptus (errata version published in 2017). The IUCN Red List of Threatened Species 2016: e.T22051A115165242. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22051A50196111.en. Downloaded on 16 April 2020.

IUCN, (2020a). *Deforestation and forest degradation*. Retrieved from IUCN: https://www.iucn.org/resources/issues-briefs/deforestation-and-forest-degradation

IUCN, (2020b). *Human-Wildlife Conflict Task Force*. Retrieved from IUCN SSC: http://www.hwctf.org/about

Kideghesho, J. R. (2015). 2. Realities on Deforestation in Tanzania - Trends, Drivers, Implications and the Way Forward. In M. Zlatic, *Precious Forests - Precious Earth* (p. Chapter 2.). IntechOpen.

Krebs, C. J. (1989). *Ecological Methodology*. New York: Harper & Row, Publishers, New York.

Lyon, L. (2019). Hyenas Probaby Have More Friends Than You: Spotted hyena social hierarchies. *SITN: Science in the News*.

McGuinness, S., & Taylor, D. (2014). Farmers' Perceptions and Actions to Decrease Crop Raiding by Forest-Dwelling Primates Around a Rwandan Forest Fragment. *Human Dimensions of Wildlife, 19,* 179-190.

Megaze, A., Balakrishnan, M., & Belay, G. (2017). Human-wildlife conflict and attitude of local people towards conservation of wildlife in Chebera Churchura National Park, Ethiopia. *African Zoology, Volume 52, 2017 - Issue 1,* 1-8.

Mgoola, W., & Msiska, H. (2017). The Status and Distribution of the Clawless Otter (Aonyc capensis) in Vwaza Marsh Wildlife Reserve and Nyika National Park, Northern Malawi. *IUCN Otter Spec. Group Bull. 34 (1)*, 3-17.

Mikula, P., Saffa, G., Nelson, E., & Tryjanowski, P. (2018). Risk perception of vervet monkeys Chlorocebus pygerythrus to human in urban and rural environments. *Behavioural Processes, Volume 147,* 21-27.

Myers, N., Mittermeier, R., & Fonseca, G. (2000). Biodiversity hotspots for conservation priorities. *Nature,* 853-858.

Nelson, B. (2013). Roadkill on new African road commonly includes lions, cheetahs and zebra. *Earth Matters*.

Noss, R. (1993). Wildlife corridors. *Ecology of Greenways*, 43-68.

Nunez, C. (2019). Deforestation explained. *National Geographic*.

Office, N. S. (2009). *Welfare and Monitoring Survey.* Zomba: National Statistical Office.

Office, N. S. (2018). *Malawi Population and Housing Census 2018.* Zomba, Malawi: National Statistical Office; Global Heath Data Exchange.

Overton, C., & Overton, M. (2007). Scientific Exploration of the Nyika National Park . *Biosearch Nyika*.

Periquet, S., Roxburgh, L., le Roux, A., & Collinson, W. (2018). Testing the Value of Citizen Science for Roadkill Studies: A Case Study from South Africa. *Frontier Ecology Evolution 6*, 15.

Plumptre, A. J., & Wronksi, T. (2013). Tragelaphus scriptus Bushbuck. In J. Kingdon, & M. Hoffmann, *The Mammals of Africa: Vol. 6. Pigs, Hippopotamus, Chevrotain, Giraffes, Deer and Bovids.* (pp. 163-172). London: Bloomsbury Publishing.

PROTA. (2016, January 21). *Wageningen, Netherlands: Plants Resources of Tropical Africa*. Retrieved from PROTA4U Web Database: http://www.prota4u.info

Ramkissoon, Y. (2005). *An Assessment of the Problem of Vervet Monkeys in the Former Westville Borough: Management Implications.* KwaZulu-Natal: University of KwaZulu-Natal.

Razack, Awede & Adjagba. (2015). Acute and Subchronic Toxicity of *Gmelina arborea* Roxb, (Verbenaceae) in Wistar Rat. *International Journal of Toxicological and Pharmacological Research 7(2)*, 116-122.

RIPPLEAfrica. (2020, January 20). *General Information About the Environment in Malawi and Deforestation in Africa*. Retrieved from RIPPLE Africa: https://www.rippleafrica.org/environment-projects-in-malawi-africa/deforestation-in-africa

Sibyabona. (2020, April 16). *Common Duiker*. Retrieved from Siyabona Africa Private Tours and Safari: http://www.krugerpark.co.za/africa_common_duiker.html

Thompson, S. (2003). Environmental Impacts of Construction on Habitats- Future Priorities. *Environmental Studies*, 277-286.

Trombulak, S., & Frissell, C. (2000). Review of ecological effects on roads on terrestrial and aquatic communities. *Conservation Biology 14*, 18-30.

UNESCO. (2020, January 21). *Lake Malawi National Park*. Retrieved from UNESCO World Heritage Centre: https://whc.unesco.org/en/list/289/

UN-Habitat. (2011). *Malawi: Lilongwe Urban Profile.* Nairobi, Kenya: United Nations Human Settlements Programme.

USDA. (2016). *Agricultural Research Service 2016 Annual Report on Science.* Washington, D.C.: United States Department of Agriculture.

Vaughan, J. (2019). Addressing Malawi's deforestation crisis. *Africa Geographic*.

Versteegh, C. P., & Sosef, M. S. (2007). Revision of the African genus Annickia (Annonaceae). *Systematics of Geography of Plants*, 91-118.

Witt, A., & Luke, Q. (2017). Guide to the naturalized and invasive plants of Eastern Africa. In A. Witt, & Q. Luke, *Guide to the naturalized and invasive plants of Eastern Africa* (p. 601). Wallingford: CABI.

Woodroffe, R., Thirgood, S., & Rabinowitz, A. (2005). *People and Wildlife; Conflict or Coexistence.* Cambridge: Cambridge University Press.

Woodroffe, R., Thirgood, S., & Rabinowitz, A. (2005). The future of coexistence: Resolving human-wildlife conflict in a changing world. *People and Wildlife: Conflict or coexistence*.

WWF. (2005). Human Wildlife Conflict Manual. *Wildlife Management Series*, 6.

WWF. (2019, November 29). *Africa Deforestation*. Retrieved from World Wide Fund For Nature (WWF): https://wwf.panda.org/our_work/forests/deforestation_fronts2/deforestation_in_the_congo_basin/

Youmatter. (2020). What Is Deforestation? Definition, Causes, Consequences, Solutions. *youmatter*.

YPTEa. (2020, April 16). *Monkey (Vervet)*. Retrieved from YPTE: Young People's Trust For the Environment: http://ypte.org.uk/factsheets/monkey-vervet/overview?gclid=Cj0KCQjw4dr0BRCxARIsAKUNjWTGA93-P4NtfH5BZmJSo1-Ou-ciNldpK9ru1pl18NZWe8FiQn4OOEcaAjfuEALw_wcB&hide_donation_prompt=1

YPTEb. (2020, April 16). *Hyaenas*. Retrieved from YPTE: Young People's Trust For the Environment: http://ypte.org.uk/factsheets/hyaenas/hyaena-habits#section

**Image References:**

Ando di, 2010, African civet, Digital image by Diposkan oleh Ando di, True Wild Life All About Wild Life, accessed 4 March 2020, <http://true-wildlife.blogspot.com/2010/12/african-civet.html>

Baumann, 2019, Ripening Fruit (Hexalobus monopetalus), Digital image by Günter Baumann; African plants - A Photo Guide, Useful Tropical Plants, accessed 4 March 2020, <http://tropical.theferns.info/image.php?id=Hexalobus+monopetalus>

Bingham, 1976, Schrebera trichoclada, drawing by Patricia Bingham, Flora of Zambia: Species information, accessed 4 March 2020, < https://www.zambiaflora.com/speciesdata/image-display.php?species_id=144120&image_id=13>

Birnbaum, 2019, Tree growing in native habitat (Hexalobus monopetalus), Digital image by Philippe Birnbaum: African plants – A Photo Guide, Useful Tropical Plants, accessed 4 March 2020, <http://tropical.theferns.info/viewtropical.php?id=Hexalobus+monopetalus>

Burkill, 1985, Ziziphus abyssinica, drawing by H.M. Burkill, JSTOR Global Plants, accessed 4 March 2020, < https://plants.jstor.org/compilation/Ziziphus.abyssinica>

Burrett, 2020,  Schrebera trichoclada,, Digital image by R Burret, National Botanic Garden, Harare Zimbabwe, Flora of Cparivi: Species information, accessed 4 March 2020, < https://www.capriviflora.com/speciesdata/image-display.php?species_id=144120&image_id=3>

Chester Zoo, 2020, Cape Porcupine *Hystrix africaeaustralis*, Digital image by Chester Zoo, Chester Zoo Upton-by-Chester, Chester, accessed 3 March 2020, <https://www.chesterzoo.org/our-zoo/animals/porcupine/>

Churi, P. 2020, Larval host plants — Gmelina-arborea, Digital image taken by Churi P, In Kunte, K., S. Sondhi, and P. Roy (Chief Editors), Butterflies of India, v. 2.76. Indian Foundation for Butterflies, accessed 4 March 2020, <http://www.ifoundbutterflies.org/larval-host-plants/1044/Gmelina-arborea>

Dlamini, 2018, Serval cat, Digital image by Sboniso Dlamini, local news network iab. South Africa, accessed 4 March 2020, <https://northcoastcourier.co.za/118549/serval-killed-cheetah-scare-etete/>

Doyle 2008, Galago moholi, Digital image by Gerald Doyle, Primate Info Net National Primate Research Centre, University of Wisconsin- Madison, accessed 4 March 2020, <http://pin.primate.wisc.edu/factsheets/entry/lesser_bushbaby/taxon>

GoogleEarth, 2020, Lilongwe Wildlife Centre (Lingadzi Namilomba Forest Reserve), Digital image taken from Google Earth Maps, accessed 7 January 2020, <https://www.google.com/maps/place/Lilongwe+Wildlife+Centre/@-13.9732454,33.7847419,3757m/data=!3m1!1e3!4m5!3m4!1s0x1921d3253bd83b11:0xfd4ff894ad6e2bd1!8m2!3d-13.9720199!4d33.7835383>

GoogleEarth, 2020b, Malawi, Africa, Digital image taken from Google Earth Maps, accessed 14 April 2020, < https://www.google.com/maps/place/Malawi/@-13.4868562,33.9021707,1297228m/data=!3m1!1e3!4m5!3m4!1s0x18d85bdd9313c0d7:0x44a32e1729668543!8m2!3d-13.254308!4d34.301525>

Morad, 2019, Gmelina arborea Roxb, Digital image taken by Ahmad Fuad Morad, Kampus UNHAS, Makassar, Suluawesi Selatan, Indonesia, accessed 4 March 2020, <https://www.flickriver.com/photos/adaduitokla/48176988496/>

Naizgi Ethiopia Tours, 2019, Cape bushbuck, Digital image by Naizgi Ethiopia Tours, Naizgi Ethiopia Tours, accessed 4 March 2020, <http://www.naizgiethiopiatours.com/?fbclid=IwAR2n2ViXuZh0SMBW0SldexLqytQMnnLCXcWfqRXZ09JSnN6x8WANTsmAfy8>

Nartan, D. (2016). Lilongwe Wildlife Center. *Journey to Nowhere*. Retrieved from Journey to Nowhere.

Poeticpenguin, 2019, Spotted Hyena standing, National Geographic Kids, Digital image by Poeticpenguin Shutterstock, accessed 3 March 2020, <https://www.natgeokids.com/nz/discover/animals/general-animals/spotted-hyena-facts/>

Prota,, 2020, Monotes africanus A.DC, PROTA4U Record Display, accessed 4 March 2020, <https://prota4u.org/database/protav8.asp?g=psk&p=Monotes+africanus+A.DC.>

Sharp, 2018, Cape bushbuck (Tragelaphus sylvaticus) female, Imbabala Zambezi Safari Cmap, Zimbabwe, Digital image by Charles J Sharp, Sharp Photography, sharpphotography.co.uk, accessed 3 March 2020, <https://commons.wikimedia.org/wiki/File:Cape_bushbuck_(Tragelaphus_sylvaticus)_female.jpg>

Sloviak, 2020, African Bush Pig, Digital image by Michal Sloviak, Our Breathing Planet, accessed 3 March 2020, <https://www.ourbreathingplanet.com/african-bush-pig/>

Starr and Starr, 2019, Gmelina arborea trunk of tree growing at Kahanu Gardens, NTBG, Kaeleku Hana, Hawaii, Digital image by Forest Starr and Kim Starr, Creative Commons Attribution 3.0 License Flickr, accessed 4 March 2020, <https://www.flickr.com/people/starr-environmental/>

QGIS, 2020, Bing Aerial Satellite image by QGIS, Lingadzi Namilomba Forest Reserve, QGIS 3.1, accessed 20 June 2020.