COMPARISON AND OPTIMISATION OF NOCTURNAL SURVEYING TECHNIQUES IN SOUTH AFRICA

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ABSTRACT

Animals are surveyed many different ways and have been for many years. Nocturnal animals in South Africa, such as aardvark (*Orycteropus afer*), porcupine (*Hystrix africaeaustralis*) and serval (*Leptailurus serval*) are notoriously elusive and difficult to detect. Many different methods have previously been used to study them, but direct empirical comparisons between methods are rare. Discovering if there is one overall technique that is better than any other or if there is an ideal combination of methods will assist future researchers in their studies, making it easier for them to discover particular species as well as finding them more often. In this study, it is aimed to find whether or not there is a single method that is better at detecting nocturnal species than any other method, or whether or not it is a combination of multiple methods used in tandem, as previously thought. Two different types of camera trapping and driven nocturnal transects using spotlights are compared with one another over an 18 month period to discover which is best for detecting a range of nocturnal species found at a site in South Africa. It was found that more common species, such as jackal were found often on driven nocturnal transects, with the rarer species found more often on camera traps, however not all species that are present on the site were found using either method, indicating a high degree of chance in discovering rarer species. These results suggest that while there may not be any one method that gives the best chance to discover all nocturnal species, researchers can pick certain methods for certain species in order to give the best chance of discovery.

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas.

Any views expressed in the thesis are those of the author and in no way represent those of the University.

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Lastly I would like to dedicate this thesis to Reine and Maggie, a rhino cow and calf that were poached in January of 2021.

We will forever miss you.

CONTENTS

1 – Introduction

Animals are surveyed in many different ways and for a variety of reasons. Such surveys can include population estimates, censuses, presence/absence studies and full species inventories (Burton *et al*., 2015) and are primary tools of for ecology, conservation and management. Surveys frequently involve time-consuming and resource intensive methods such as aerial surveying from planes or helicopters, radio telemetry and live trapping programs for capture-mark-recapture surveys (Meek *et al*., 2014, Khaemba *et al*., 2001), or repeated ground-based surveys such as walked or driven mammal transects (Munari, *et al*., 2011). Such surveying methods are often also relatively expensive, and present ethical challenges if they require the physical handling of individuals, with potential stress, injury and potentially lethal outcomes. Despite these challenges, researchers and wildlife managers often still rely on these techniques as they can be an effective and evidence-informed approach to monitor distribution and abundance of species, especially across large spatial areas (e.g. Lethbridge *et al*., 2019; Jewell, *et al*., 2020). Such techniques can also aid in understanding inter- and intra-species interactions, for example, determining whether an introduced prey species could actually have a negative effect on the population of a predator species (e.g. in cane toads (*Rhinella marina*) and Australian freshwater crocodiles (*Crocodylus johnstoni*), Fukuda *et al*., 2015). Additionally, the results of surveying can be used to inform management interventions including animal carrying capacities, culling or off-take quotas, and specific species conservation actions.

Conservation areas, such as national parks and private reserves, where monitoring and management of specific species is especially intense play a key role in the preservation of biodiversity (e.g. Cowling, *et al*., 2001), and can have an important effect on the socioeconomic development for areas as well (e.g. Hanks, 2008), with these areas being located all around the world, from Indonesia (Eghenter, 2000) to Southern Africa (Hanks, 2008; Gallo, *et al*., 2008), Australia (Hayward, *et al*., 2014) and South America (de Melo, *et al*., 2014). Fenced reserves have become an important part of this especially in southern Africa, where in some places fencing is a legal requirement for wildlife ranchers to be able to own wildlife, such as Botswana, Zambia and South Africa (Lindsey, *et al*., 2011).

Management of fenced wildlife reserves are a key area in which methods like these are used. In South Africa (and other places), private fenced game reserves are a key component of wildlife and habitat conservation. Where animals are kept within fenced land it is usually necessary to manage predator and herbivore numbers. Such reserves can vary greatly in their sizes, from 1,600 ha to over 25,000 ha for some (Sims-Castley, *et al*., 2005). Proper habitat management is needed to keep the reserve capable of supporting an ecologically realistic range of species: graze (grassland)and browse (trees and shrubs) management, for example, through the use of burn management regimes (Morris and Scott-Shaw, 2019; Goodenough, *et al*., 2017[a]; Hart *et al*., 2020; Docherty, 2019).

Recently, the advent and development of new technologies has increasingly provided opportunities for alternatives to established surveying techniques. Technology-driven surveying tools can have the advantage of being less invasive, and less ethically problematic to achieve similar outcomes for populations counts, presence/absence studies and species inventories. For example, techniques that use unmanned aerial vehicles (UAVs) are being tested with multiple different objectives, including surveying and monitoring populations, as well as in anti-poaching contexts (Penny, *et* al., 2019). UAV surveying covers multiple taxa including large mammals (Kellenberger, *et al*., 2017; Eikelboom, *et al*., 2019), birds (Rush, *et al*., 2018; Oosthuizen, *et al*., 2020) and marine species (Raoult, *et al*., 2020; Hodgson, *et al*., 2017) and has been used successfully in many different locations and habitats globally. Whilst these methods have been shown to be effective when properly used, larger UAVs are still relatively expensive and lower priced UAVs generally have lower weight payload capability for cameras, and poorer battery life. Increased legislation internationally around UAVs also require users to undergo training and licensing in many territories in order to operate them legally and safely (Hodgson, *et al*., 2017).

Other new advances in technology offer lower-priced solutions but remain non-invasive. In particular, small-scale camera trapping has been used extensively (Burton et al., 2015; Meek, et al., 2014; Kelly, 2008; Kucera and Barrett 2011; Jansen, *et al*., 2020; Fidino, *et al*., 2020). Meanwhile, technology that was previously only available in portable formats to military personal, or in well-funded research programmes, has now become commonplace, including night vision scopes (Allison and Destefano, 2006), and thermal imaging (Focardi et al, 2001; Amos et al, 2014; Goodenough et al., 2017[b] Cilulko et al., 2013; Hart, *et al*., 2015).

These methods cover a range of different species including large and small mammals and birds, and can be used in a variety of habitats (Allison and Destefano, 2006; Amos et al, 2014; Cilulko et al., 2013).

Despite the advantages presented by advances in technology for wildlife surveying, many researchers and practitioners still use established and reliable methods, such as spotlight transects (Wilmott, *et al*., 2018; Stenkewitz, *et al*., 2010; Busschots, *et al*., 2020; Kaminski, *et al*., 2019) and track counts (Espartosa et al., 2011; O'Neil, *et al*., 2019; Braczkowski, *et al*., 2020). The trade-off is that although these methods are relatively simple (requiring only walking or driving on transects) and cheap in terms of equipment, they can be extremely time-intensive (which can add considerable cost) and rely on well-trained, experienced observers.

Wildlife data can be used in a range of different ways. These include the estimation of population sizes, for example using playback recordings and camera trapping (Anile *et al*., 2012; Mills et al., 2001), long term monitoring of populations where camera traps and spotlight surveys are used for detection in order to determine frequency or presence-absence (Fukuda et al., 2015; Willcox et al., 2019) and quantification of animal richness using audio playback (Bowler et al., 2016; Mills et al., 2001; Thorn et al., 2010). Table 1 provides more evidence on a wide range of uses for several non-invasive commonly used survey methods. This demonstrates that, many different species that can be studied, in a wide number of locations around the planet.

Table 1: Some examples of the different methods that are used in surveying studies, including the different reasons for studying, the locations, species studied and references.

Method Used	Reason(s) for Study	Location(s)	Species Studied	Reference(s)
Camera Traps	Population Density Estimations	Central Africa, Peru	Many Large African Mammals, Small and Large	Palmer, *et al.*, 2018; Bowler, *et al.*, 2016

			bodied arboreal mammals	
	Detection	South East Asia, China, Central Africa, South Africa	Pangolins, Brown Hyaena, Caracal, Jackal	Willcox, *et al.*, 2019; Thorn, *et al.*, 2010
	Population Monitoring	South East Asia, China, Central Africa,	Pangolins	Willcox, *et al.*, 2019
Playback of audio Recordings	Population Density Estimations	South Africa	Spotted Hyaena	Mills, *et al.,* 2001.
	Detection		Brown Hyaena, Caracal, Jackal	Thorn, *et al.*, 2010.
Spotlight Surveys	Population Density Estimations	South Africa	Springhare, Cape Hare, Steenbok	Stenkewitz, *et al.*, 2010
	Population Monitoring	Australia	Saltwater Crocodile, Freshwater Crocodile	Fukuda, *et al.*, 2015
	Detection	Australia, South Africa, Italy	Koala. Brown Hyaena, Caracal, Jackal. Brown Hare, Fallow Deer, Red Deer.	Wilmott, *et al.*, 2018; Thorn, *et al.*, 2010; Focardi, *et al.*, 2001

Thermal Imaging	Detection	Italy, South Africa	Brown Hare, Fallow Deer, Red Deer. Many African Antelope.	Focardi, *et al.*, 2001; Goodenough, *et al.*, 2018
UAVs	Detection	Australia	Humpback Whales	Hodgson, *et al.*, 2017

1.1 – Nocturnal Animals

Nocturnal animals are generally elusive species that are active at night, are often relatively small and tend to occur at low densities in the places that they are found (Thorn, *et al.*, 2009). This combination makes such species hard to detect and observe. In addition, quite often little is known about the ecology and behaviour nocturnal species because of their elusiveness (Kucera and Barrett, 2011), which makes detecting and observing them important to help gain a better understanding of their behaviour – and in turn better knowledge of behaviour can help generate more targeted (and thus more robust) surveying protocols.

Often nocturnal animals are absent from species inventories because the most common survey methods, such as point counts and line transects, are typically undertaken during daylight hours (e.g. Maffei, *et al.*, 2005; Bowler, *et al.*, 2016). While some nocturnal species do have some diurnal activity, daylight activity is usually limited and tends to be crepuscular, when the animal will either be starting to forage/hunt (dusk), or returning to its burrow or place of rest (dawn) (Bowler *et al.*, 2016).

Due to their nature of often being elusive, survey methods that are better adapted to surveying at night should be used as this is the time when they are more active and thus more likely to be found. Two methods which are used often for surveying nocturnal species area camera trapping and nocturnal transects (spotlighting) (Munari, *et al.*, 2011; Amos, *et al.*, 2014; Willcox, *et al.*, 2019; Meek, *et al.*, 2014; Thorn *et al.*, 2010). This paper will outline the history of each of these techniques, how and why each of them are used and the advantages and disadvantages of each, as well as some recommendations for studies in the future.

1.2 – Camera Trapping

Camera traps are remotely activated cameras that can be placed in the field that allow animals to take photos of themselves through a variety of means. Camera traps have long been an effective method for studying many types of species for various reasons. Camera traps have been used to study vertebrates for the last 80 years (Swann, *et al*., 2004) ranging from species inventories for specific study sites, through to absence/presence and behavioural studies. Behaviour studies often have a specific behavioural focus such as monitoring feeding where baited locations can be used to elicit behaviour (Palmer, *et al*., 2018; Foster and Harmsen, 2012), but can be used to simply monitor general behavioural traits.

1.2.1 – History of Camera Trapping

The camera traps have become a staple and consistent method for ecological studies, but they were not always as they are now and have developed substantially over time since their first inception. ’Camera trapping’’ was initially known as “flashlight trap photography” which was defined as a process where a photographer can leave out a camera system which allows an animal to take a picture of itself (Nesbit, 1926 in Kucera and Barrett, 2011). The first known use of a system was in the 1890s where George Shiras III deployed a camera with a trip wire attached to a flash system. An animal passing by the set-up would activate the flash and release the shutter of the camera, thereby taking a picture of itself (see Figure 1). The system was very effective, and, as a result, Shiras took many photos of different species, including: American mink (*Mustela vison*), North American porcupines (*Erithizon dorsatum*), striped skunks (*Mephitis mephitis*), moose (*Alces alces*) and grizzly bears (*Ursus arctos*) and he was able to take photographs during both the day and night (Shiras, 1906; 1908; 1913).

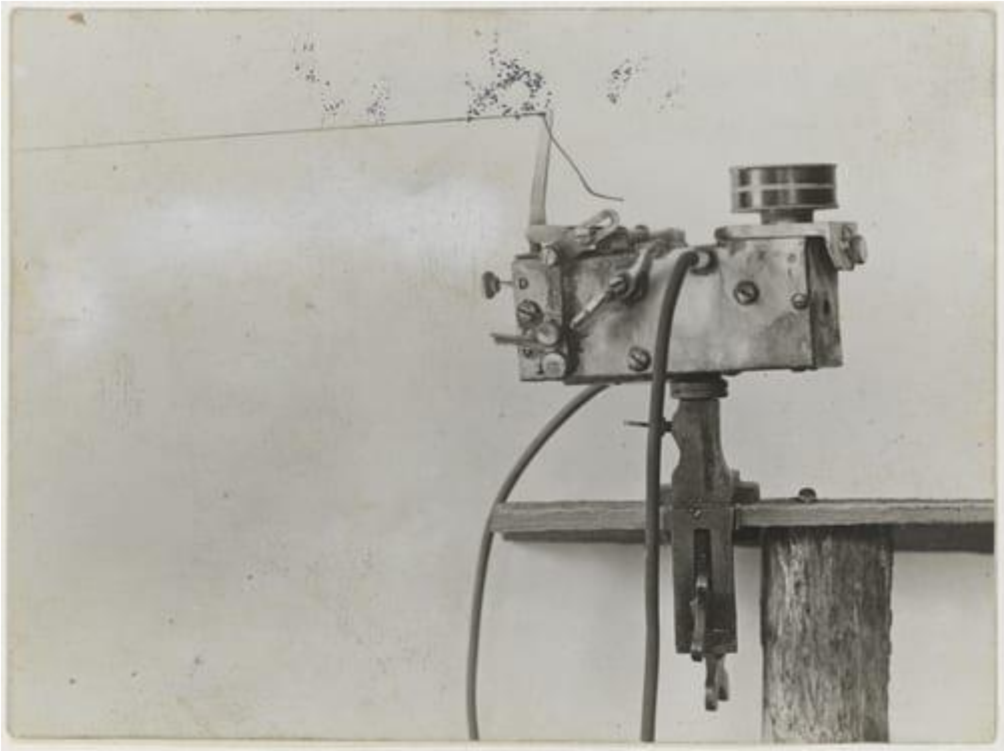


Figure 1: The flash system attached to a trip wire as used by George Shiras III in the 1890s. (NatureSpy, 2019)

Shiras' pioneering system was very successful at photographing multiple species in part because of the measures that he implemented to attract animals. For instance, frequently he would attach bait to the trip wire so that when an animal pulled on the bait when feeding, activating the camera (Kucera and Barrett, 2011). Shiras also developed innovative ways to capture images of American beavers (*Castor canadensis*), wherein he would find a dislodged branch in the beavers' dam wall, and attach the wire to this branch so that when repair activity was undertaken, the beaver took its own photo.

One of the first applications of using such a system to study a site in a research capacity rather than as a novelty, was in 1927, where Frank Chapman used a flashlight trap system to try and document the species found at a recently established research station on the island of Barro Colorado in Panama. The system used trip wires across known animal trails as well as bait to entice predators. Using this system, Chapman photographed mountain lions (*Puma concolor*), ocelots (*Leopardus pardalis*), Baird's tapirs (*Tapirus bairdii*), white-lipped peccaries (*Tayassu pecari*), as well as others (Chapman, 1927 in Kucera and Barrett, 2011). His work also led Chapman to note that some species had individuals that could be identified uniquely by these methods based on their markings.

As well as being one of the first documentations of species inventory using 'camera trapping' Chapman also made inferences on the behaviour of some of the species. In one example, he noted that some felids seemed to be aware of the trip wire when stretched across a path and would step over it, whereas peccaries appeared oblivious to its presence.

1.2.2 – Developments in Camera Trapping

Camera trapping has gone through many developments from the early days of its use by Shiras and Chapman. One of the first major developments was the ability to take multiple exposures without needing to reset the entire system between image capture. Dodge and Snyder (1960) developed one of the first portable systems, and by incorporating a 6-V car battery and motor-drive, they were able to take multiple exposures without the need to reset the apparatus.

Seydack (1984) in South Africa made further improvements to both the overall system and the way that camera trapping could be used to census animals over a longer period of time than was previously possible. He used a trip plate that was placed on a trail that connected to an auto-winding 35mm camera with a flash. Each time an animal weighing 2 kgs or more stepped on the plate, the system would activate. The camera also operated off of a 6-V battery, and had a flash capacity of 16 bulbs. Unlike Chapman's experiments with trip wires in 1927, the trip plate seemed relatively undetected by passing animals and was thus more effective at capturing images. The cameras could be left out for 1 month before being moved to the next survey block, thus reducing the regularity of human intervention in the survey design. Working over three years, Seydak used this apparatus and method to identify 14 species of mammals, as well as estimating population density for some species such as bushbuck (*Tragelaphus sylvaticus*) as individuals were identifiable based on coat pattern and horn morphology, and leopards (*Panthera pardus*) using their spot pattern.

One of the next major technological advances in camera trapping was developed by Carthew and Slater (1991), who implemented an infrared beam as a triggering device. When the beam was interrupted by an animal, the infrared sensor would send a signal to a modified automatic, 35mm camera with integrated flash (Figure 2). This camera had automatic exposure control as well as the ability to record date and time.

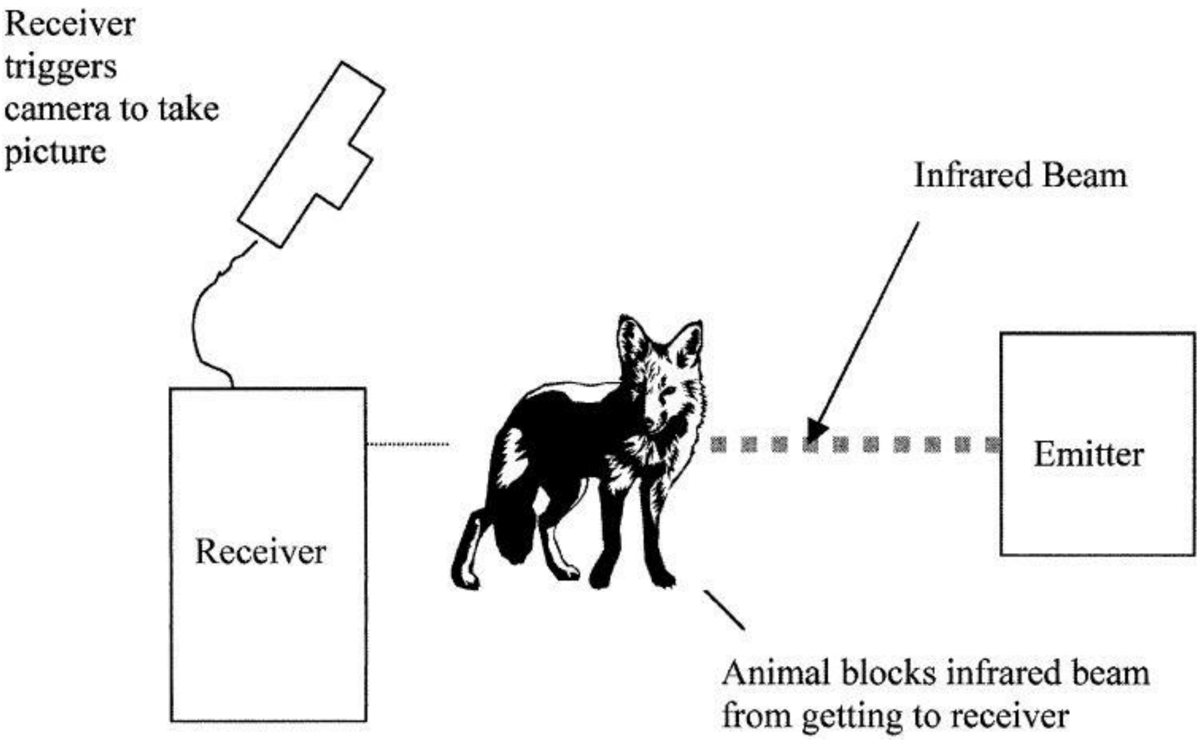


Figure 2: A beam breaker camera trap, similar to that described above. From Swann, et al.*, (2004).*

One further advancement has been the change from using film cameras to digital. Only in the last 15 years have camera traps made the move to digital (Fegraus, *et al*., 2011) which has allowed many things to happen. These devices are now able to produce hundreds to tens of thousands of images with 32GB SD cards. These images are high resolution as well as enabling the collection of a large amount of metadata to go with it, such as: date, time, temperature as well as others (Fegraus, *et al*., 2011). In addition, in the last 5 years, the price to capacity of SD cards has made huge improvements, for example, a 32GB SD card can cost as low as £5.99 (PC World, 2021). Additionally it has been found that digital camera models photograph smaller species at substantially higher rates than film cameras (due to their small size) while at the same time photographing medium and large mammals with the same efficiency (Kelly, 2008). This has also paved the way for cameras to be able to record videos allowing for better analysis of behaviours, that was previously not possible with only photos.

1.2.3 – Modern Camera Traps

Nowadays, there are many different types of camera traps, each with a whole host of different settings that can be tailored to specific types of study. Most camera traps work using a passive infrared (PIR) sensor, which measures the infrared light in the detection zone in front of the camera (usually up to 20m) once this beam detects something in this zone, it begins to record a video or take photos (Burton, *et al*., 2015). As described by Meek *et al*. (2014), PIR sensors detect 'heat in motion' by responding to changes infrared energy emitted by background temperature and by passing objects. If a cold object moves in front of a warm background, this is detected as well. In most modern camera traps the sensitivity can be adjusted to suit a particular location or subject being studied. For example, a high sensitivity is requited for when the weather is warm, as there will be a lower difference between the surroundings of an animal and the animal itself. A low sensitivity is useful for cold weather, as in these conditions the camera will detect anything that is warmer than the surrounding area (Bushnell, 2019). Another type of sensor is an active infrared sensor (IR) which detects objects by emitting a beam of infrared that bounces off of an object or individual and hits a receiver which activates the camera.

Modern camera traps have many options dependant on what type of studies are being done, especially for nocturnal studies. Some companies that make camera traps offer many different types of flash for their camera traps. Table 2 shows some examples of the types of flash LEDs offered, what images they produce at night and the types of studies these are used in.

Table 2: The types of LEDs offered in some modern camera traps, what types of images they produce at night and the types of studies they are used in.

Type of Flash LED	Image Produced at Night	Type of Study
Infrared	Black and White	Detection and behavioural studies that are not concerned about differentiating between individuals of species and

		the camera being detected by the animal
Black	Black and White	Detection and behavioural studies that are not concerned about differentiating between individuals of species but are concerned about the camera being detected
White	Colour	Detection and behavioural studies where individual identification is required.

Another major advance in the camera traps has been the downsizing of components, which allows modern camera traps the ability to record high quality images and videos (Bushnell, 2019), without the need for complex systems to be set up. Camera traps are now able to be powered by AA batteries for flexibility of movement, or if need be can be set up with a D/C connected battery if they will be placed in one location for a longer period of time. Figure 3 below shows an example of a modern camera trap, set up on the trunk of a tree using a simple bracket and tripod-screw mount system.

Figure 3: A modern camera trap attached to the trunk of a tree using a bracket. The camera is located in the centre of the system, with the LEDs located above and the PIR sensor located below. From Bowler, et al. *(2017)*

1.2.4 – Considerations When Using Camera traps

There are advantages and disadvantages to camera trapping. The main advantage is that the technique gives, temporally, very good coverage as a single camera trap can survey one location for a relatively long time without the need for user involvement. This, however, leads into its main disadvantage; camera trapping usually gives poor spatial coverage since cameras can only monitor a relatively small area of ground. To help negate the spatial issues, a researcher can place multiple camera traps in different locations within the same study site to increase spatial coverage, but this does have cost and time implications.

There are a number of aspects to be aware of when designing a camera trap study (Meek, 2014). One major factor is the zone of detection, which is the area in which the infrared beam is active; the larger the zone of detection, the larger the area a single camera trap can monitor. The zone of detection is made up of two components, one - the field of view and two – the distance that the cameras PIR sensor can reach. The researcher needs also to be aware of the size of the species(s) that they are studying to ensure the placement is optimal. For example, the height of the camera is crucial;, a camera placed too high will miss smaller, faster species passing close to the camera's base, while a camera set too low could miss some key identifying features of a species or particular individual (Meek, *et al*., 2014; Burton, *et al*., 2015).

The actual placement of the camera in the study area is also important with regard to the orientation and placement of the detection zone; the camera must be detecting a region that animals are known to traverse (see Figure 4).

Camera traps now come with many different specifications and settings. Some settings that are important in surveying include: sensor sensitivities (how well the sensor can differentiate between temperature differences), the ability to take nocturnal photos, the use of additional daylight lights to brighten images, the use of active or passive infrared systems, and different trigger response times (the time between the sensor detecting an object or animal and the camera taking a photo). As detailed in Table 2, different models are adapted for different scenarios, and it is therefore important to use the correct equipment to record the focal species.

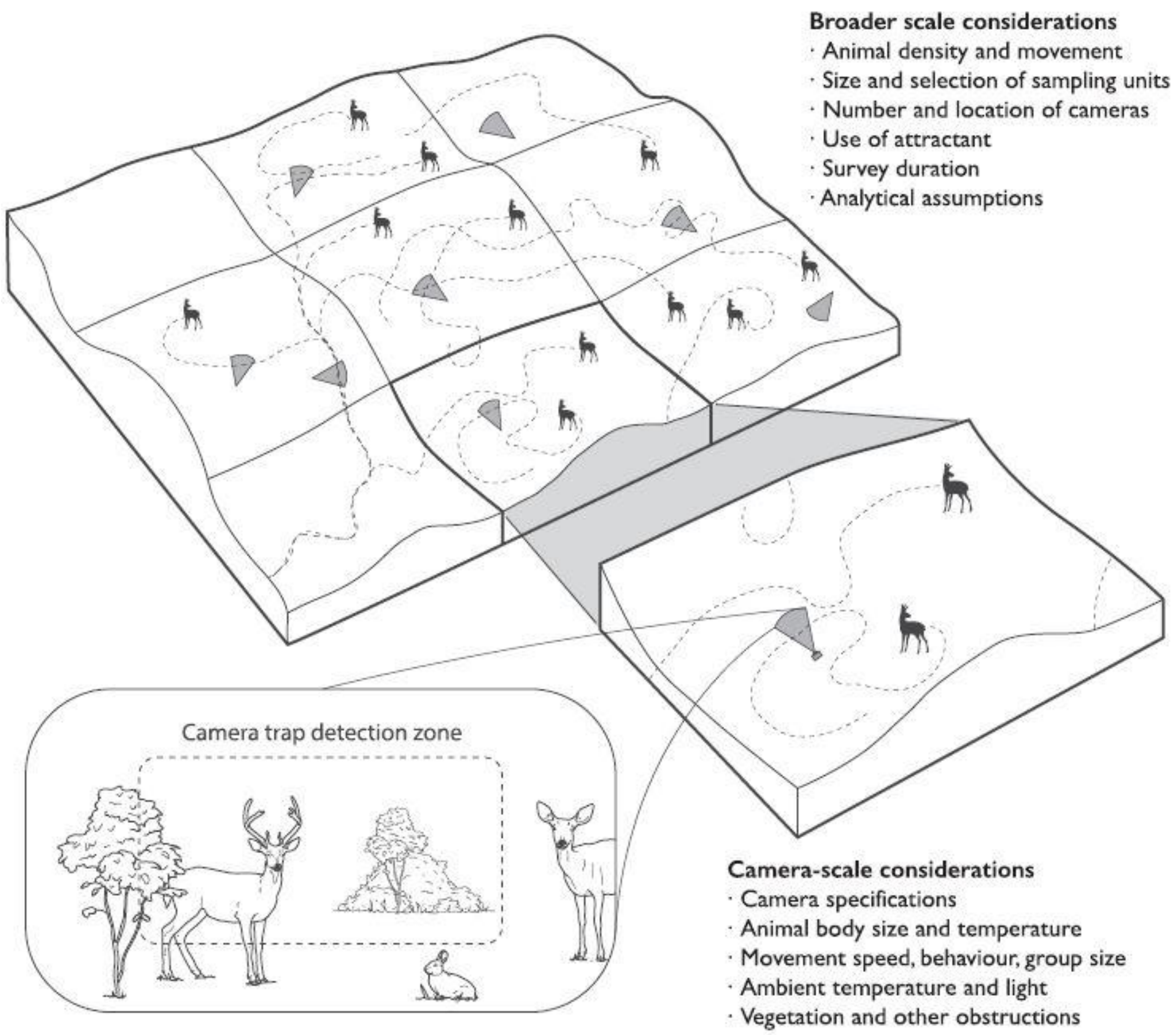


Figure 4: How the detection of animals via camera traps is affected by how the camera is placed, in the overall area being studied and how the height can have an effect the detection of some animals and how some considerations should be taken. (Image by Jeff Dixon in Burton et al., 2015).

1.3 – Spotlight Transects

Spotlight transects, also known as nocturnal surveys, are a common direct survey method used in many different ways to assess a variety of species. Essentially, nocturnal surveys are transects that are completed at night, using powerful spotlights to aid an observer in detecting the target species in the dark (Thorn, *et al*., 2010). They are widely used in ecology to establish: species presence, species abundance, population estimates, distribution and movement patterns, habitat use, and behaviour (Focardi *et al*., 2001; Munari *et al*., 2011; Fukuda *et al*., 2015) (Table 3).

Spotlight transects can be either line transects or strip transects, with the former being more effective at estimating overall population densities and the latter being quicker to complete, providing a much faster assessment of a study site (Scott, *et al*., 2005). Studies that use nocturnal surveys are typically done with relatively few spatial replicates and are repeated seasonally (Scott, *et al*., 2005; Mohsen, 2017).

Table 3: The different reasons for study using nocturnal surveying techniques and the locations and focal species of study.

Reason(s) for study	**Location(s)**	**Species Studied**	**References**
Population Density Estimations	South Africa, Jordan	Springhare, Cape Hare, Steenbok, Fox, Hare.	Stenkewitz, *et al.*, 2010; Scott, *et al.*, 2004
Population Monitoring	Australia	Saltwater Crocodile, Freshwater Crocodile.	Fukuda, *et al*., 2015
Reintroduction Monitoring	Australia	Bridled Nailtail Wallaby, Greater Bilby, Numbat.	Berry, *et al*., 2019
Detection of Species	Australia, South Africa, Italy	Koala. Brown Hyaena, Caracal, Jackal. Brown Hare, Fallow Deer, Red Deer, Squirrel Glider.	Wilmott, *et al.*, 2018; Thorn, *et al.*, 2010; Focardi, *et al*., 2001; Goldingay and Sharpe 2004.
Comparison Between Methods	North America	Sandhill Crane, Whooping Crane.	Allison and Destefano, 2006

Human Impact	Gabon	Nocturnal Primates, Small Ungulates and Carnivores.	Laurence, *et al*., 2007

1.3.1 – History of Spotlighting

Unlike camera trapping, the methods used in nocturnal spotlight surveys have remained more-or-less unchanged over time. For example, Fukuda, *et al*. (2015) collected data using the same standardised survey protocols from 1978 through to 2013. A literature search undertaken on the topic of 'spotlight surveys' showed records going back to Ealey and Dunnet (1956) in Australia where marsupials were found using spotlights at night, and tagged with collars with reflective tape for easier marking the next time. Marlow (1958) also surveyed nocturnal marsupials in New South Wales in Australia using spotlighting methods that would be identical to those used today.

Though advancements have been made in torches, most especially the use of very bright and low-power LEDS, stronger lights have not necessarily meant that detection rates have increased. For example, Goldingay and Sharpe (2004) showed there was no difference in the detection of gliders (Genus *Petaurus*) when using a 50W or 100W light. One reason for this could be the usefulness of eyeshine in detecting species (Laurance, *et al*., 2007). Eyeshine occurs when light passes through the retina and reflects back from the tapetum lucidum, a layer of tissue located behind the retina, and additional brightness does not necessarily make it any easier to spot eyeshine at night (more information on the tapetum lucidum can be found in section 2.3.1). If researchers detect eyeshine, then additional illumination could be used if required to identify the species. Although the practical aspects of spotlight surveys have not changed drastically over time, researchers have generally become more diligent about recording such as length of transect and time spent, as well speed of movement. These variables are essential when comparing species detection over space or time as it allows for the calculation of standardised and comparable metrics such as encounters per hour or per kilometre (e.g. Waltert, *et al*., 2006 in blue duiker, *Cephalophus monticola*).

1.3.2 – Modern Spotlighting

Spotlighting is a simple and versatile approach. It can be used in walked transects that take time to complete, but are thorough and all-terrain, driven transects that cover more ground but are more restricted to roads, and even on water-based transects by boating down rivers (Amos et al., 2014; Munari et al., 2011; Willcox et al., 2019; Fukuda et al., 2015). As well as using eyeshine to identify animals, more experienced observers can use the behaviour and locomotion of animals encountered (including using the sounds of animals moving around in the bush), to get a good idea of location, then use a spotlight to identify the species (Willcox, et al., 2019). Spotlighting is now often used in tandem with other methods (e.g. spotlighting in Munari et al, 2011), either to get a comparison between the two, or to combine the two to get an overall estimate of population sizes (Amos et al., 2014; Munari et al, 2011; Focardi et al., 2001).

1.3.3 – Considerations When Using Spotlighting

Spotlighting is a relatively cheap method of surveying nocturnal wildlife, however, despite these advantages, some aspects of its use need to be considered carefully. It has the opposite pattern to camera trapping when it comes to strengths and weaknesses; with spotlighting (especially when supporting transect approaches) giving very good spatial coverage, but poor temporal coverage. i.e. it covers a lot of ground but observers only spend a short amount of time at any locations (especially when compared to the amount of time camera traps can be in one location).

Eyeshine is key for finding many nocturnal species (e.g. ; Thorn, *et al*., 2010; Wilmott, *et al*., 2018), and can assist in location and identification of species (e.g. using inter-ocular distance and height). However, the effectiveness of this layer can vary greatly between species, which can cause problems of detection bias., For example, many pangolin species (Manidae) do not have a strong eyeshine making them difficult to spot simply using spotlighting (Willcox *et al*., 2019; Newton *et al*., 2008; Rode-Margono, *et al*., 2014). Therefore, it is important that observers must use direct sightings, as well as the assistance of listening for movement to detect such animals. Compared to this, species such as koalas (*Phascolarctos* *cinereus*) and brown hyaena (*Hyaena brunnea*) have a large, bright eyeshine that makes them easily detectable and identifiable in the field (Thorn, *et* al, 2010; Wilmott *et al*., 2018).

The behaviour of the targeted species(s) can also be important in the usefulness and accuracy of spotlighting as a surveying tool. In some cases, such as brown hyaena and pangolin, once light is initially shone on it, or it is disturbed during its foraging, the individual may turn their head away from the light, thus the observer loses track of the individual (L. MacTavish 2019, pers. comm.), or smaller species may hold very still and not make noise, potentially being missed by the observer (Rode-Margono, *et al*., 2014). Table 4 expands on some elements that need to be considered when using spotlight methods.

Table 4: Some considerations to be made when using spotlighting as a survey method with resolutions and references.

<table>
<tr><th colspan="2">Consideration</th><th>Resolution</th><th>References</th></tr>
<tr><td colspan="2">Misidentification of Species</td><td>• Work to be completed by an experienced observer with binoculars and spotlights</td><td>Thorn, et al., 2010</td></tr>
<tr><td rowspan="3">Environmental Conditions</td><td>Precipitation</td><td rowspan="3">• Repeats on multiple days
• Repeats in different conditions
• Repeats in different times of year</td><td rowspan="3">Thorn, et al., 2010;
Meek, et al., 2014.</td></tr>
<tr><td>Temperature</td></tr>
<tr><td>Time of Year</td></tr>
<tr><td rowspan="2">Levels of disturbance</td><td>Driven</td><td rowspan="2">• Cover all roads within study site equally.
• Record areas of high disturbance and poaching for consideration</td><td rowspan="2">Thorn, et al., 2010</td></tr>
<tr><td>Poaching</td></tr>
<tr><td colspan="2">Different Ranges of Spotlights</td><td>• Make sure that same equipment is used</td><td>Thorn, et al., 2010</td></tr>
</table>

1.4 – Gaps in Knowledge

This study identifies and covers some key gaps in knowledge of aspects of nocturnal detection methods. Unlike other studies that have compared camera traps with other spotlighting in the Amazon (Munari, *et al*., 2011), this paper will cover these two methods on species found in grassland habitat in South Africa, very different to the forest habitat found in the Amazon. It will also compare different methods within each of the two, camera trapping and nocturnal transects, and how these methods compare in the detection rates of different species with respect to survey effort. It is, also, not known how these different techniques and methods within each technique compare, in terms of efficacy (species found) and efficiency (species versus effort).

1.5 – Aims and Objectives

The main goal of this project is to discover if there is a difference in the nocturnal species community recorded at a site in South Africa when using four different survey methods in order to help streamline further studies by enabling researchers to use one or multiple of these techniques to discover species more easily and more often. This overall aim can be broken down into a number of sub aims that answer specific questions, which are:

1. What are the differences in species frequency detection curve with survey effort across the different methods?
2. How many nights does it take for all species in the nocturnal community to be detected using each method?
3. Can it be narrowed down to one method that is 'best' or is it rather a combination of multiple methods used in tandem?
4. Do the four methods start to give similar results and if so, how long does it take for this to happen?

2 - Methods

2.1 - Study Site

All field work was undertaken at Mankwe Wildlife Reserve, a privately-owned reserve in the North West Province of South Africa, 4 km from Pilanesberg National Park, and close to the South African border with Botswana (Figure 5, Figure 6 and Figure 7) (25°15'S, 27°17'E). The site is on land that was formerly the safety buffer zone around a munitions factory that no longer produces explosives. It covers an area of approximately 4,750 hectares and is surrounded by a game fence ca. 30 km long.

Mankwe has a climate classified as "mild sub-arid" with an average daily mean temperature of 23 °C Celsius in December and 11 °C in July. It has a mean annual rainfall of 575 mm, falling mostly between October and March. The site also has a monthly water deficiency resulting in a potential shortage of water from natural sources (Table 5). The terrain is relatively flat, with some rocky ridges, with altitudes ranging between 1000-1200 m (Yarnell, *et al.*, 2007). The close surrounding area includes farmland as well as a town and a main road to the South. Further from the site, the area is a major mining district, with 7 platinum mines within ca. 20 km as well as the tourist resort of Sun City .

Table 5: Comparison of the mean monthly rainfall figures (mm) for Mankwe with mean monthly potential evapotranspiration (PET) from Rustenburg (~40 km South), and the difference (Δ) between the two. (From University of Brighton Biology Field Trip Handbook)

(mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	95	87	83	33	16	7	6	9	13	44	80	100
PET	189	165	165	133	120	101	110	140	167	197	184	195
Δ	-94	-78	-82	-100	-104	-94	-104	-131	-154	-153	-105	-95

Mankwe supports indigenous grassland, bushveld and acacia woodland on predominantly flat terrain, with a crystalline layer of granite underneath. It is home to ca. 47 species of large mammals, including giraffe (*Giraffa camelopardalis*), zebra (*Equus quagga burchellii*) and eland (*Taurotragus oryx*) with several large carnivores (brown hyaena (*Hyaena brunnea*), leopard (*Panthera pardus*) (although these are only occasionally found), caracal

(*Caracal caracal*), serval (*Leptailurus serval*) and black-backed jackal (*Canis mesomelas*)). There are over 300 species of recorded birds, 30 species of reptiles, 19 species of small mammals and 61 species of dung beetles (the only invertebrate group to have been properly catalogued on-site). Figure 7 shows a biome map of South Africa, the study site is located approximately halfway between Mafikeng and Pretoria, on the boundary between savannah and grassland.

Mankwe has a total of 22 main water sources: 11 artificial pans, 4 natural pans, and 7 dams. The site has two main rivers flowing through it, with many tributaries throughout the reserve running in a south-easterly direction. Artificial pans are needed because natural water sources dry up during the dry season of most years due to the water deficiency as shown previously in Table 5.

One method by which grassland is managed is through rotational burning (Brockett, *et* al., 2001; Trollope and Trollope, 2004). Mankwe is divided into sections by roads and firebreaks, the resulting patch mosaic is burnt in a regime, such that any given patch is burnt every 4-5 years. This burning reinvigorates the grassland communities to grow new grass to increase the overall number of grazing units on the reserve by having more palatable and energy rich grasses for animals to graze on (Brockett, *et* al., 2001; Trollope and Trollope, 2004; Bothma and du Toit, 2016). Exceptions to this burning regime include a buffer strip around the Eastern and Southern perimeters. This is a strip of grass directly next to the perimeter road that is never burnt. This practice results in the grassland community in that area becoming dominated by climax grass species that are less palatable, which means that animals are less likely to graze in the area that is next to an outside road and thus potentially being opportunistically poached from the road. Firebreaks and camp areas are also exceptions to this rule as they are burnt every year to ensure that if a bush fire started (e.g. due to a lightning strike) the fire would be contained within part of the reserve and away from key infrastructure.

The fieldwork for the project was completed over a 20-month period between March 2019 to November 2020. This covered four complete wet and dry seasons in year 1 and year 2. In year 1, rains arrived later than usual in early November, whereas in year 2 the rains arrived at a normal time in early October.

Figure 5: Mankwe's location, shown by the red dot, compared to Johannesburg, South Africa.

Figure 6: The study site, shown by the red dot, in relation to Botswana and Zimbabwe.

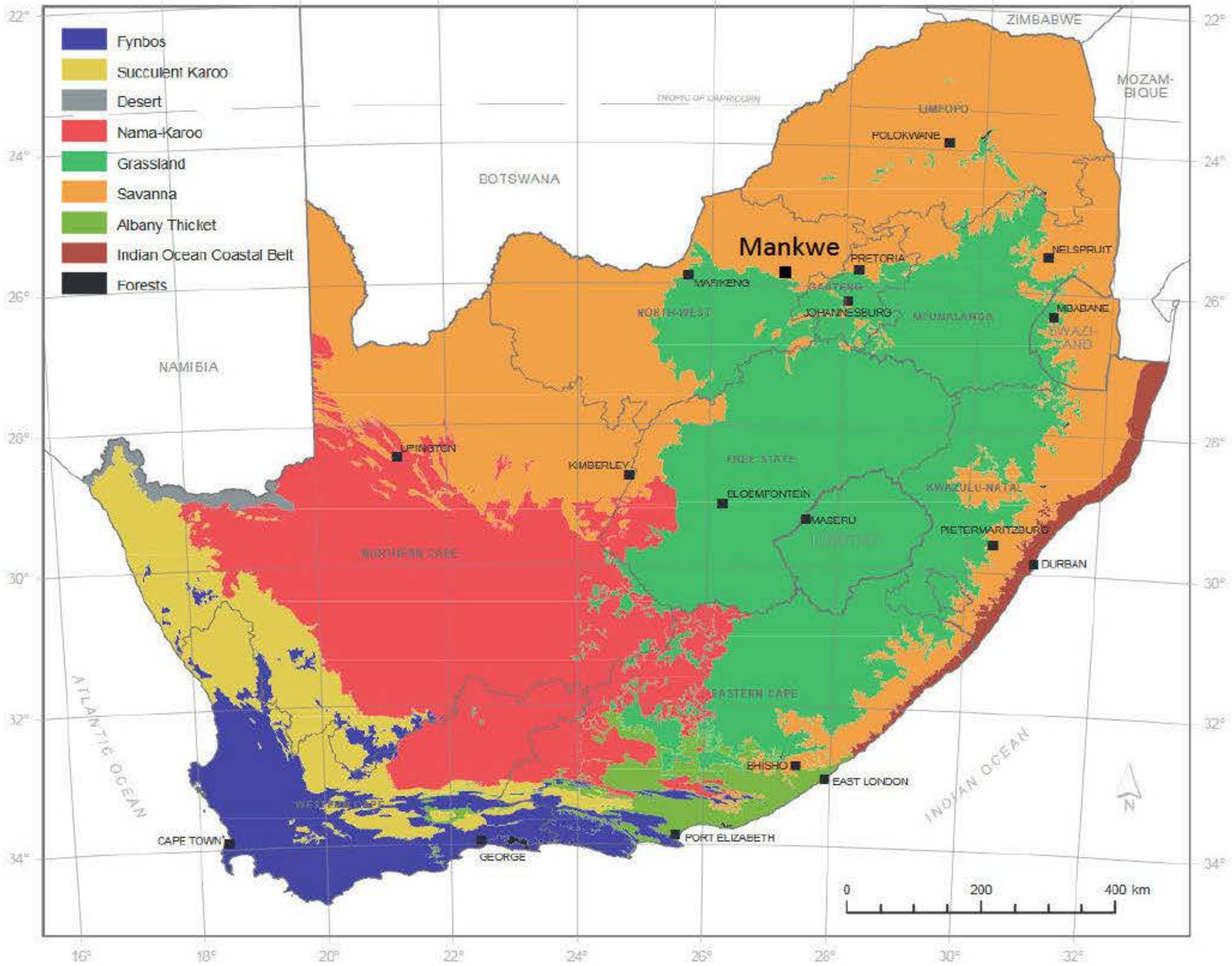


Figure 7: The biomes of South Africa, Lesotho and Swaziland (now known as Eswatini). Mankwe is approximately halfway between Mafikeng and Pretoria. Mucina & Rutherford (2006) in Bothma and du Toit (2016).

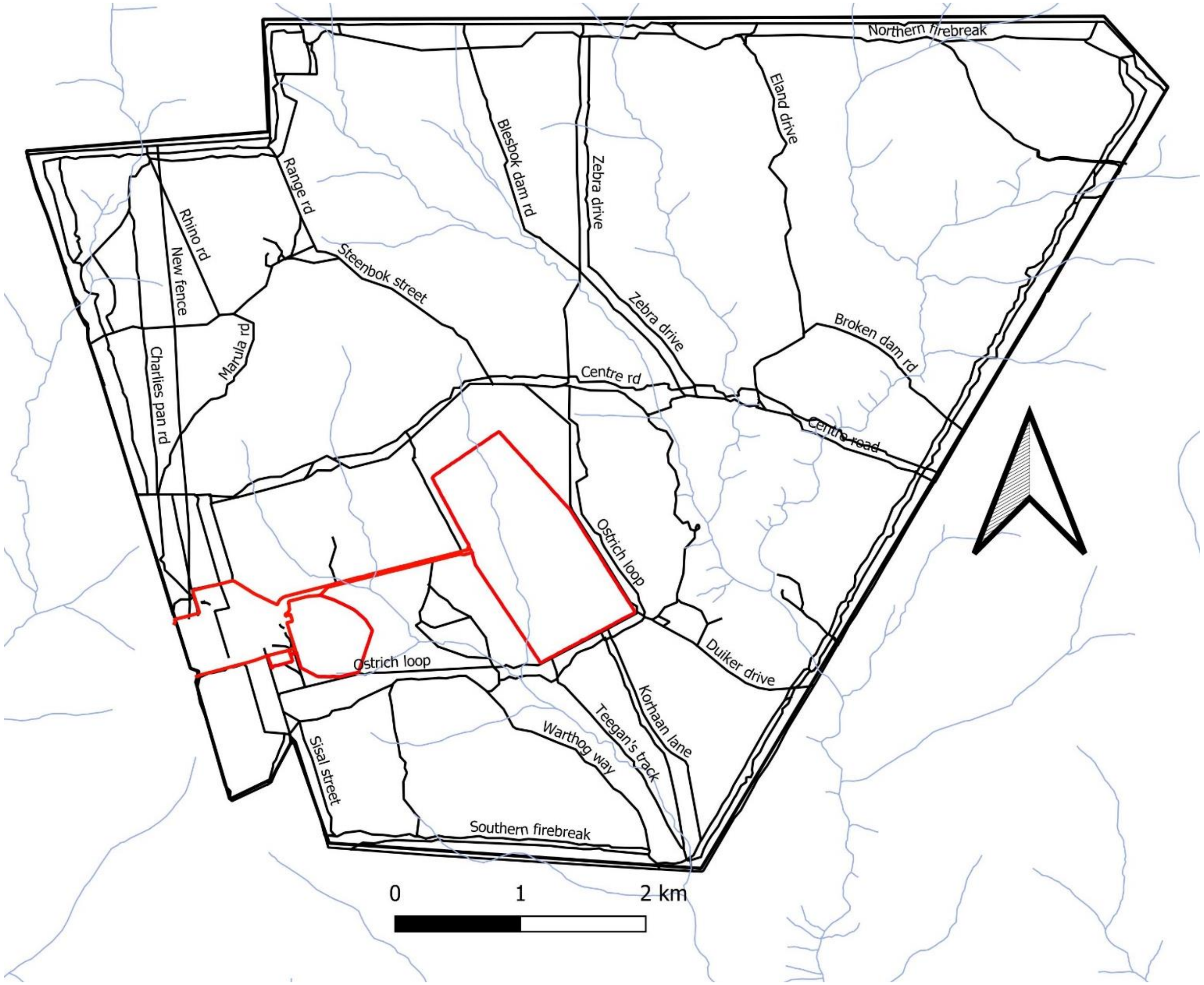


Figure 8: Map of Mankwe, the study site, showing roads and fences. Roads and perimeter fences are in black. Red indicates the interior factory munitions fence line. Blue lines show the rivers and tributaries through the reserve; many of these are ephemeral.

2.2 - Camera Trap Methods

The camera trap element used two different types of camera trapping deployment. The first type of deployment used cameras placed at points that had been procedurally generated throughout the reserve excluding the central factory area, hereafter referred to as 'bush cameras'. The second type of deployment involved camera traps that were located at artificial and natural pans, hereafter referred to as 'pan cameras'. Both methods followed the standard protocol described below.

2.2.1 - Standard Trapping Protocol

The same type of camera trap was used over the entire study period at both bush and pan locations (see below). Cameras were mounted on 1m-high metal angle-iron style fence posts, that were cut into sections using an angle grinder (Figure 9). These posts were hammered into the ground at least 10cm using a sledgehammer or 4-pound hammer to reduce the likelihood of posts being knocked over by animals. When cameras were set up on posts, it was essential to face away from sunrise or sunset directions to minimise lens flare at these times. Cameras were initially (up until month 10) deployed for 4-7 nights as the focus at this time was to detect species and thus create an overall species list for each sample location over the entire deployment period. Later in the study (months 10-20) cameras were deployed for 10 nights at a time to develop cumulative species detection curves at each sample location over the 10-night period. Cameras were placed between 30 and 45cm from the bottom of the post which is considered the ideal height for smaller nocturnal animals (Meek *et al.*, 2014). Nocturnal species were recorded from sunset to sunrise (as defined by times recorded on images between 17:30 – 06:30). If a nocturnal species was seen during the day, its presence was noted but that sighting did not form part of the analysed data.

The cameras used were Bushnell™ Trophy Aggressor cameras with a PIR (passive infrared) sensor (see website www.bushnell.com). These were chosen because they have a high degree of customisability of settings and are known to be reliable at the study site (M. Dawson, pers comm). The infrared flash was chosen over white flash (Table 2) because this study was not concerned with identification of animals to individual level, for which a white flash camera producing colour images would be typically used. Black flash (as defined in Table 2) was not used for the study because behaviour was not a focus (black flash is ideal for behavioural studies as it illuminates the animal without distracting it). Bushnell cameras also have a quick trigger speed of 0.2 seconds after detection with a short (1-second) recovery time between images. Each camera has a field of view of 38°. A total of eight Bushnell camera traps were used throughout the study. Camera settings used for the project are outlined in Table 6 below.

For storage on camera, the study used 16GB or 32GB SanDisk Ultra SD cards, dependant on the length that the camera would be left out for. Although the cameras can be connected to a D/C power supply, for this study the alternative of 8x AA batteries was used since camera turnover was relatively quick and DC power connection was not an option for many locations.

An event for this project was described as an animal triggering the camera up until it left the frame and then there is a 30-minute period where no individual of the same species is seen as this would be classed as the same individual that was seen before. Once there has been a 30-minute gap between the last photo of an individual and the next photo is that of an individual of the same species, it can be recorded as a new 'event'.

Table 6: Settings used for the cameras throughout the study. Sensor level shows Auto/Low as it was found that Low had no effect on animal detectability but reduced the number of false triggers compared to Auto, making it easier to sift through images.

Camera Setting	**Setting Options**	**Setting Used**	**Rationale**
Mode	Photo/Video/Hybrid	Photo	Study was only looking at detection so only images were needed

Capture Number	1/2/3	3	3 images per trigger allows for 3 chances for identification if the animal is fast.
LED Control	Low/Medium/High	High	High was chosen since this means that all 36 LEDs fire when the camera is triggered helping to illuminate the animal up to a distance of 30ft.
Interval	60min to 1s range of settings available. (60min-1min are set in one minute increments, 59s-1s are set in one second increments)	3s	3 seconds was chosen so that if the first trigger did not produce any legible photos, then an additional set of pictures are taken.
Sensor Level	Auto/Low/Normal/High	Auto/ Low	In the beginning auto was chosen, as it allows the camera to determine the best setting based on its current operating temperature. Later on this was changed to Low as auto was proving to have many false triggers, and low seemed to not have an effect on detectability.
NV (Night Vision) Shutter Speed	Auto/High	Auto	Auto was chosen as it meant that the camera could decide on what to use dependant on the situation which could be high variable (i.e. an animal moving fast or slow)

Figure 9: A variety of different types of camera locations used during the study. Panel (a) shows a camera pointed towards one of the artificial pans. Panel (b) shows a camera on an open game trail. Panel (c) shows a game trail in a thicket area. Panel (d) shows a camera in an open area.

All pictures that were recorded were viewed; none were discarded without first looking at them. All images were stored on a 1TB hard drive on a Windows 10 laptop, and backups were stored on 32GB memory sticks. During image sorting, any night-time images of species were saved in folders that were specific to species and location. All setup data were entered into an Excel sheet in the format shown in Figure 11 below. After this is a section where species are recorded, where multiples are recorded. At the end of the table was a section

	AG	AH	AI	AJ	AK	AL
1	Number of species	Cumulative total	OR, if no species seen, enter 0 here	Total Triggers	Number of Triggers in Night	Notes
57	0	0	0	2361	0	
58	2	2			33	
59	2	3			48	
60	0	3	0		3	
61	0	3	0		6	
62	1	3			6	
63	0	3	0		18	
64	0	3	0		0	
65	0	3	0		3	
66	1	4			99	

Figure 10: Headings showing end analyses for number of species and triggers found per night.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Location	Type of location (pan = 1; random site in bush = 0)	Location number	Location Type	Burn Age	Years since burn	GPS Location South	GPS Location East	Date on which night started (DD/MM/YYYY	Julian date	Year	Trapping Event
634	W3	0	23	Game Trail	2015	5	25.21623	27.26624	06/09/2020	250	2020	1
635	W3	0	23	Game Trail	2015	5	25.21623	27.26624	07/09/2020	251	2020	1

Figure 11: The headings for recording location and date

where more information about the cameras deployment was recorded, such as cumulative species and number of triggers, this is shown in Figure 10.

All times of animal sightings were recorded as well so that they could be used to generate an encounter histogram throughout the night. One very important aspect of this study was that absence data were assumed. In other words, if a species was not recorded it was assumed to not be present.

2.2.2 –Bush Camera Traps

QGIS 3.12.3 was used to generate points on a map of the reserve, as shown in Figure 12 below. One hundred and fifty points were generated all over the reserve, such that was a gap of at least 150m between each point, and a 150m distance between the point and any roads (to eliminate the effect of disturbance and not to overlap with the night drive transect methods). The points were given an alphanumeric code with an initial letter denoting the burn block, running NW to SW and the number giving the order within the block. Points were examined to see if they were possible to reach and any points that were not, e.g. within restricted area of the factory, were moved to the geographically nearest position, whilst adhering to the rules set out above. While 150 points were generated, it was not expected that all of these would be used. Figure 13 shows the points that were used in the study.

Figure 12: All 150 random points generated over the reserve. Points are in grey, roads are in black and fences are in red. Points are numbered and lettered. Each letter represents a patch name, and each number is the point number within that patch. For example, I10 is the 10th point in patch I.

Since there were a number of differing burn ages, with only a few of the older aged burns as well as some patch sizes being relatively small in size reducing availability to trap within the parameters set out, at least two cameras were deployed within each burn age.

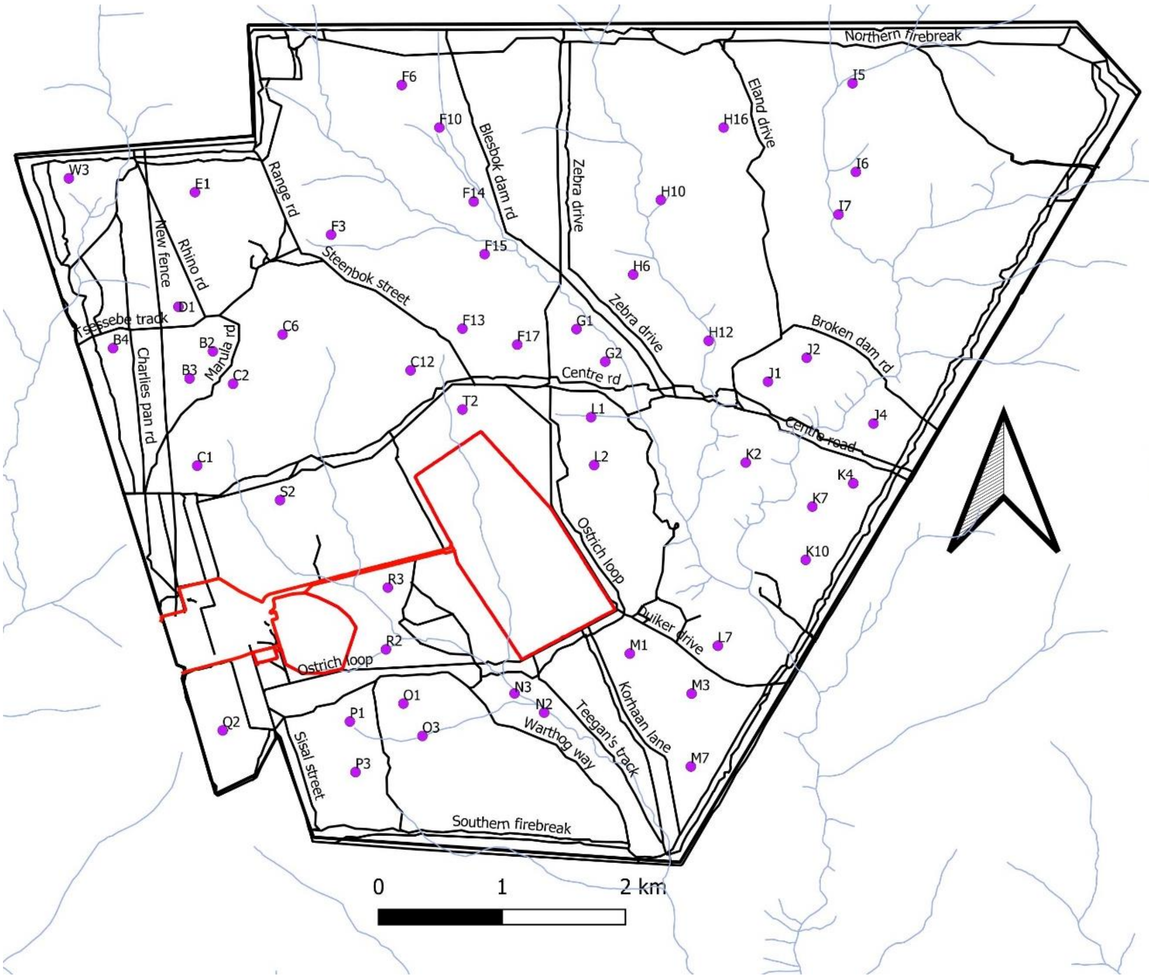


Figure 13: Random points used in the study. These are shown in purple. Every other aspect is the same as in Figure 6.

Using a Garmin® GPSMAP® 62 GPS, with a precision of 3m, a post and camera were taken to within 30m of the given point, and, if possible at that location, a suitable area was chosen for the camera to face towards, such as: a game trail, burrow, or open area (Figure 14). It the deployment site, grass and shrubbery around the camera's field of view and trigger zone was cleared up to a distance of 3m. This was done to reduce the likelihood of false triggers occurring Figure 15 shows the before and after of grass around a camera set up). Cameras were then set up as described previously and left.

Figure 14: Examples of locations that camera traps would be placed at. Figure (a) shows a burrow and figure b shows a game trail.

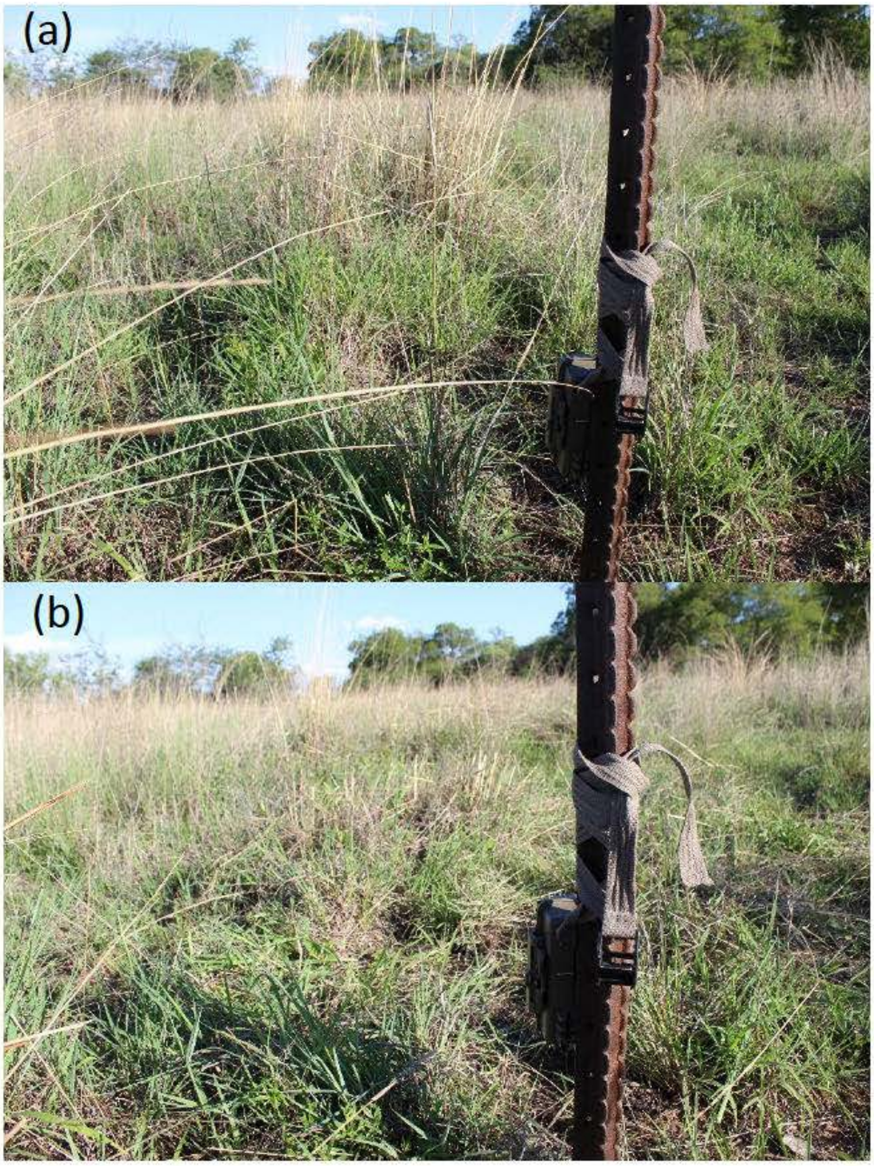


Figure 15: The before and after of clearing the grass around a set camera trap. 9(a) shows the before and 9(b) shows after.

2.2.3 – Targeted Pan Camera Traps

For this study, targeted camera traps were placed at natural and artificial pans. These were chosen since open water sources are essential for many species on site and the show site has a monthly water deficiency (see Table 5 in Section 2.1), making animals likely to use these water sources. Figure 17 below shows the pans, natural and artificial around the reserve. For this study, seven artificial and three natural pans were chosen, some of the pans were left out of the study as they were in need of repair at the start of the study.

There were two types of artificial pans. Pumped pan are pans that are refilled by pumping water from a natural bore hole that has been dug close to the pan, using the underground water table as a source. Pumped pans are pumped on a fortnightly basis in the dry season and once a month in the wet season, dependant on the amount of rainfall. The second type of artificial pans used were continual flow pans. These pans are on a slow (trickle) continual flow from municipality water sources, and these can leave wallows next to them when they overflow which they can do often in the wet season. Figure 17 shows pumped and continual flow pans.

Natural pans are sources that retain water well during the wet seasons, possibly even into the dry season. Figure 18 shows a natural pan with water. When the natural pans dried up during the dry season, they were taken out of the study since the water availability that made them attractive for animals was not there anymore.

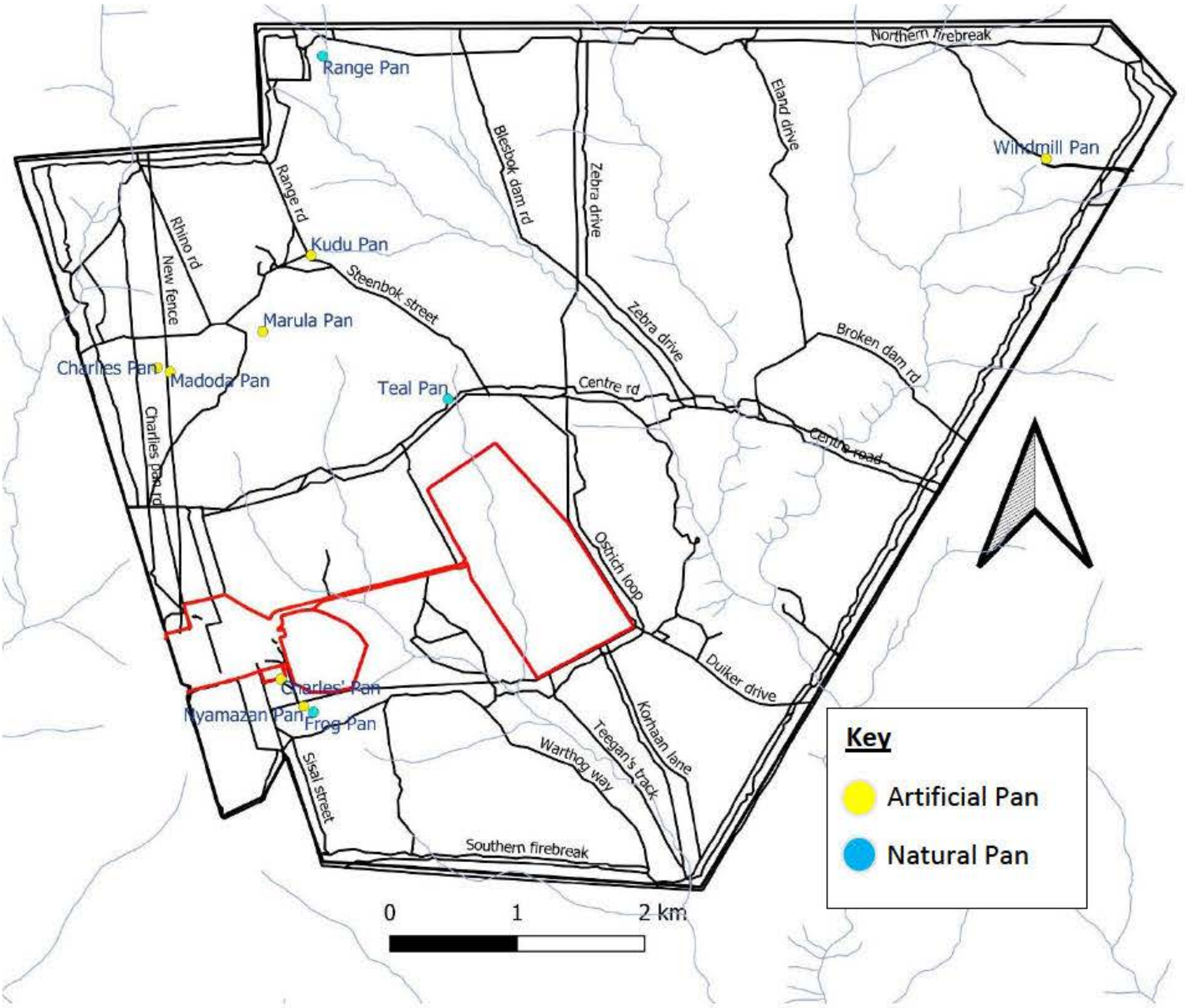


Figure 16: Map of the reserve will all the pans used in the study shown.

Figure 17: The two different types of pans found at the study site. 10(a) shows a continual flow plan, Marula pan, the pipe at the bottom right of the photo is left on to keep water flowing into the pan, the amount of water flowing can be adjusted dependant on how often the pan is used by animals. 10(b) shows a pumped pan, Kudu pan, these pans are pumped using a bore hole, the concrete structure at the bottom of the photo. These pans are pumped ca. every two weeks in the dry season and once a month in the wet season, dependant on use by animals.

Figure 18: Teal pan, a natural pan on the site during the wet season.

Cameras for this section of the study were set up the same as described in section 2.2.1. The 10 selected pans were each deployed to between 3-5 times for a total of 46 deployments to pans.

2.3 - Night Drive Methods

There were two different night drive methods for this study. One method involved an experienced observer (the author) recording driven transect details (time, distance) and recording nocturnal species that were seen. Effort was known for such transects such that sighting rates could be calculated by time or distance and a lack of a record was known to be because an animal was not seen as distinct from an animal simply not being recorded (i.e. the data were true presence/absence not presence-only). The second method was an ad hoc recording method making use of a 'sightings book' in which multiple "casual" observers (with varying levels of experience and knowledge) would record if they had seen a nocturnal animal whilst doing other work at night. In both cases, the same nocturnal species were recorded as using camera traps and sighting time between sunset and sunrise was also noted. More detail on the two types of records is given below.

2.3.1 – Driven Transects

Dedicated driven transects were undertaken by the author. More information was recorded with this method than with the ad hoc method. With each drive, the time at the start and end of the transect was noted and the trip odometer on the vehicle was reset to zero at the start allowing the distance covered to be recorded. The vehicle was driven at an average speed of around 20 km/h. Whilst driving, all individuals of nocturnal species seen were recorded, as well as the time at which they were seen. It was also important to record if no species were seen (see comments above regarding assumptions of presence/absence).

Vehicles driven were an Isuzu Fleetside pick-up truck and a Kia K2700. Each vehicle was equipped with an overhead 10-30 volt, 810mm, LED bar light with 60 LEDs as well as a handheld LED 1000-lumen spotlight deployed from the driver's side window. The overhead light bar increases the field of view provided by the headlights, and the handheld spotlight allows illumination of potential target animals with a focussed light to help identification. The illumination ranges of each of the sets of lights are shown in Figure 19.

One drawback of spotlighting is that animals that are just out of reach of the light for identification purposes are still detectible because of reflected light from the animal's eyes, a phenomenon known as 'eyeshine'. Eyeshine is caused by the tapetum lucidum, a layer of tissue that is located behind the retina acting as a retroreflector, reflecting visible light back through the retina and thereby allowing more light to be picked up by the photoreceptors (Figure 20) (Willcox *et al*., 2019; Newton *et al*., 2008).

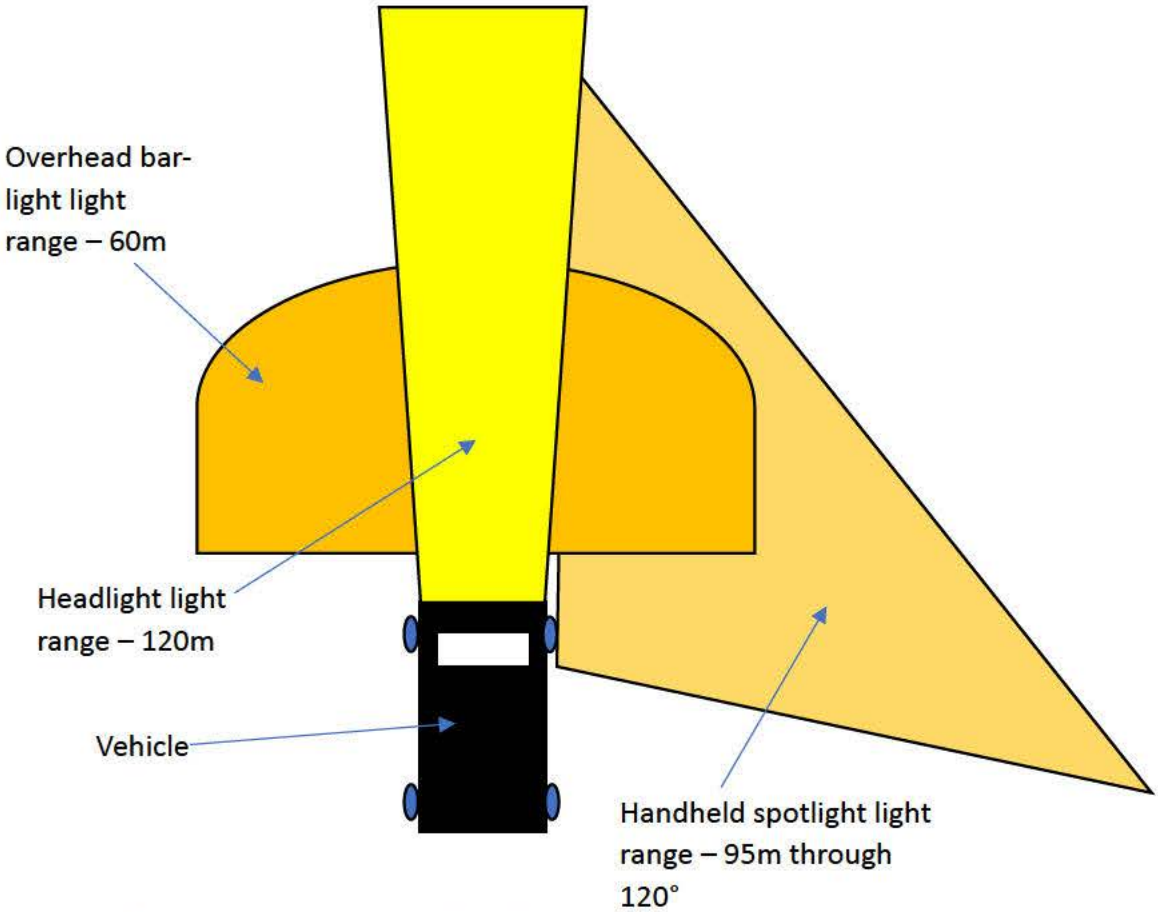


Figure 19: The visual light ranges of each of the different lights used with the vehicle. Visual light range is the furthest that light reaches from the source that an observer can still make out what they are seeing. Or use vehicle to work out a rought scale bar?.

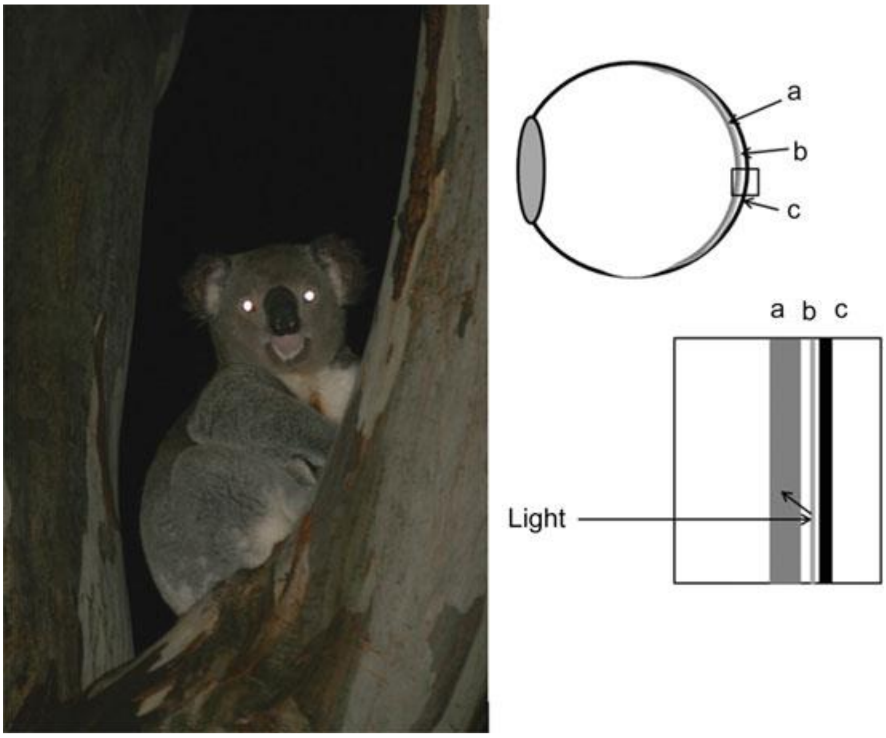


Figure 20: Tapetum lucidum of nocturnal and crepuscular vertebrates. The light gets reflected by the layer behind the retina and thus increases photon absorbance. Small letters indicate (a) the retina, (b) the tapetum lucidum, and (c) the choroid (Image illustrated by Schroer. Photo courtesy of Annette Krop-Benesch) (In Schroer and Hölker, 2016)

Neither locations of species nor their distribution were required to assess the effectiveness of nocturnal driven transects. Consequently, specific routes for transects were not needed, and the only metrics required were distance travelled and duration. Even so, all roads were driven more-or-less equally, including both internal and perimeter roads, to give a good coverage of the entire reserve (as with camera traps). On this, transects were not given any specific time or length as all drives were looked at cumulatively and variety of lengths of drives were wanted.

Data were recorded in a booklet whilst on the drives and then regularly entered into an Excel spreadsheet. Variable data recorded with an example are shown in Figure 21 below. At the end of the spreadsheet were columns for if no species were seen on the drive or , where animals were seen, the number of *species* seen in total and the cumulative total of *individuals* seen.

Drive Number	Date on which night drive started (DD/MM/YYYY)	Date on which night drive ended (DD/MM/YYYY)	Time of night drive start (24hr clock)	Time of night drive end (24hr clock)	Total Time Driven (hr:min)	Julian Date	Year	Total distance travelled (km)
1	28/02/2019	01/03/2019	22:27	00:35	01:08	59	2019	25

Figure 21: Data recorded for each night drive, Julian date is a date format on a 1-365 day scale, in this case, 28/2/19 is 59 in Julian date format.

2.3.2 – Ad Hoc Records

These were sightings that were recorded by other observers that included those experienced or inexperienced at nocturnal driving and identifying animals. Sightings were recorded as ad hoc records, and any night drives where no species were seen were not recorded (as is the case with ad hoc and visitor sightings records in general). Unlike the formal night drives, therefore, this method only recorded sightings of nocturnal individuals, the date and the time of the sighting, and was thus presence-only data. It did not have any specific transects and did not record the amount of time spent driving or the distance covered, meaning survey effort was unknown. One main drawback of this is that many sightings may have not been recorded due to the preference of rarer species, such as: aardvark (*Orycteropus afer*), serval (*Leptailurus serval*) and honey badger (*Mellivora capensis*) over more common species such as jackal (*Canis mesomelas*) and scrub hare (*Lepus saxatilis*).

Data from these observers were recorded in a logbook at the main camp and were then transferred over to an Excel spreadsheet. In practice, the observers also messaged via WhatsApp personally or to a communal group when animals were seen and the time. This helped in ensuring that sightings were subsequently recorded in the logbook.

2.4 - Species Identification

For all methods of this study, the focal group will be nocturnal mammals, as opposed to species that are recorded at night and will exclude bats and galagoes. A full list of the species being recorded is shown in Table 7 below.

Table 7: The focal species of the study

Serval	Caracal	Bushpig	Jackal
Hyaena	Small Spotted Genet	Large Spotted Genet	White Tailed Mongoose
Honey Badger	Aardvark	Aardwolf	Scrub Hare
African Civet	Spring Hare	Porcupine	Mountain Reedbuck
Steenbok	Duiker	Bushbuck	

When identifying animals during the study, it was important to look at a few key defining features of each species. In some case, species were quite distinct from one another and thus easy to identify, for example Figure 22 shows a porcupine. This species is easy to identify as there is only one species of porcupine in South Africa (Ngcobo, *et al*., 2019) and as such one only needs to look for the quills on the animal to identify it. This is true for both night drives and camera traps.

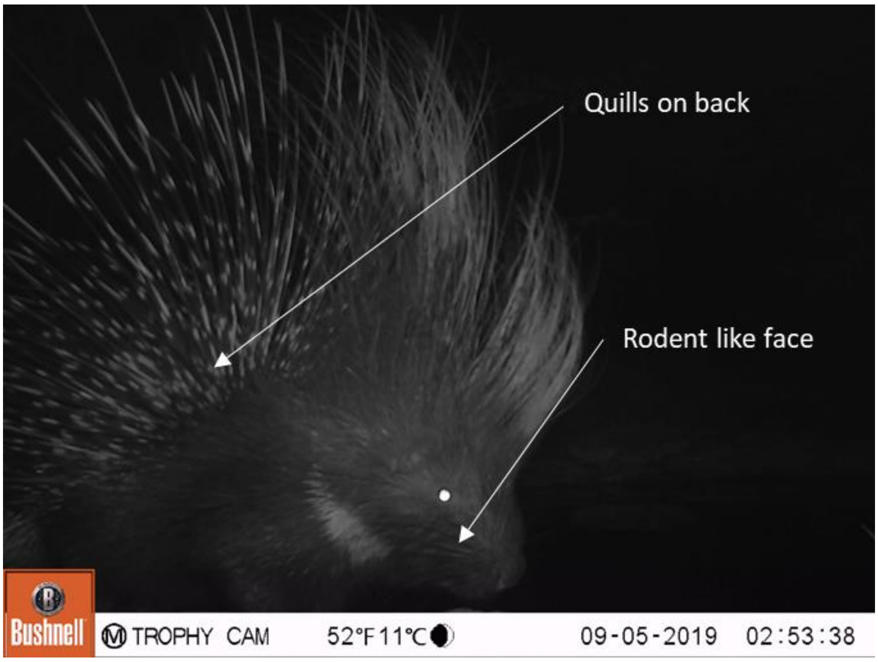


Figure 22: A captured image showing a porcupine with some its key identifying features annotated.

However, some species were very similar to one another, which made accurate identification harder. A good example of this is similarities between large spotted genets, small spotted genets, and African civets. All three of these species are relatively small, viverrid species with long bodies and short legs with all three also having long tails and black and white stripped and spotted patterning. Figure 23, Figure 24 and Figure 25 below show images of these three species as well as the key identifying features of each of them as well as the distinguishing features between them.

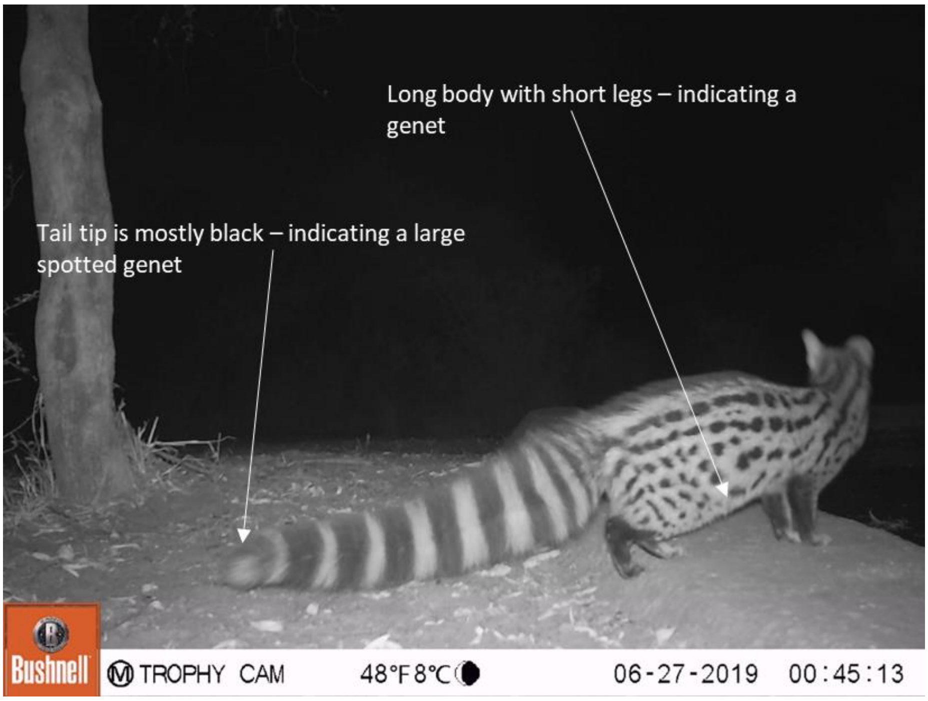


Figure 23: The distinguishing features of a large spotted genet. Here the tail tip is mostly black, an indication of a large spotted genet.

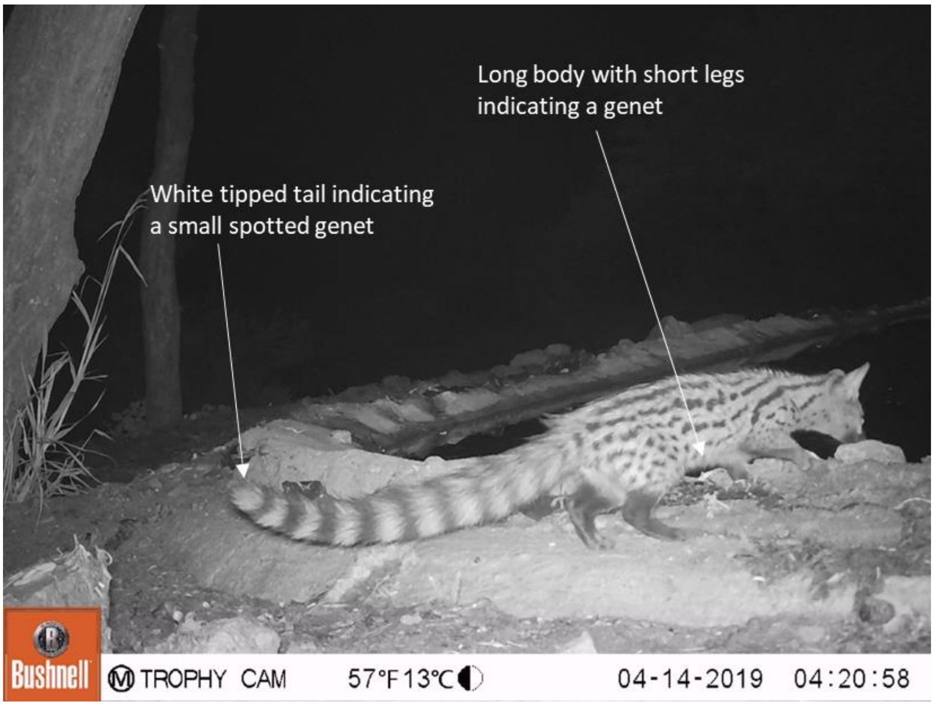


Figure 24: The distinguishing features of a small spotted genet. Here the tail tip is completely white one of the small spotted genet's key features.

Figure 25: The distinguishing features of an African civet (Civettictis civetta) compared to genets (Genetta spp.).

2.5 - Data Analysis

2.5.1 – Species Accumulation Curves

Species accumulation curves were used to show, cumulatively, how many nights were needed before the entire community of target nocturnal species was encountered. This process was undertaken for each method except for ad hoc records (i.e. bush cameras, pan cameras, night drives) in MS Excel. Doing this allowed comparison between methods to discover which was fastest at detecting all species present at the reserve and for subsets of those species (e.g. 90% of species). For each camera trap, after each night, new data were checked against previous night(s) to see if there any new species were seen or not and adjust the cumulative total accordingly. This was repeated for all camera traps across the whole dataset. The same method was done for night drives but with cumulative drives instead of cumulative nights. Logarithmic trendlines were calculated to produce r-square values and equations to assess the goodness of fit. Figure 26 below shows an example done for camera trapping over the first 15 cumulative nights of the entire dataset used to produce a species accumulation curve.

Cumulative Nights	Cumulative Species
1	0
2	1
3	2
4	2
5	2
6	2
7	2
8	2
9	2
10	2
11	3
12	3
13	3
14	4
15	4

Figure 26: An example of the data used to produce the species accumulation curves over all camera traps. Cumulative Nights on the left show how many nights, cumulatively, have passed. Cumulative species on the right show how many new species have been seen, cumulatively, after the number of nights that have been.

2.5.2 – Randomisation of Data

Since it is difficult to produce replicates within this study as it is a long term study of a single site, another way of producing replicates was needed to generate averages and confidence intervals around species accumulation curves. Once the main species accumulation graphs were generated from the original dataset, non-parametric bootstrapping (i.e. pseudo-repeats of the original data based in this case on randomised re-ordering of the original data rather than randomised sub-sampling), was used.

The bootstrapping method for this study involved repeatedly randomising the data for night drives and camera traps in Excel using the following method:

- An additional column was added in which every individual drive or camera deployment (not individual night) was given a random number using the function '=randbetween(a-b)'

- The function gives the cell a randomly generated value between a lower value 'a' and a higher value 'b'.
- This range was 1-357 for night drives as this was the total number of night drives.
- The range for camera trapping was 1-100 as there were fewer 'individual' camera trap deployments than night drives.
- Once every individual drive or camera deployment had random number assigned to it, the 'custom sort' function was used to arrange the data from lowest to highest according to the randomly generated column.
- The data was now in a randomly different set from the original data and a species accumulation curve was completed, as detailed in section 2.5.1.
- This process was repeated until there were 25 of these 'pseudo-repeats' of the data set, making 26 species accumulation graphs in total including the original data.

2.5.3 – Randomisation Analysis

Using these pseudo-repeats of the same overall dataset, averages and confidence intervals were produced to allow generalisations and inferences to be made in a way that would have not been possible for a single dataset (and thus a single species accumulation curve). A mean species accumulation curve was produced, this being the mean number of nights to discover each new cumulative species (for camera traps) or the mean number of drives to discover each new cumulative species (for night drives). The next step was to calculate the range, standard deviation and 95% confidence intervals for all cumulative species values for camera traps and night drives, to give an understanding of the variability (and thus the role of chance) in how long it took to encounter/detect each new species. Three graphs were produced to show in the variability metrics (range, SD and 95%CI) in comparison to the mean accumulation curve.

This allowed generalisations and inferences to be made about the data in a way that would not be possible with a singular dataset and detection curve (Lunneborg, 1999). Permutating the data in this way has been talked about before with the detection curves of bird data

(Xuan Mao, *et al*., 2005), as well as in Cusack, *et al*., (2015) where bootstrapping with replacement was used to create confidence intervals with species detection curves.

2.5.4 – Individual Species Analysis

This analysis focussed on the number of nights and the amount of distance travelled it took to see each individual specific species (rather than the cumulative species number as previously analysed). The mean amount of survey effort (camera trap nights or night drives) needed, as well as 95% confidence intervals, were calculated for each individual species in the community (e.g. African civet, aardvark etc.).

2.5.5 – Discriminant Function Analysis (DFA)

To investigate camera trapping in more detail, and establish whether bush cameras and pan cameras were recording substantially different species communities, a discriminant function analysis (DFA) was conducted. Only the first four nights of each camera deployment were used, this was because deployment nights for different traps varied but all traps were deployed for four nights as a minimum. The DFA was done using IBM SPSS Statistics 27 (IBM, 2020) and used information on species found for each individual bush camera and each individual pan camera. The analysis aimed to predict whether data from each individual camera in the dataset was a bush camera or a pan camera with the overall classification accuracy compared to the percentage of cases that could have been predicted by chance (the prior probability, calculated from the sample sizes: pan cameras = 46; bush cameras = 50). The fundamental basis of DFA is that if the model produced is robust and useful, then most of the cases should be correctly classified, i.e. if the percentage of cases correctly classified is substantially more than that of the prior probability. However, if the model is not robust and useful then a substantial number of cases will be incorrectly classified and the percentage of cross-validated cases will be less than (or equal to) the prior probabilities. Cross validation was used in this analysis. This is a method of discriminant function analysis where many models are produced using the data provided but leaving one case out each time and classifying that case using a model built on all other cases. This process is repeated until all the other cases have been the one left out and classified and combines the end results together to produce a cumulative model.

After this, a stepwise analysis was used; this allows the variables (species) that are the most important factors in achieving accurate classification to be identified, as well as removing all of the factors that were either not useful in the model or that were actually detracting from it and creating ‘noise’. These species that were identified were then run through their own DFA to analyses their effectiveness.

3 – Results

During the study, eight camera trap units were deployed 96 times over a total of 657 nights. In total 389,108 images were taken of which 31,000 were taken at night with 3,289 showing target nocturnal species (0.84% of all photos taken). Camera traps were deployed both in the bush and at water holes (pans). Cameras were deployed to bush locations 50 times and to pans 46 times (10 pans surveyed 3-5 times). Of the total 389,108 images taken, 181,557 were from bush cameras but only 2,115 (1.17%) of these were nocturnal. In comparison, 207,551 photos were taken by pan cameras with 21,040 of these being nocturnal (10.14%).

Over the period of data collection, 357 “night drives” were undertaken. Together, these covered a distance of 8,385 km driven over a total of 437 hours and 3 minutes. The shortest drive was 2 km (6 minutes), while the longest drive covered 63 km (3 hours and 47 minutes). Drives were, on average, 23.5 km with an average duration of one hour and 13 minutes. In total, there was 459 animal encounters, with 767 individuals being observed. Ad hoc data showed 221 recordings of 245 individuals being recorded.

During this study 18 of the total 20 historically confirmed species at the site, were recorded across all methods. Night drives discovered 16 species, with both camera trapping methods also recording 16 unique species, with pan cameras detecting 15 species and bush cameras discovering 12. Ad hoc recording detected 16 different species.

3.1 – Camera Trap Analysis

3.1.1 Species Accumulation Curves

A greater number of the target species was encountered, in a shorter period of time, using the targeted pan cameras compared to bush cameras (Figure 27 b and c). The species accumulation curve for pan cameras had a steeper gradient within the first 100 days, especially initially, than the comparable species accumulation curve for bush cameras. For example, after 100 trapping nights, bush cameras detected 5 of the target species, whereas pan cameras detected 10 of the target species. By the end of data collection (i.e. after 657 trapping nights), bush cameras had detected 12 of the target species and pan cameras had detected 15 of the target species (all cameras combined detected 16 species as some species were only found on pan cameras and some only on bush cameras Table 8 below shows which species were detected by each method). R squared values show that all three of the graphs (displaying data for all camera, pan cameras, and bush cameras, respectively) have trendlines that fit the data well, accounting for 87.9% of variance in cumulative species number for bush cameras, 91.3% for pan cameras and 95.5% when considering all cameras combined.

Table 8: Species that were seen using each method of camera trapping. Check marks (✓) indicate a species was seen by that particular method and crosses (X) show that that species was not seen.

Species	Seen on Bush Camera	Seen on Pan Camera
Serval	✓	✓
Caracal	X	✓
Black-Backed-Jackal	✓	✓
Brown Hyena	X	X
Small Spotted Genet	✓	✓
Large Spotted Genet	✓	✓
White-tailed Mongoose	✓	✓

Honey Badger	✓	✓
Aardvark	✓	✓
Aardwolf	X	X
Scrub Hare	✓	✓
African Civet	X	X
South African Springhare	X	X
Cape Porcupine	✓	✓
Mountain Reedbuck	✓	✓
Steenbok	✓	X
Common Duiker	✓	✓
Cape Bushbuck	X	✓
Bushpig	X	✓
African Wild Cat	X	✓

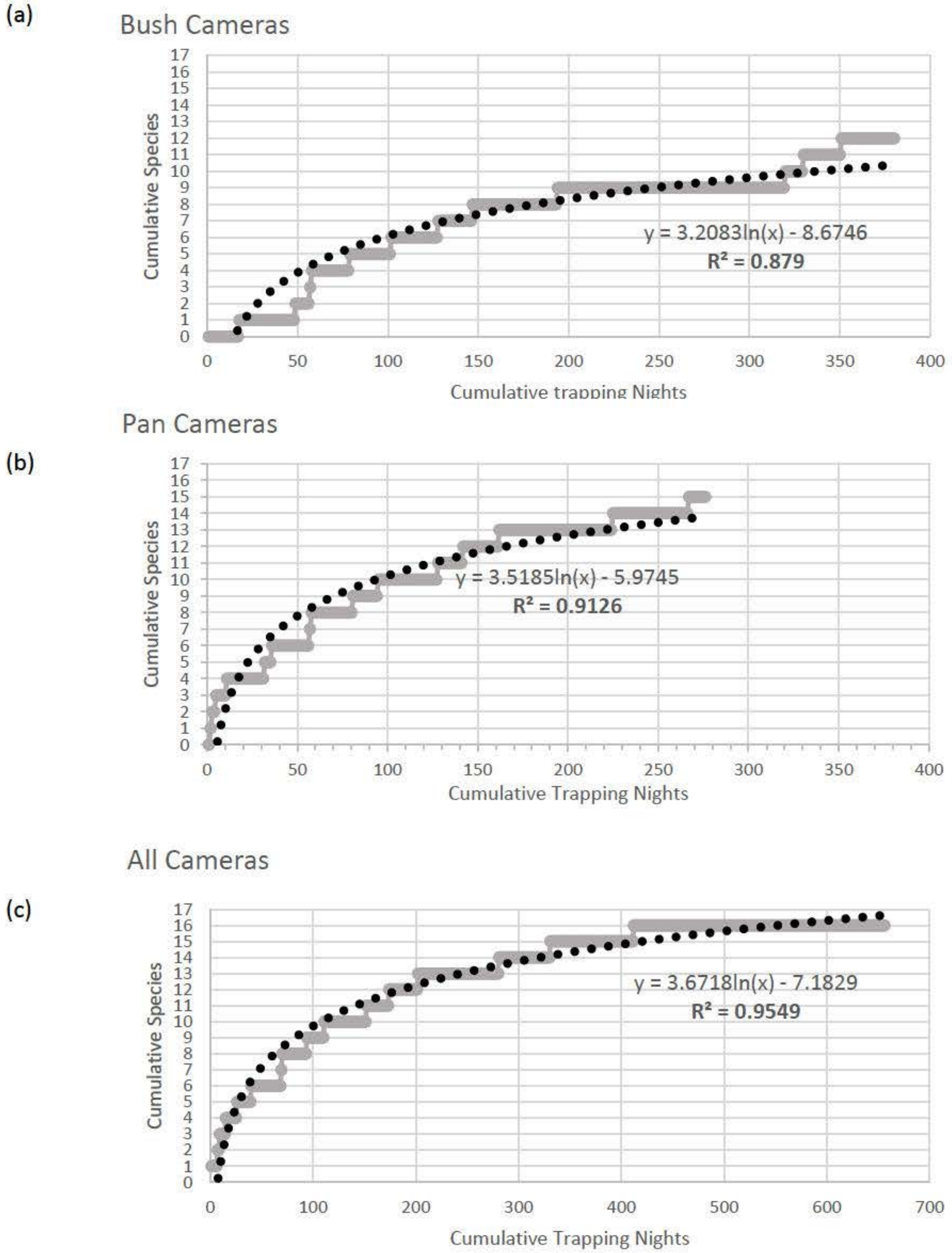


Figure 27: The species accumulation curves for each aspect of camera trapping; bush cameras (a), pan cameras (b), and all cameras (c). Each data set is shown in grey, with the trendline shown in black. The equation of the graph is shown underneath, in the format y = mx + c. Underneath this is the R^2 value, shown in bold. Note the difference x-axis scales for (a) and (b) relative to (c).

3.1.2 - Randomisation Of Data

After creating the initial species accumulation curves for the original dataset, data from the pan cameras were randomised 25 times and new species accumulation curves were plotted to give a total of 26 species accumulation graphs including the original data (see section 2.5.2 for the rationale for this). This process was repeated for bush cameras.

There was some variation in the randomised replicates that were produced. While most produced a consistent pattern with periods between when new species were seen remaining very similar, some graphs produced highly inconsistent patterns with uneven intervals between the detection of each new species. This was found with, both, bush cameras and pan cameras and replicates such as this are helpful with producing confidence intervals as they show that in some cases 'luck' may play an important factor in data collection.

R-squared values found for different randomized replicates of the data were very similar. As can be seen from Table 9, there was a similar amount of variation in species detection explained by number of trapping nights with both types of camera placement, however pan cameras have a slighter higher overall R-square value compared to bush cameras. Pan cameras also had higher minimum and maximum values, as well as a lower standard deviation around the mean, however standard deviations were very small for both pan and bush cameras. This shows us that overall, for both methods and across all of the randomisation process, the data fit the trendline to a high degree. Standard deviation was low for both pan and bush cameras showing that the r-square values have low variance.

Table 9: Showing the variance in the R-square values through the randomisation of both bush and pan cameras.

Camera Type	Mean R-Square Value	Minimum R-Square Value	Maximum R-Square Value	Standard Deviation
Pan	0.917	0.844	0.976	0.028
Bush	0.905	0.829	0.951	0.033

3.1.3 Camera Trap Randomisation Analysis

Using the randomised datasets and the original data, range, standard deviation and 95% confidence were calculated and plotted (see section 2.5.3 for details of the method) to investigate the impact of change encounters with species made to the data and thus how repeatable the results would be likely to be.

There was a large overlap in the ranges of how many nights were needed to detect successive cumulative species (e.g. the range of nights needed to detect, say, five species overlapped with the range of the number of trapping nights needed to detect 1-9 species) shown in Figure 30 (a). The largest range was for the 10th species detected, which spanned 226 nights; the smallest range was 37 nights for with the first species detected. This shows that the number of nights that it takes to find the later species numbers is more varied than with initial species. This suggests that rare species will take longer to find and the number of nights at which they are identified is likely to be randomised.

All standard deviations had overlap, shown in graph (b) with some of the lower number of species overlapping many others, such as with the fifth species, which overlaps with the mean values of the fourth and third species. The highest standard deviation was the 10th species with 60 nights, and the lowest was eight nights with the first species.

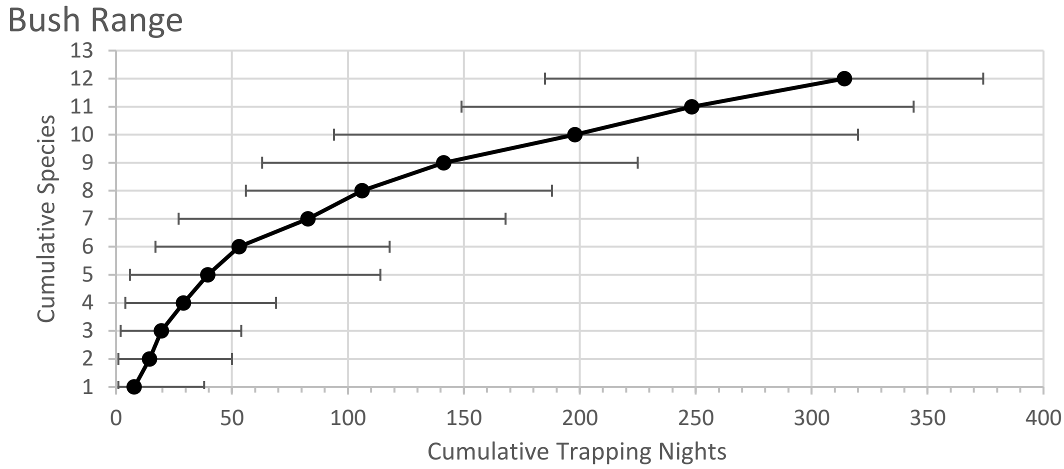
95% confidences, especially with the higher cumulative species, did not overlap, showing there was a significant difference in the number of nights it took to detect these species overall when taking into account all of the randomised sets and the original data, this is shown in graph (c). The highest number of nights for 95% confidence was the 10th species with 23 nights, with the lowest being species one with only 3 nights covering 95% of variation in the data.

This same process was carried out on pan cameras as well, shown below in Figure 31. The range, in graph (a), showed a notable amount of variance around each species, with the highest range being 168 nights, on the 14th species and the lowest being 16 nights on the first species. The lowest value of one night occurred in the first six species, with the lowest being two nights with the 7th species. The difference in the highest and lowest values increased as the cumulative number of species and cumulative nights trapped increased. As with bush cameras, this shows that the number of nights it takes to detect later species is more varied than the initial species which, again, suggests that the rarer species will take longer to detect and at a relatively random time.

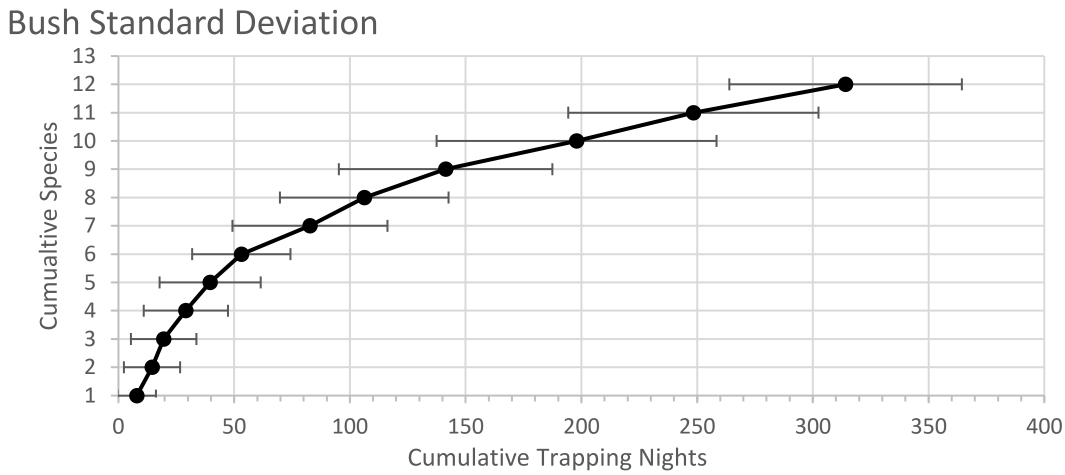
Standard deviation also increased as cumulative species and cumulative trapping nights increased. The highest standard deviation found was 47 nights with the 14th species, the lowest being four nights with the first species. Standard deviation also showed a relatively high amount of overlap, with every standard deviation overlapping with the next mean value down at least. In some cases many values overlapped with one another. For example, the eighth overlaps with the seventh, sixth and fifth species. This shows that that there was a high amount of variability around the mean throughout all cumulative species numbers, with this variation peaking at the 10th species.

As with bush camera traps, 95% confidences overlapped in many of the smaller cumulative species numbers the higher numbers not overlapping as much, this is shown in Figure 31 (c). It had a maximum of 17 nights covering 95% of the variation in the data with the 14th species, and a minimum of only one night with the first species. This shows that despite the large overlaps in range, for 95% of cases, higher cumulative species are less likely to overlap with one another.

(a)



(b)



(c)

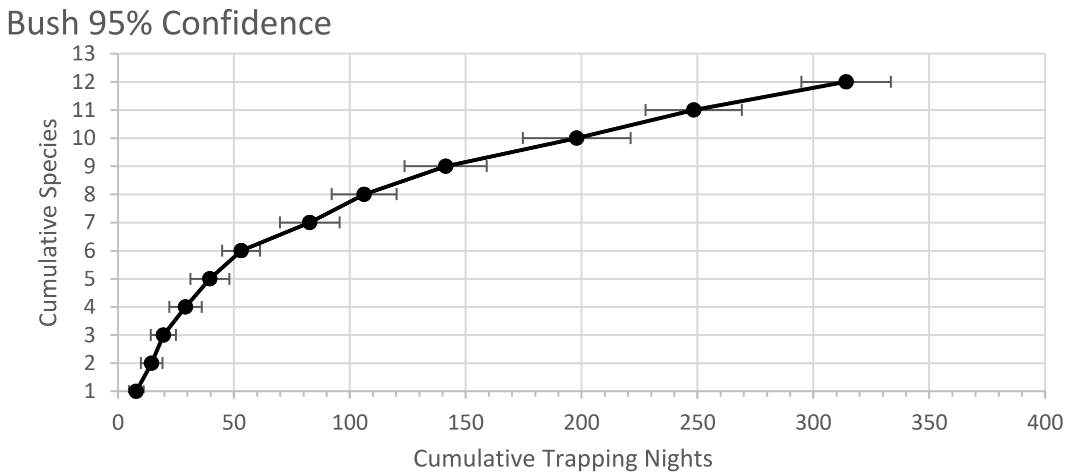


Figure 28: Graphs showing the analysis done on the combined randomised and original data of bush camera traps. Graph (a) shows the mean night at which each cumulative species was detected, with the range found in the data for each stage, graph (b) shows the standard deviation around the mean and graph (c) shows the 95% confidence around the mean.

(a)

(b)

(c)

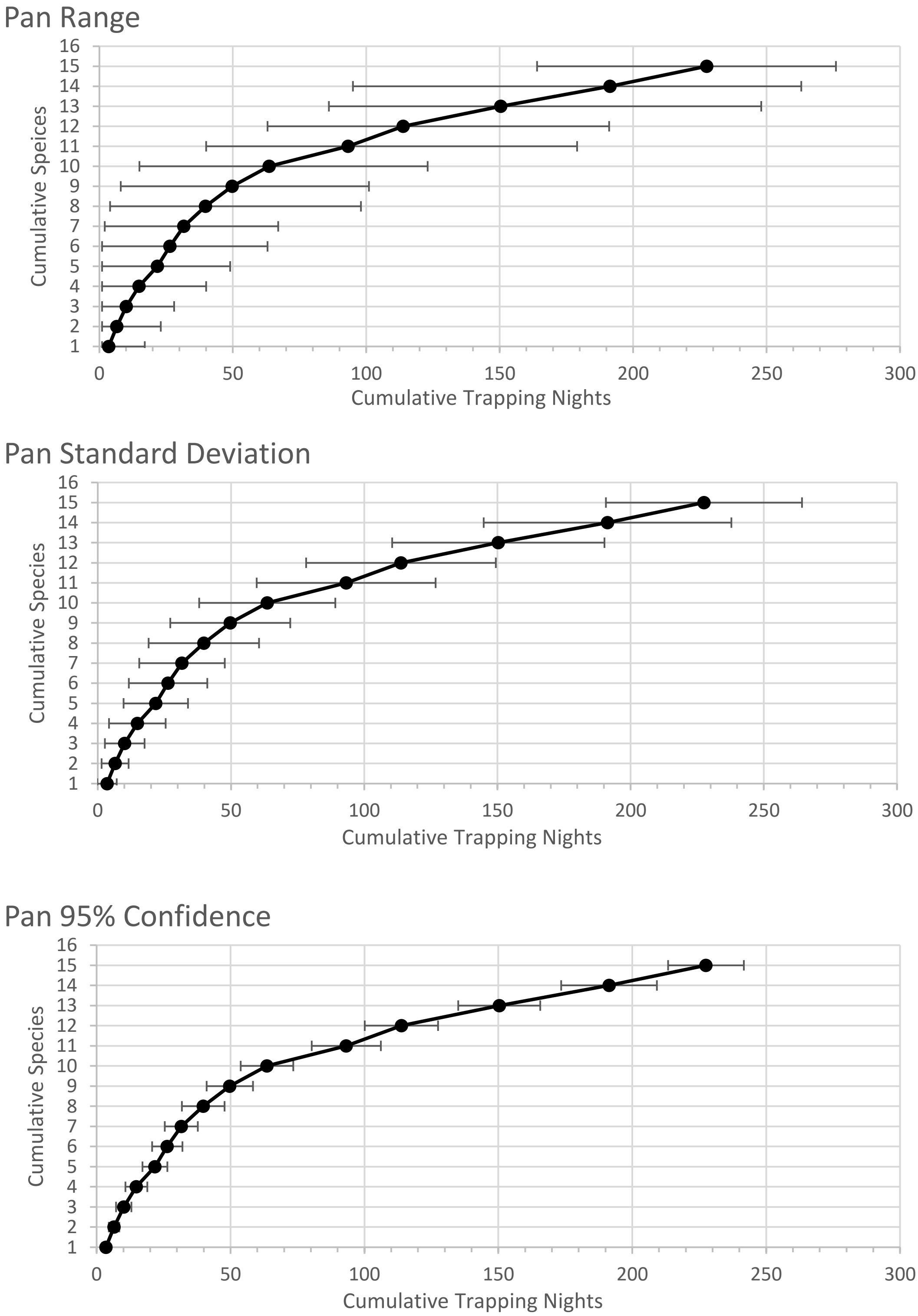


Figure 29: Graphs showing the analysis done on the combined randomised and original data of pan camera traps. Graph (a) shows the mean night at which each cumulative species was detected, with the range found in the data for each stage, graph (b) shows the standard deviation around the mean and graph (c) shows the 95% confidence around the mean.

3.1.4 – Number of Nights Needed for the First Sighting of Particular Species

To further investigate the substantial amount of variation that there was in the number of trapping nights, the original dataset and the randomised repeats were analysed to quantify the cumulative number of trapping nights it took to detect each specific species (not just cumulative species richness as in section 3.1.3). This also involved calculating the mean number of nights needed using the randomized data replicates, and then calculating the 95% confidence of each of those values (Figure 32). The mean number of nights varied greatly with both graphs (a) and (b), with the greatest number of nights required to detect a particular species for pan and bush being: 153 and 224 nights, respectively. The lowest for each was: six nights for pan cameras and 24 nights for bush cameras.

These two graphs show that species were more likely to be detected quicker at pan cameras than at bush cameras. The extremes of this variation can be seen clearly with mountain reedbuck which were more likely to be seen earlier at pan cameras than at bush cameras, with the mean number of nights to first sighting on pans being 57 nights, whereas bush cameras were 245 nights on average. Another very large difference is aardvark, where at pans it took a mean of 24 nights to the first sighting, but on bush cameras it took 186 nights.

The exceptions to this were scrub hare and large spotted genet. Scrub hare had a mean number of 30 nights to first sighting on pan cameras, with bush cameras taking 25 nights to first detection. Large spotted genet had a mean of 50 nights to first sighting on bush cameras, with pan cameras taking 54 nights.

a)

b)

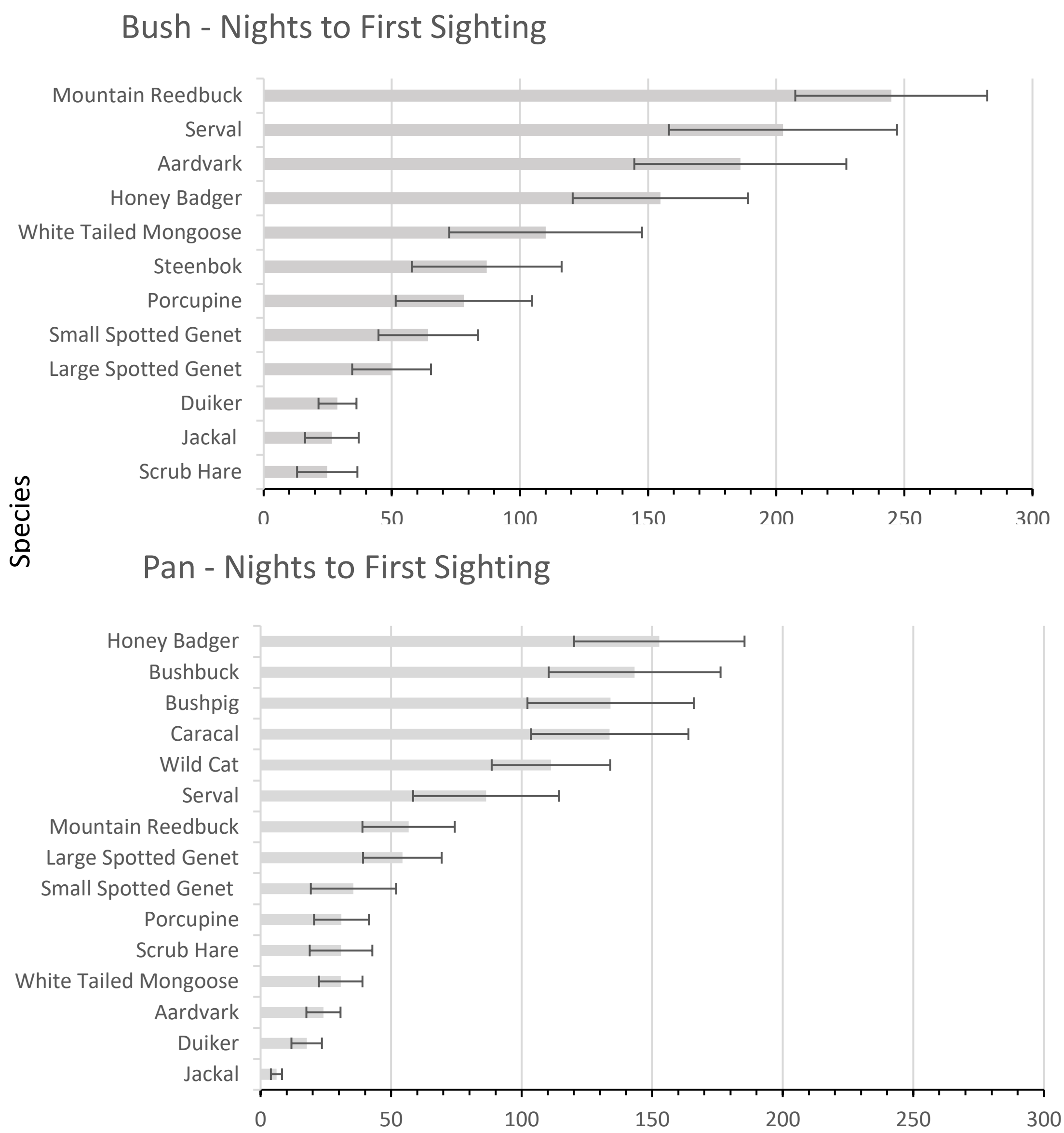


Figure 30: The mean number of trapping nights to the first sighting of a particular species, with graph (a) showing the results detected by pan placed camera traps. It was calculated from the original data set and the subsequent 25 randomised repeats. The error bars show the 95% confidence intervals for each of the species. Graph b) shows the mean number of trapping nights to the first sighting of a particular species, but detected by bush camera traps instead. The error bars also show the 95% confidence intervals.

3.1.5 – Discriminant Function Analysis (DFA)

A DFA was performed on the camera trap data to establish whether the species community differed substantially and consistently between pan and bush cameras. This was done to assess if DFA could be used to classify cases as pan or bush cameras based on the species community detected at a level notably higher than a prior chance, based on prior probabilities. If so, this would be evidence of cameras in different locations detecting different communities.

After a baseline model using all data had been calculated (as described in section 2.5.5), a stepwise analysis was undertaken to establish which specific species were driving these community-level differences. The species identified to be driving factors in the stepwise analysis were: jackal, porcupine and white-tailed mongoose, with jackal being the most important driving factor, then porcupine and then white-tailed mongoose (Table 9). Separate DFAs were then run on the models that were indicated by the output, so a DFA on only jackal, and then one on jackal and porcupine, and finally one on jackal, porcupine and white-tailed mongoose (Table 10). Each of these species were selected since they were detected at pan camera traps far more often than at bush camera traps, this disparity is shown in Table 11 below. As can be seen, each of the species had been seen at least 3 times as often on pan cameras as bush cameras.

Table 10: The stepwise analysis results from each of the steps described above. The prior possibility for these classifications was 55.6. (For more on cross-validation see section 2.5.5).

Model	**Species in Model**	**% Cross-Validated Overall Classification Accuracy**	**% Cross-Validated Classification Accuracy for Pans**	**% Cross-Validated Classification Accuracy for Bush**
Overall	All	66.7	37.6	90.0
Stepwise 1	Jackal	57.8	20.0	88.0
Stepwise 2	Jackal + Porcupine	67.8	27.5	100.0
Stepwise 3	Jackal+ Porcupine + White-Tailed Mongoose	71.1	40	96.0

Table 11: The number of times the species chosen by the DFA's occurred using each camera deployment.

	Number of Times Detected	
Species	**Bush Cameras**	**Pan Cameras**
Jackal	15	93
Porcupine	16	48
White-Tailed Mongoose	3	9

3.2 - Night Drive Analysis

3.2.1 – Species Accumulation Curves

Species accumulation curves were used to find out how many kilometers, cumulatively it took to see each number of cumulative species, similar to section 3.1.1 with camera traps.

Figure 33 below shows the species accumulation curve for the original night drive data. As can be seen by in the graph, the first 11 cumulative species were detected in under 2000 km, whereas the last 5 cumulative species took over 6000 km to detect.

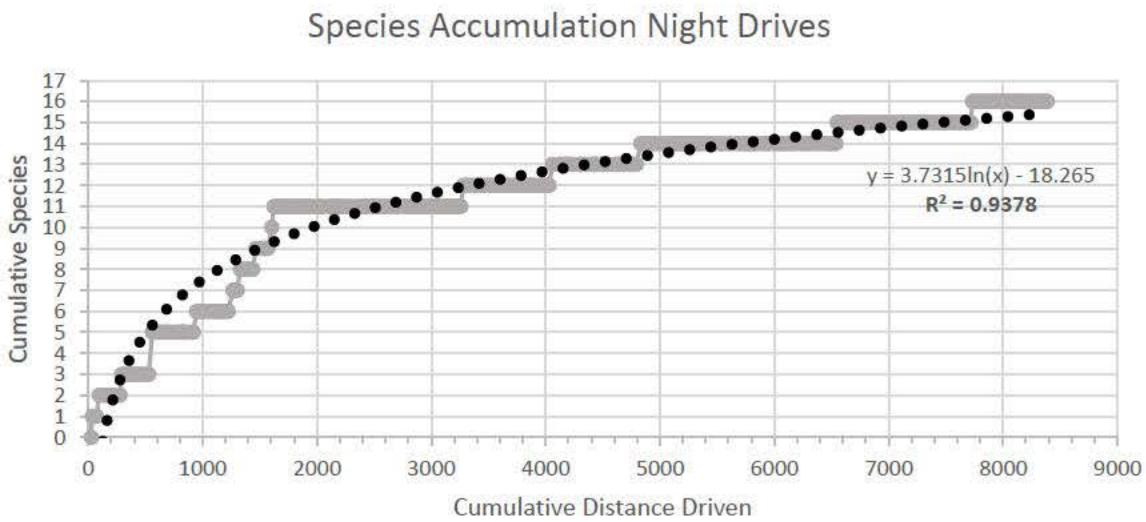


Figure 31: The species accumulation for night drives, the data set is shown in grey, with the logarithmic trendline shown in black. The equation of the graph is shown under the trendline, with the R-square value in bold underneath this.

3.2.2 – Randomisation of Data

Similar to camera trapping, after the initial species accumulation curve was completed for night drives, the data were randomised 25 times to give multiple replicates and allow calculations of means, range, SD and 95%CI (see section 2.5.2 for methods and rationale).

Similar to what was found with camera trapping there was some variation in the replicates, but most seemed to follow the same trend of the original data. Some replicated also had highly inconsistent patterns, with all species being found early with others showing that new species would sometimes be seen in 'clusters'. As with camera trapping, these different types of replicates are insightful when permutating data in this way as it shows the element of chance.

3.2.3 – Randomisation Analysis

As in section 3.1.3: range, standard deviation and 95% confidence analysis was calculated for night drives to allow the importance of chance species encounters to be considered. As displayed in Figure 34, there was a lot of variation in the species accumulation curves plotted using different randomised replicates of the same dataset. To draw out this variation, Figure 35 shows the results of the same analyses that were done on night drives. The range of the cumulative distance to each cumulative species, shown in Figure 35 (a), increased as the cumulative species increased, with many of the results overlapping, for example, the sixth species overlaps with the next four species, as well as the next two below, and this is repeated throughout the lower numbers. The higher species, whilst having higher ranges only overlap with one or two above and below.

This shows that the distance it takes to find the later species is more varied than with the initial species. The highest range occurred in species 16 with 5,991 km between the earliest sighting and latest sighting. The lowest difference in range was with species one with only 86 km separating the earliest and latest sightings.

Standard deviation also overlapped in night drives, shown in Figure 35 (b). Many of the lower cumulative species numbers overlapped with many of the other smaller numbers, whereas the higher numbers only overlapped with one number above and below. The highest deviation was in species 16 with 1886 km, while the lowest was in species one with only 51 km.

As with standard deviation, many of the smaller cumulative species numbers overlapped in their 95% confidence intervals, shown in Figure 35 (c) below, overlapping with the one above and below. The exception to this was the higher species numbers, 15th and 16th which did not overlap with any other species numbers, despite these being the cumulative species numbers with the highest 95% confidence values. The highest value was the 16th species with 725 km and the lowest being the first species with only 8 km.

(a)

(b)

(c)

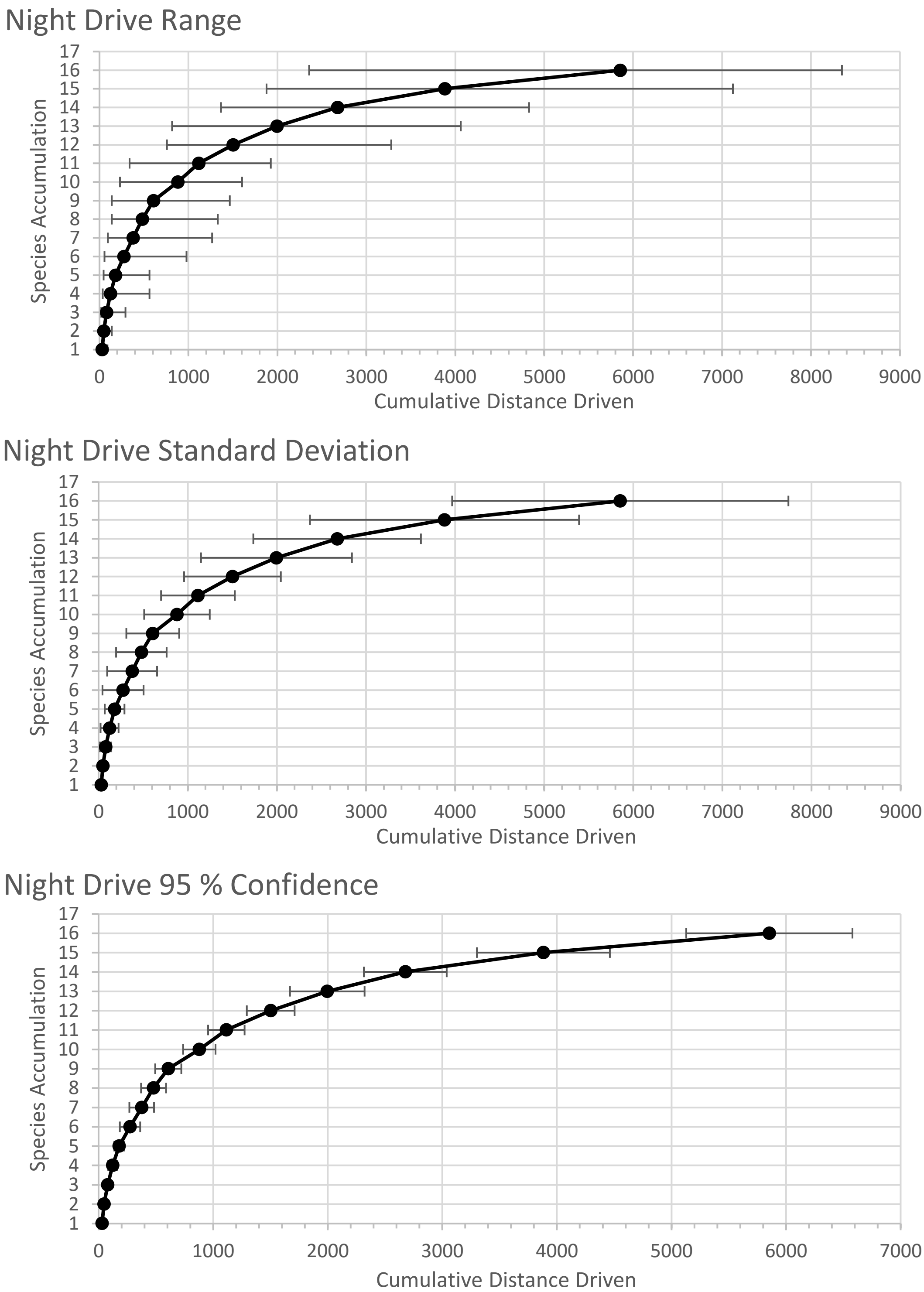


Figure 32: The analysis done around the mean of the combined data from the randomisation process and original dataset. Graph (a) shows the range around the mean. Graph (b) shows the standard deviation and graph (c) shows the 95% confidence intervals.

3.2.4 – Distance to First Sightings of Particular Species

There was a considerable amount of variation, not only between species accumulation curves as shown in the section above, but also between the amount of distance driven before specific species were encountered. To analyse this, as with camera trapping in section 3.1.4, the mean distance to the first time a species was detected, as well as 95% confidence was calculated and this is shown in Figure 36 below. The mean distance varied greatly, with the longest being 4,186 km for African civet and the shortest mean distance being 49 km for scrub hare. As well as this, 95% confidence intervals overlapped throughout, with the highest interval being 1,069 km with African civet and the lowest being only 8 km with scrub hare.

Civet took much longer to find on night drives than other species as its lower 95% interval for distance is over 3,000 km and this interval does not overlap with many other species. This is probably due to the rarity of the species on site, meaning that it takes more survey effort to encounter. The most common species with the shortest mean distance is scrub hare, as well as having the lowest 95% confidence interval which shows that it is the most likely species to be seen first. There also appears to be a slight jump from serval to aardvark, which indicates a "step-change" in the rarity of species, as the next species all start to take longer to see.

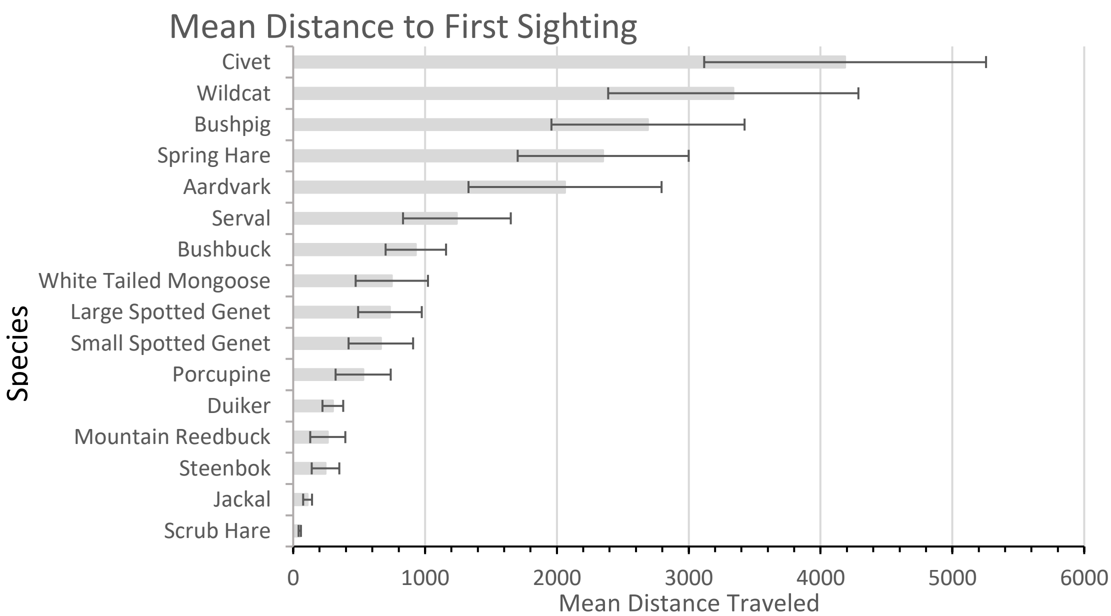


Figure 33: The mean distance to the first sighting of a particular species, detected by driven night transects. The error bars show 95% confidence intervals for each species.

3.3 – Ad hoc data

As mentioned previously ad hoc records discovered 16 of the 20 species historically found at Mankwe. Table 12 below shows how many times each of the species were seen during the study and compares this with the amount of times it was seen on night drives, with the percentage of these sightings against the total of all sightings. As can be seen, percentages of sightings of more common species such as jackal (15.92% and 16.56%), scrub hare (47.35% and 51.63%) and duiker were about the same between both techniques. Opposed to this, rarer species (such as the genets, aardvark, civet, and porcupine) had a high percentage of sightings in the ad hoc recordings than the dedicated night drives.

Table 12: How many times each species was seen by Ad Hoc and Night Drive recordings during the study period, as well as the percentage of this against all sightings of all species. If a species was not seen, it is marked with Not Found, with the percentage of that species showing N/A.

Species	How Many Times Seen By Ad Hoc	How Many Times Seen By Night Drives	Percentage Compared to All Sightings Ad Hoc (%)	Percentage Compared to All Sightings Night Drive (%)
Serval	1	6	0.41	0.78
Caracal	2	Not Found	0.82	N/A
Jackal	39	127	15.92	16.56
Hyaena	Not Found	Not Found	N/A	N/A
Small Spotted Genet	8	10	3.27	1.30
Large Spotted Genet	12	12	4.90	1.57
White-tailed Mongoose	1	6	0.41	0.78
Honey Badger	2	Not Found	0.82	N/A
Aardvark	5	3	2.04	0.39
Aardwolf	Not Found	Not Found	N/A	N/A
Scrub Hare	116	396	47.35	51.63
African Civet	8	1	3.27	0.13
Spring Hare	4	3	1.63	0.39
Cape Porcupine	24	13	9.80	1.70
Common Duiker	13	50	5.31	6.52
Steenbok	4	28	1.63	3.65
Bushbuck	4	13	1.63	1.70
Mountain Reedbuck	2	92	0.82	12.00
Bushpig	Not Found	6	N/A	0.78
African Wildcat	Not Found	1	N/A	0.13

4 – Discussion

This study found that there was no overall method that could be deemed solely the most efficient or even that one method was effective at surveying an overall nocturnal species inventory. Rather, it shows that multi-faceted methods will most likely be more effective, with the strengths of one complementing the weakness of others. Broadly, these findings agree with other studies that compare multiple methods (e.g. comparing sign surveys, spotlighting and audio playbacks (Thorn, *et al.*, 2010); comparing diurnal, nocturnal and camera trapping surveys (Munari, *et al.*, 2011)). However, this study found one thing that is in stark contrast with other studies in this area: spotlighting was found to detect the most species, and was efficient at discovering some of the less rare species.

4.1 - Are there differences in species frequency detection curve with survey effort across the different methods?

Four different methods were assessed in this study, and as much as possible these methods have been analysed and compared using species frequency detection curves, the only exception being the ad hoc observation as these did not contain a time or distance variable.

When looking at the original dataset for camera trapping techniques (section 3.1.1, Figure 7), pan-based cameras discovered four more species than bush camera traps and in a shorter amount of time, discovering them in 273 nights, whereas bush cameras reached 12 species in 347 nights. This shows that targeted camera traps placed at pans were more effective at discovering nocturnal species, as well as more efficient at detecting them, than cameras placed randomly in the bush.

Both camera-trapping deployment types failed to discover all 20 species of nocturnal animals that have been found at Mankwe and that were likely present over the study period (section 3.1.1, Table 7) Pan cameras detected four species that were not detected on bush cameras (caracal, bushbuck, bushpig and African wild cat), whereas bush cameras detected one species that pan cameras did not (steenbok). Species detection curves still showed an upward trend, indicating that if data collection continued, the other species would likely be detected eventually. These species are known to still be at Mankwe, as African civet and spring hare were discovered in night drives, some brown hyaena spoor had been detected on the reserve during the project and aardwolf were discovered on a different project that involved the use of randomly placed camera traps. Leopard, while seen previous on the site had not been discovered during the study and had last been seen in 2017.

Night drives discovered more species than both camera trapping techniques individually: 16 species in total versus, 12 (bush) and 15 (pan), with a collective 16 species between the two. As with camera traps, the line of best fit indicates that further data collection effort would likely lead to additional species being seen but with every increasing effort. The most efficient period of the night drive data collection seems to be in the first 2000 km where 11 species were discovered. It took a further 6000 km (three times the distance) to see the next five species (less than half the total found in the first 2000km). To find out which was more efficient, first of all cost of each methods need to be analysed.

The high number of detections by spotlighting is also in great contrast to some other studies such as Bearman-Brown, *et al*., (2020) where spotlighting was significantly less effective at detecting West European hedgehogs (*Erinaceus europeau*) in comparison to thermal cameras and specialist search dogs. This disparity could be due to a number of different reasons, one main reason could be, as described by Bearman-Brown, *et al.*, the fact that increased ground cover reduces detection distances and therefore number of detections, with the highest number of detections for this study coming from bare soil or mown grass. Since the grassland habitat of South Africa is starkly different, being much more flat and open than the jungle of the Amazon (Munari, *et al*., 2011) and woodland of the United Kingdom (Bearman-Brown, *et al*., 2020), it means that sightings using spotlighting at night are much more likely to happen. This difference shows the importance of testing out different methods in extreme differences in habitat, as one method that is not effective in multiple places may actually be much more effective in the right circumstances.

To quantify in terms of actual cost, how much it takes to find a specific species using both camera trapping and night drives, a base price first needs to be calculated. For camera traps, the base price is only the camera itself with a Bushnell Trophy Aggressor costing £199.99 (Cameraland, 2021). For night drives the base price is the is the spotlight costing £36.99 (Amazon, 2021), assuming that a vehicle is already available (as would be the case most of the time). The additional costs (consumables cost) associated with each method vary depending on how long it takes for species to be discovered. For camera trapping, consumables are batteries and for night drives the additional cost is fuel and mileage associated costs (degradation of brakes, tyres and so on). A camera takes eight AA batteries, a set of which costs £2.50 and lasts three deployments of 10 nights (so a total of 30 nights). Night drive costs are mostly are dependent on fuel. Allowing for fuel as well as tyre wear and tear, the standard fuel rate in the UK is 45p per mile (Gov UK, 2021), which converts into 72p per kilometre. This however only shows consistent driving and should only be a guide, as stoppage whilst identifying species take up time without moving.

Using these values per deployment and kilometre, prices for each different species can be calculated for each method. This is shown in Table 13 below. As can be seen, for the most part night drives are cheaper to discover species than camera traps, and this can be attributed to the expensive initial cost of the camera. However, as the distance gets higher, the cost of diesel takes over the expenses this point is once the cost of the night drive and spotlight gets over the cost of the camera trap and 1 set of batteries, this is because the cost of fuel overtakes the cost per set of batteries. This analysis, however does not take into account the amount of times a species was seen, for example, aardvark was only seen three times in night drives whereas it was seen a total of 26 times on pan cameras, therefore the efficiency on camera traps was better in terms of the rarer species. Species which would be more efficient for night drives would be more common ones, such as scrub hare, jackal, duiker and steenbok as they are seen often on both sides. Interestingly, mountain reedbuck were seen more often on night drives as well as being cheaper to discover. This may be due to night drives covering a lot more area and coming across more habitat of mountain reedbuck.

Table 13: Prices to the first time a species is discovered using the method set above. Some species were not found in some particular method and are shown as a N/A in the table.

Species	Price to Discovery using Bush Cameras (£)	Price to Discovery using Pan Cameras (£)	Price to Discovery Using Night Drives (£)
Jackal	202.55	202.55	67.51
Duiker	202.55	202.55	121.15

Aardvark	217.91	202.55	614.32
White Tailed Mongoose	210.23	205.11	246.40
Scrub Hare	202.55	205.11	50.91
Porcupine	207.67	205.11	185.56
Small Spotted Genet	207.67	205.11	223.08
Large Spotted Genet	205.11	205.11	242.45
Mountain Reedbuck	223.03	205.11	110.38
Serval	N/A	207.67	384.64
African Wild Cat	N/A	210.23	971.69
Caracal	N/A	212.79	N/A
Bushpig	N/A	212.79	790.67
Bushbuck	N/A	212.79	302.96
Honey Badger	215.35	215.35	N/A
Steenbok	207.67	N/A	105.59
Spring Hare	N/A	N/A	695.33
African Civet	N/A	N/A	1209.19

The distance that it took to discover all the species also shows that night drives overall are less efficient at detecting species since it requires so much effort in terms of time and mileage to produce these results, whereas camera traps require less effort to produce a similar result. Table 12 also shows that even is cost scenarios, the rarer species are much more expensive to discover than compared with camera traps. This is true for the species that were not even detected using night drives, as much more distance will be needed to find them, and thus even more money spent on fuel.

Interestingly more common species are much cheaper to discover when using night drives, this could be due to the fact that species such as jackal and scrub hare use roads as a main 'highway' of sorts when traveling to look for forage at night.

4.2 - How many nights does it take for all species in the nocturnal community to be detected using each technique?

No method discovered all of the nocturnal species that are known to be present. Out of all methods, night drives discovered the most with 16, with pan camera traps discovering 15 and bush cameras the lowest with 12. As for efficiency pan cameras require the least amount of researcher effort since it discovered more species that bush cameras in less amount of time. Cameras also requires less researcher effort than night drives as it is only the set-up, take down and analysis of photos, night drives require the observers' full attention, and being late at night, tired observers may have an effect on the efficiency of sightings. This is supported by Munari, *et al*. (2011) which also showed that well rested observers helped increase efficiency. To that end, in this study night drives were carried out as part of anti-poaching patrols that happen every night, and thus it may be more effective if spread out over different nights, with an observer that takes alternating nights off to be able to rest and approach the task afresh.

4.3 - Is one method the 'best'?

When comparing between both camera trapping methods, pan placed camera traps are the better option: they discover more species than bush cameras and at a greater rate. When looking at this at a species level, as shown in section 3.1.4, on average in the combined data, pans were quicker at detecting every single species except for scrub hare, and even the difference at this level is marginal, with the mean only differing by five trapping nights, which compared to the number of overall trapping nights is negligible.

Comparing this with night drives is tougher as the comparison between distance driven and number of nights is difficult to quantify. Instead, amount of researcher effort can be substituted for some of these comparisons. For example, in the case of rarer species, i.e. species that took either many nights or a large distance to discover, comparing the number of man hours needed to be put into discovering that species can be comparable. Aardvark for example, with night drives took a mean distance of over 2000 km to discover (section 3.2.4) whereas when camera traps are placed at pans, it took less than a mean of 30 nights. If four cameras are left out for 10 nights at a time at pans, as described in this study, then aardvark will likely be discovered for the first time in the first set of traps. Compare this to night drives, driving non-stop at an average of 20 km/h it would take an average of 100 hours to see an aardvark.

In contrast, when looking for more common species such as jackal for example, one is likely to discover them on both techniques very early as well as discovering them many times as they come to pans often (Kasiringua, *et al*., 2017; section 3.1.5 - Table 9 showing that jackal was the greatest influence on whether or not a case was a pan or a bush site), as well as using roads as efficient travel routes. In this case, night drives may be a better option since it is less expensive to run, and the encounter rate is similar to that of camera trapping.

4.4 - Do the four methods start to give similar results and if so, how long does it take for this to happen? Do the camera trap methods converge before the others?

Overall between camera trapping and night drives, night drives and pan cameras were the two methods that seemed to begin to give similar results, but over different scales of effort. Both, pan cameras and night drives had an initial period where many species were discovered in relatively short succession, and then larger gaps between the discovery of new species occurred. Contrary to the question 4.5, the largest difference was actually between bush cameras and pan cameras, this could be attributed to a number of different things.

One of the main differences between camera trap deployment types is down to the particular species that most commonly use these areas around the study site. This is particularly shown by the DFA in section 3.1.5, where jackal, porcupine and white-tailed mongoose are the key driving factors when identifying between bush cameras and pan cameras. This is in contrast to some studies, such as Cusack, *et al*., (2015), where all three of these species were more commonly found on game trails than in random locations. One explanation for this difference between Cusack *et al*., and this study is here different types of locations around the generated point are used to put the camera up, not only game trails, and thus the game trail results could be being masked by the other types of locations used such as open areas and thickets.

One aspect that could be driving this is that pans are a mainstay water source on the study site, which may mean that species in general are more likely to visit them, as well as visit them on more occasions, than a location in the bush. The only exception to this would be if the bush location is close to a burrow, for example, and that particular species uses that route often, purely because of its proximity to the animals sleeping place. The reason why night drives found more species than bush cameras can also be attributed to the fact that dirt roads are transportation centres and facilitate movement for animals (cougars (*Puma concolor*) in Dickson, *et al*., 2012; kangaroo rat (*Dipodomys stephensi*) in Brock and Kelt, 2003; multiple species in Bitetti, *et all.*, 2014). Brock and Kelt shows this especially, showing that kangaroo rats were more active on dirt roads compared to gravel roads and even when grassland habitat was adjacent to the road.

Despite all this, the bush placed camera traps detected more species than expected since these camera traps are not targeting areas that are more likely to yield detections, the fact that the bush placed camera traps discovered more than 50% of the species, including many rare species, such as serval, aardvark and honey badger, as well as detecting steenbok which pan cameras did not discover may indicate that these procedurally generated locations are somewhat effective in discovering species. This echoes the results found by Gray (2018) where he used randomly deployed cameras to monitor forest ungulates and discovered many mammalian species as well as many IUCN Threatened mammals, such as clouded leopard (*Neofelis nebulosa*), sambar deer (*Rusa unicolor*) and asiatic black bears (*Ursus thibetanus*).

This is also supported by Cusack, *et al*., (2015) in Southern Africa who showed that the choice of placement between random vs trail based cameras did not seem to affect the overall community structure, as well as having a similar case, where both types of deployments did not detect all species known to be in the area, with both species lists overlapping, but also containing species that were detected on one and not the other, such as African wild dogs (*Lycaon pictus*) being detected by trail cameras and ground pangolins (*Smutsia temminckii*) by the random cameras. Cusack, *et al*. went as far as suggesting that if extensive surveys could be conducted (> 1400 trapping nights) randomly placed cameras may even yield a more complete list of species, whilst also suggesting that researchers with less time or not many camera traps available, trail based cameras would produce more detections more rapidly.

4.5 – Ad Hoc Recordings

When compared to dedicated night drives, ad hoc records had a higher percentage of discoveries of rarer nocturnal species, such as porcupine (9.80% ad hoc, 1.70% night drive), large spotted genet (4.90% ad hoc, 1.57% night drives). These numbers, however, may be skewed due the low number of points in the dataset. One aspect that was unexpected was the amount of recordings of the more common species. For example scrub hare and jackal were the most common species recorded, with scrub hare the most at 47.35% of all recordings and jackal second most at 15.92 recordings. One possible explanation for this is that some of the observers were current or previous researchers and so understood the importance of data collection. Another explanation could be that they are extremely common, and not all were recorded due to boredom of constantly having to stop to record these species, meaning these numbers may in fact be still underrepresenting the number of actual sightings by all observers.

One disparity between the two methods is the number of sightings of mountain reedbuck, where only 2 were seen by ad hoc, and 92 were seen by dedicated night drives. One explanation for this could be that observers found it difficult to differentiate between mountain reedbuck and common reedbuck (*Redunca arundinum*) which are very similar in shape and size, with mountain reedbuck being marginally smaller, with smaller horns. This meant that observers chose not to record the species as it was incorrectly identified as a common reedbuck. Similar to this, the numbers for small spotted genet and large spotted genet may be incorrect as for an inexperienced observer, it is difficult to distinguish between the two species, as shown in section 2.4, with Figure 24 and 25.

Through literature research on the topic of ad hoc recordings being used in species detection and species lists, no data for this topic, in Southern Africa has been published, even though many private reserves and national parks have species sightings books or groups that continually record information of times and places of sightings of many different species. For example, Latest Sightings – Pilanesberg, is a WhatsApp group and Facebook page (Facebook, 2021) that visitors of Pilanesberg National Park (Northwest Province, South Africa) can report sightings of any species or events they see while in the park. More work needs to be done to understand what these types of ad hoc recordings can be used for, and whether or not these data are reliable.

As said above, ad hoc recordings found the same amount of species richness, as night drives which shows that they are somewhat reliable for detecting species on a site, which shows some degree of reliability, however, since there are differing levels of knowledge in identification of some species, some may be misidentified and therefore the data may be unreliable. One way around this could be the use of larger datasets, giving more chances of more experienced observers of correctly identifying species.

4.6 – Limitations

One main limitation of this study is that camera trapping had a relatively low sample size, as well as a differing amount of deployments for each deployment method, with pan cameras having 46 deployments, whereas bush cameras had 50 deployments. This is counterbalanced however as this is a comparative study, and as such we can look at rates of discovery to help counteract this imbalance of data.

As well as this, many of the night drives began at the same time, due to this study being conducted as part of the deployment of anti-poaching teams and anti-poaching patrols. Since the teams were deployed at similar times every night, the number of drives may skew what species were detected as some individuals may be active at different times during the night.

A further limitation is that this study only looks that the effectiveness of these methods in a savannah ecosystems and as such all of these methods need to be tested and compared in other ecosystems. As well as this other savannah sites need to be assessed to confirm the results found here are the same as other sites that may have more predators or large herbivores such as lions (*Panthera leo*), elephants (*Loxodonta africana*), hippo (*Hippopotamus amphibius*) etc.

Lastly, while this study is good for detection of species, it is tough to estimate populations using these data as without spatial data, it is difficult to infer if you have potentially seen the same individual or not.

4.7 – Recommendations

Moving forward, this study suggests that when conducting species surveys, there may not be one particular method that is best overall when it comes to detecting all the species that may be located on a site, and a combination of different methods may be the best course of action. As mentioned by Cusack, *et al*. if restricted by time for camera trapping, pan cameras may be the best deployment type to use as it yields the most species when compared to bush cameras. This may also be the best option for low timescales in general, such as a very quick survey of a site for potential species located there, since it takes large amount of distance to discover many species with night drives. If researchers have more time to conduct surveys, then a combination between the bush deployments and pan camera deployments will potentially yield the most species as the randomness of the bush points could assist in seeing some other species (Cusack, *et al*., 2015; Gray, 2018), this will also end up cheaper to run in the long term, as shown by Table 12, when the distance gets very high the cost to run night drives becomes more and more expensive.

Table 14 below shows some of the advantages and disadvantages of each of the methods evaluated in this paper.

Table 14: The advantages and disadvantages of each of the methods tested in this study.

Method Tested	Advantages	Disadvantages
Dedicated Night Drives	~ Good for detections of common species such as jackal, scrub hare, ~ Cheap initial cost to run as use of vehicle and spotlights only needed. ~ Good spatial coverage	~ Expensive in the long run as dependent on fuel to run. ~ Finding more 'rare' species has a high element of chance involved. ~ Poor temporal coverage over any 'single' location
AD Hoc Night Records	~ Continuous data collection as it can be recorded outside of any research project ~ Can be recorded by anyone at any time ~ Minimal cost as it is during other activities	~ Potential for misidentification of some species due to similarities with others with inexperienced spotters ~ Bias towards more novel species over more common species
Targeted Camera Traps	~ Allows for season recordings at the same site	~ Bias data to one habitat or individual territory.

	~ High chance of success as many animals are water dependent – especially during the dry season ~ Usually easy location to access. ~ Excellent temporal coverage of one location.	~ Expensive up front cost, as well as batteries in the long run. ~ Limited behavioural and habitat utilization monitoring as location is fixed. ~ Poor spatial coverage
Random Camera Traps	~ Covers a wide range of habitats and territories. ~ Good for species that are not water dependent	~ High rate of false triggers due to environment. ~ Lower success rate due to placement not targeted specifically for nocturnal species

Future researchers can build from this study in a number of ways, one suggestion is similar repeats of the study, but expanding it to multiple sites located in savannah habitats as well as repeating the study in different habitats, such as forest to evaluate whether or not it is as effective. As well as this, studies should aim to achieve more trapping nights to further evaluate whether or not the different deployment types converge on data gathered in the long term. In addition, this study highlights the need, as with any survey or monitoring programme, for design of the research question and methods to be carefully considered, in cost, effort and the ability to be replicated. As mentioned by Wilcox *et al*. (2019), Meek *et al*. (2014) and Smith *et al*. (2016), having standardised, high quality methods are important for this as to allow for the comparison of different sites when doing surveys as well as having data that is suitable for analysis.

Furthermore, the surprising findings that ad hoc night drive recordings produced a high number of different species detections over a period of time highlight the amount of data that is recorded in sightings books in reserves around the world. These findings echo that of Tantipisanuh and Gale (2018) in Thailand, that unpublished data can hold key information on where to find 'hotspots' of particular species or groups of species.

5 – References

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