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Factors that affect owl ecology in an agricultural matrix in east Gauteng

by

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SUMMARY

Factors the affect owl ecology in an agricultural matrix in east Gauteng

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Anthropogenic impacts are extensive and affect species at individual and population levels as well as communities. To understand these anthropogenic impacts we have to understand various factors, such as agriculture, and the expansion of roads and how these affect populations, species and communities. The Boesmanspruit Highveld Grassland ecosystem, between Springs and Devon, Gauteng, is a critically endangered ecosystem, dominated by agriculture in the area, urbanisation and extensive road networks. The agricultural crops include maize, soya beans, and cultivated fields for animal feed. The region also contains the vulnerable African grass-owl (*Tyto capensis*), and three other owl species namely, the western barn owl (*Tyto alba*), the spotted eagle-owl (*Bubo africanus*) and the marsh owl (*Asio capensis*).

The extensive road network, and particularly the N17 highway in this area have resulted in continued owl roadkills in the area. During 2002-2003 an average of 9.2 dead owls per kilometre per annum was reported. Various factors contribute to these high mortality

numbers, one being that maize trucks carrying grain along the N17 may spill grain onto the road, which lures rodents to feed on the waste and in turn attracts owls to the road where they can easily hunt, putting the owls in danger of being struck by vehicles at night.

The aim of this research was to assess the species of owls in the area and their abundance, estimate their occupancy and unpack the ecological and anthropogenic factors that may be driving owl occupancy in the area. Road surveys were done for 5 nights, in October 2018, January 2019 and April 2019 allowing for a 15 night occupancy estimate. Only three of the reported four owl species were found, namely the western barn owl, the spotted eagle-owl and the marsh owl. The data collected during these surveys were used in an occupancy model to determine the occupancy of owls in the area, providing an estimate of 0.817 (SE = 0.102). The abundance was determined to be approximately 2 owls per 4 km^2 (SE = 1.21). Covariates were also used to assess the factors that may be affecting the high occupancy of owls in the area. The covariate that had the greatest effect on the occupancy of owls in the area was water sources. With water sources incorporated into the models, occupancy increased to 1 (SE = 3.427×10^{-16}) from the initial 0.817. This increased the abundance estimates to approximately 6 owls per 4 km^2 (SE = 3.091). Comparing occupancy across the different months that were sampled, it was found that owl occupancy was highest in October 2018 at 0.996 (SE = 0.155), and lowest in April 2019 at 0.526 (SE = 0.173).

Food resources are a key driver for owl occupancy. Rodent communities and density was assessed in the area. The rodents caught were mostly *Mastomys* species (92%) and the remaining rodents were identified as *Rhabdomys dilectus* (8%). Up to 55 rodents were caught in a hectare, with the highest number of rodents caught in the April 2019 sampling and the lowest number of rodents caught in the October 2018 sampling. The abundance of rodents increased as the height of the crops increased and fields where soya beans were being grown had the largest number of rodents.

Comparing the species caught in the live traps of the rodent survey with an unpublished small pellet analysis done in the area, the barn owls regurgitated pellets contained four species of small mammals (*Otomys* spp., *Gerbilliscus* spp., *Mastomys* spp. and a shrew species *Myosorex* spp.), while only two rodent species were trapped in the fields.

The asynchronous owl-rodent abundance reported in the study indicate that the three owl species are likely more driven by habitat availability and nesting opportunities, rather than purely by food availability. It is therefore important that the owl breeding seasons, and in particular grass-owl breeding seasons are taken into consideration when managing agriculture in the area. It is also important that when making decisions on where to build new infrastructure, areas where owls may be more likely to nest should be avoided. It should also be noted that where rodents are being controlled by ecologically based methods, such as by owls, it is likely that these methods alone are not effective enough to control the levels of rodents in the area. Therefore, it is important that other ecologically responsible methods of rodent control are used in the area.

DECLARATION

I, Caroline Grace Hannweg, declare that the thesis/dissertation, which I hereby submit for the degree Master of Science in Wildlife Management at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ....

DATE: ..15..NOVEMBER.........2019.....

Disclaimer:

The dissertation consists of a series of chapters written in a format for journal manuscript submission. Chapter 2 has been prepared for submission to the Journal of Wildlife Management. As a result, the format of Chapter 2 may vary from other chapters. Some replication will also occur between chapters.

Chapter 1: Introduction

Anthropogenic effects have a large impact on wildlife throughout the world (Rands et al. 2010). These effects are the result of urbanisation, afforestation, mining and agriculture and leads to effects such as habitat loss, degradation and fragmentation (Hockey et al. 2005, Scheun et al. 2015, Taylor et al. 2015, Mamba et al. 2019).

Agriculture in particular affects wildlife in a number of ways, including wetland draining, grazing, ploughing, fencing and burning (Hockey et al. 2005, Muck and Zeller 2006, Taylor et al. 2015). Agriculture also creates heterogeneity in environments (Mamba et al. 2019). This allows for pioneer and generalist species to make use of the land that specialist species may not be able to make use of anymore (Mamba et al. 2019). This wildlife then has the potential to become an agricultural pest as they can utilise and take advantage of the available resources in an agricultural landscape (Swanepoel et al. 2017, Mamba et al. 2019). This then not only excludes specialist species from this land, but also creates issues for humans, by damaging crops, spreading zoonotic diseases and occasionally destroying infrastructure (Brown et al. 2007, Mdangi et al. 2013, Swanepoel et al. 2017, Mamba et al. 2019). While there are many methods of pest control which do not damage other wildlife, if used incorrectly these can have a negative effect on non-target species in the area, either directly or through secondary poisoning (Paz et al. 2013, Geduhn et al. 2015, Serieys et al. 2019).

Another anthropogenic factor that has an effect on wildlife is roads (Ansara 2004, Collinson et al. 2015, Kioko et al. 2015, Williams et al. 2019). Roads affect wildlife by habitat degradation and fragmentation and also by limiting access of animals to certain resources (Gomes et al. 2009, Collinson et al. 2015, Williams et al. 2019). However, one of their biggest impacts is roadkill (Ansara 2004, Kioko et al. 2015, Williams et al. 2019). Nocturnal animals, such as serval (*Leptailurus serval*) and owls, are especially vulnerable to being struck by vehicles as driver visibility is low at night and nocturnal animals are vulnerable to being blinded by car lights on roads at night, and may also have trouble escaping as reflectors on roads can blind them (Tarboton and Erasmus 1998, Gomes et al. 2009, Kioko et al. 2015, Williams et al. 2019). Owls are one of the most common families of animals killed on roads (Gomes et al. 2009, Williams et al. 2019).

In South Africa, the Highveld grassland area in the east of Gauteng is one of the most transformed landscapes in South Africa (Grobler et al. 2006, Avenant 2011). It has many busy regional roads running through the area, including the N17 highway which runs from Johannesburg (Gauteng) to Oshoek (Mpumalanga), and runs through large areas of agriculture between Springs and Devon in Gauteng. It is made unique by the fact that historically, it is the ideal habitat for a number of owl species, most notably, the African grass-owl (*Tyto capensis*), an owl that is currently listed as regionally Vulnerable by the regional IUCN Red List assessment (Taylor et al. 2015). Additionally, the study area falls within the Boesmanspruit Highveld Grassland ecosystem, a critically endangered ecosystem (SANBI 2013). Grass-owls nest on the ground in grass patches (Tarboton and Erasmus 1998, Hockey et al. 2005, Taylor et al. 2015). Main threats reported by Taylor et al. (2015) include habitat loss, while intensive grazing (trampling) and early and unplanned fires may compromise breeding success. Furthermore, the Gauteng population also experience road fatalities which contribute to high levels of mortality (Ansara 2004, Taylor et al. 2015). Specifically, African grass-owls require rank grassland near wetlands and water sources, for nesting. The wetlands and water sources which are historically found in the area between Springs and Devon do provide habitat for grass-owls, but historic and current extensive agriculture and urbanisation in the area has degraded and fragmented these habitats, leading to the critically endangered listing of the ecosystem (SANBI 2013, Taylor et al. 2015). Another owl regularly reported in the study area, the marsh owl (*Asio capensis*), also nests on the ground, experiencing similar threats as the grass-owl (Tarboton and Erasmus 1998, Hockey et al. 2005). Two species regularly reported in the area, the western barn owl (*Tyto alba*) and spotted eagle-owl (*Bubo africanus*) are more general in their nesting habits. The area is reported to have a high abundance of multi-species of owls (Ansara 2004). Thus, it is possible for the increased competition for food and resources to likely competitively exclude the more sensitive grass-owls out of the area (Wiens et al. 2011, 2014, Kajtoch et al. 2015).

In this area between Springs and Devon, along the N17 highway, there are have been many reports of large numbers of owl roadkills with an average of 9.2 dead owls per kilometre per annum reported in a study done in 2002 and 2003 (Ansara 2004). Such a major road brings through large amounts of fast moving traffic, and with large numbers of owls in the area there is the risk of them being hit by vehicles (Williams et al. 2019). A theory has been put forward that the reason for this high number of owl roadkills is the transportation of grain in the area (Ansara 2004). The agriculture in the area consists mostly of maize (*Zea mays*) and soya beans (*Glycine max*) (Cowling et al. 2004). Trucks transport the grain from the farms in the area to nearby silos. However, some of the local farmers in the area speculate that there is often an issue of the trucks not transporting grains in an appropriate manner or being in poor condition and as a result spill large amounts of grain onto the roads (Ansara 2004, Gangadharan et al. 2017). Generalist rodents will utilise the grain on the roads or next to the roads as it is plentiful and easily accessible (Ansara 2004, Gomes et al. 2009, Williams et al. 2019). This in turn attracts owls to the roads because of easy hunting opportunities (Ansara 2004).

Another factor may be the surrounding habitat (Gomes et al. 2009, Williams et al. 2019). For example, if a road crosses a wetland or lies next to a wetland, it may be that more owls that prefer wetland areas, such as the African grass-owls, will be found along this road. A study done on servals from 2014 – 2017 along 410 km of the N3 highway between

Johannesburg, Gauteng and Durban, Kwa-Zulu Natal, found that season, habitat type and rodent abundance had a significant effect on the number of servals killed in the area (Williams et al. 2019). Similarly, in Japan and North America other mammal species were also found to have increased numbers of roadkill deaths when the roads were in and around their preferred habitat, and in Portugal the same was found for owls (Saeki and McDonald 2004, Beaudry et al. 2008, Gomes et al. 2009). A final factor is that owls are perched so often because, unlike diurnal raptors they cannot use air currents and thus need to conserve more energy (Gomes et al. 2009). Owls then require more perches, and these are often fence poles and telephone poles which are often along roads (Gomes et al. 2009).

For many species, fencing, overpasses and underpasses are recommended to mitigate roadkills (Collinson et al. 2015, Williams et al. 2019). However, this is not a viable option for animals with flight such as owls. Not only does it not stop owls from getting to the roads, it can also cause casualties when owls fly into and are caught in fences (Hockey et al. 2005, Taylor et al. 2015). A mitigation strategy for owl roadkills is to reduce the vegetation next to roads so as to avoid ideal rodent habitats which may attract owls to the roads to prey on them (Williams et al. 2019).

Apex predator conservation is key to successful ecosystem service integrity and resilience. It is particularly important to conserve these owls due to the fact that they also contribute to ecological rodent control (Paz et al. 2013, Labuschagne et al. 2016). Ecologically based rodent management (EBRM) is a rodent management system that employs a number of methods to ecologically control rodents. This can be in the form of natural predation of animals such as owls on rodents, to help keep rodent population numbers under control (Paz et al. 2013, Labuschagne et al. 2016). Owls control rodent pest problems and agriculture provides the owls with prey (Ojwang and Oguge 2003, Paz et al. 2013, Labuschagne 2015). This allows farmers to control rodent numbers in an ecologically responsible way, as many other control methods, such as chemical rodenticides, have negative effects on wildlife (Labuschagne et al. 2016, Swanepoel et al. 2017, Serieys et al. 2019). It is particularly important that responsible rodent control is employed in this area as more responsible ecologically friendly farming practises have ecological benefits (Crowder et al. 2010), especially considering the already critically endangered Boesmanspruit Highveld Grassland, and the Blesbokspruit Highveld Grassland nearby, both of which are critically endangered ecosystems (SANBI 2013).

In order to assess the broader context of the continued owl road mortalities in the study area, it is important to know what factors are affecting why the owls are there before the matter of how to mitigate these deaths can be discussed (Gomes et al. 2009). For this reason, it is important for the broader system to be assessed and considered. This includes the factors that are affecting the rodent populations in the area and how this could be affecting how the owls in the area use this system. Further it includes which rodent and owl species are present and how they are interacting with each other.

With this in mind the aim of this study is to estimate the occupancy and abundance of the owl species in the study area. The first aim is to see which factors are affecting the occupancy and abundance of the owl populations in an agricultural matrix. In doing this I hope to better understand what contributing ecological and anthropogenic factors allow for the reported high abundances, and what species are being found in the area.

I will also investigate how rodent community and density changes throughout the year within this agricultural matrix, and how the owls may be using this prey source as another aspect that could potentially affect their occupancy and abundance.

With these aims I will discuss the project within the following research chapters: “Assessing rodent community structure and densities in an agricultural matrix in the north-east of the Sedibeng district in Gauteng” (Chapter 2); and, “The biological and environmental factors affecting owl occupancy in an agricultural matrix in the north-east of the Sedibeng district of Gauteng" (Chapter 3).

STUDY SPECIES

In southern Africa there are 13 species of owls (Sinclair and Ryan 2010, Chittenden et al. 2016). The majority of owl species are known as nocturnal birds of prey that are well known as exceptional hunters. They have strong feet and sharp talons for catching prey with zygodactyl feet allowing them to increase the surface area of their feet which helps them catch prey (Hayman et al. 1994, Kemp and Kemp 1998, Loon and Loon 2005). Their eyes are specially adapted for hunting at night by being able to dilate their pupils more than diurnal birds, more light sensitive rods than diurnal birds and large forward facing eyes for binocular vision (Hayman et al. 1994, Kemp and Kemp 1998, Loon and Loon 2005). In general, owls have an exceptional sense of hearing, with large facial discs which directs sound to their ears which have large openings and are asymmetrical, with one positioned slightly higher in the skull than the other, allowing them to more accurately locate where sound is coming from (Kemp and Kemp 1998, Loon and Loon 2005). Owls that hunt small mammals have very soft feathers, with fringes on the edges of them, which allows for silent flight which is essential for hunting at night (Hayman et al. 1994, Loon and Loon 2005, Jiguet and Audevard 2017).

Owls regurgitate food matter than they are unable to digest in the form of pellets (Loon and Loon 2005). Indigestible particles collect in the gizzard of the owl and are then regurgitated. These regurgitated pellets provide a rare insight into what owls are eating and the pellets often contain many bones as well as insect remains or seed husks (Avenant 2005). Because owls consume their prey whole, whole skulls are often found which allows one to identify the species of vertebrates the owls are eating (Loon and Loon 2005).

Owls specific to the study area are the western barn owl (*Tyto alba*), the spotted eagle-owl (*Bubo africanus*), the marsh owl (*Asio capensis*) and the African grass-owl (*Tyto* *capensis*) (Ansara 2004). These owls vary in size and weight and use various hunting methods and breeding methods (Ansara 2004, Chittenden et al. 2016).

Owls in Africa fall into two families specifically Tytonidae and Strigidae. Tytonidae includes owls with a heart shaped facial disc and a solid sheet of bone in the middle of their faces, and this means they have downward-facing bills as opposed to forward facing bills (Kemp and Kemp 1998). The Strigidae family are owls with ear tufts and forward-facing bills (Kemp and Kemp 1998). In this study area, the spotted eagle-owl and marsh owl are from the Strigidae family and the barn owl and the African grass-owl are from the family Tytonidae (Kemp and Kemp 1998).

The smallest of these owls in the study area is the barn owl (Tarboton and Erasmus 1998). This owl has a rounded, heart-shaped face which it uses for channelling sounds to its ears for hunting its prey (Tarboton and Erasmus 1998). It is commonly associated with man-made structures as it is comfortable using hollows in these structures for nesting, and hunting for prey in urban areas and around human settlements (Tarboton and Erasmus 1998, Hockey et al. 2005, Chittenden et al. 2016). Barn owls nest in cavities in buildings and often in old hamerkop nests or even old sociable weaver nests (Hockey et al. 2005, Loon and Loon 2005, Chittenden et al. 2016). Barn owls are strictly nocturnal, emerging at dusk and returning to their roosts or nests before dawn (Tarboton and Erasmus 1998, Hockey et al. 2005). Barn owls consume mostly small mammals and this makes up 75-97% of their diet, with the rest of the diet mostly made up of birds and insects. They are also known to eat bats, frogs and lizards, depending on what is available (Tarboton and Erasmus 1998, Hockey et al. 2005, Chittenden et al. 2016, Hodara and Poggio 2016). In savannah regions, barn owl diets are usually dominated by *Mastomys* species (multimammate mice) (Tarboton and Erasmus 1998). Barn owls lay eggs throughout the year but with a peak from March to May with an increase in populations from April to June, and chicks will begin flying at around 50 days after hatching (Tarboton and Erasmus 1998, Parker 2005). Barn owls practise asynchronous hatching, where the eggs hatch one at a time and thus the nesting owls always have different sized chicks (Tarboton and Erasmus 1996, Chittenden et al. 2016). This means when food is scarce, larger chicks may eat smaller ones (Hockey et al. 2005). Barn owls are well known for "boom and bust breeding" where numbers of owls breeding successfully increases dramatically, followed by periods of a decline of successful breeding (Tarboton and Erasmus 1998, Hockey et al. 2005, Parker 2005). This is most often associated with February to May in southern Africa when there are often irruptions of small mammals such as *Mastomys* species (Tarboton and Erasmus 1998, Hockey et al. 2005). When barn owl populations are at their strongest brood sizes can reach up to 10 chicks and up to 4 broods per year (Hockey et al. 2005). Their range is approximately one bird per 192 ha, but they can nest up to 50m apart in boom years (Hockey et al. 2005, Parker 2005). Barn owls will hunt at least 2 to 16 kilometres from their nest (Hockey et al. 2005). Their pellets are short and fat and are often shiny with mucous, around 45 x 25 mm (Kemp and Kemp 1998, Tarboton and Erasmus 1998).

Another owl commonly found near manmade structures is the spotted eagle-owl (*Bubo africanus*) (Tarboton and Erasmus 1998, Hockey et al. 2005, Chittenden et al. 2016). It is the largest of the four owls found in the study area and is different from the other three owls in the area, in that it is very spotted and has typical owl ear feathers (Hockey et al. 2005, Chittenden et al. 2016). They are often found in areas with human activity and can nest in manmade structures and hunt near human activity (Tarboton and Erasmus 1998, Hockey et al. 2005, Chittenden et al. 2016). Hunting takes place from perches especially next to the road, but they also occasionally chase prey on the ground putting them in danger of roadkill accidents (Kemp and Kemp 1998, Hockey et al. 2005). Their diet consists of insects, small birds, and small mammals (Hockey et al. 2005, Chittenden et al. 2016). Spotted eagle-owls lay eggs throughout the year with an increase in laying from June to November, with the maximum number of eggs reported between August and October (Tarboton and Erasmus 1998, Hockey et al. 2005, Parker 2005). The chicks then begin to fly around 40 days after hatching (Tarboton and Erasmus 1998, Hockey et al. 2005). Their home range size is reported from 1 pair per 6200 ha to 1 pair per 190 ha in central Mozambique, and were found to nest on average 1.44 km apart in Pretoria, with nests up to only 500m apart (Hockey et al. 2005, Parker 2005). Their regurgitated pellets are around 35 – 100mm x 18 – 35 mm (65 x 25 mm) (Tarboton and Erasmus 1998, Hockey et al. 2005).

The third owl found in this area is the marsh owl (*Asio capensis*) (Ansara 2004, Chittenden et al. 2016). Like the barn owl, the marsh owl has a rounded face but is a much darker brown, not white, colour (Tarboton and Erasmus 1998, Hockey et al. 2005, Chittenden et al. 2016). Like the spotted eagle-owl it has ear tufts, but they are very small and sometimes not visible (Hockey et al. 2005). It is a medium sized owl that nests in grass and despite their names, the marsh owl prefers drier grass for nesting than the African grass-owl (Tarboton and Erasmus 1998). Marsh owls are also often found in crop lands and are very sensitive to drought, and vulnerable to flooding, burning, and grazing and trampling (Kemp and Kemp 1998, Hockey et al. 2005). They nest in shallow nests under grass tufts (Chittenden et al. 2016). They will often rest on perches or on the ground while hunting (Kemp and Kemp 1998, Hockey et al. 2005, Chittenden et al. 2016). Marsh owls are often seen flying before dusk already hunting, and they are the only owls in Africa that do this (Kemp and Kemp 1998, Sinclair and Ryan 2010). They sometimes roost in flocks and are considered gregarious to an extent, gathering in groups of up to 50-75 owls (Hockey et al. 2005, Sinclair and Ryan 2010). They often favour *Otomys* species (vlei rats) in their diets, but also hunt other species of rodents including *Mastomys* species and *Rhabdomys* species, insects and birds (Kemp and Kemp 1998, Hockey et al. 2005). Egg laying mostly happens in the dry season, specifically

March to May, but they can lay eggs throughout the year (Tarboton and Erasmus 1998, Hockey et al. 2005, Parker 2005). Fledglings will begin to fly about 35 days after hatching (Tarboton and Erasmus 1998, Hockey et al. 2005). Marsh owl regurgitated pellets are long and twisted, around 60 x 10mm, and may resemble the scat of a carnivore underneath their roost perch (Kemp and Kemp 1998, Hockey et al. 2005).

The African grass-owl is a rare and difficult owl to see (Hayman et al. 1994, Chittenden et al. 2016). They are very similar in appearance to the barn owl with a white, disc shaped face but with a much darker back (Hockey et al. 2005, Sinclair and Ryan 2010, Chittenden et al. 2016). They prefer to nest in rank grass near wetlands or drainage lines, specifically in *Stenotaphrum* species (grass) and *Juncus* species (sedge) or in *Imperata cylindrica* in areas with 700 – 800mm of annual rain (Kemp and Kemp 1998, Hockey et al. 2005, Taylor et al. 2015, Chittenden et al. 2016). Owl pairs create tunnels in the long grass which sometimes lead to nest chambers, distinguishing their nests from marsh owl nests, and are known to clear their pellets away from their nests (Kemp and Kemp 1998, Hockey et al. 2005, Chittenden et al. 2016). Like the barn owl, they only emerge after dark to hunt (Hockey et al. 2005, Chittenden et al. 2016). They are mostly seen on the ground, when they emerge from the grass to hunt, or when flushed (Hockey et al. 2005). The African grass-owl predates mostly on *Otomys* species as well as on *Mastomys* species, but also preys on other small mammal species, birds and insects (Kemp and Kemp 1998, Hockey et al. 2005, Chittenden et al. 2016). Grass-owls will lay eggs throughout the year, but mostly in March to May, when the grass is at maximum cover (Tarboton and Erasmus 1998, Taylor et al. 2015). They can nest as close as 150m apart and chicks will begin to fly at about 42 days (Tarboton and Erasmus 1998, Hockey et al. 2005). Grass-owl pellets are about 50 x 25 mm (Tarboton and Erasmus 1998). African grass-owls are currently listed as Vulnerable by the Regional Eskom Red Data Book of Birds (Taylor et al. 2015). Their population size is estimated to be less than

10 000 birds in the region, with an estimated decline of 10% in the next three generations, with a generation being around 6 years (Taylor et al. 2015). The main reported threat for this species is habitat loss or habitat fragmentation from mining, agriculture, afforestation and urbanisation (Taylor et al. 2015). Other factors include wetland draining, grazing and trampling, ploughing and burning (Hockey et al. 2005). These are threats often associated with agriculture and African grass-owls are sensitive to grazing and burning in the areas where they are nesting. Poor land management practises, especially at a high frequency put extensive pressure on the remaining grass-owl populations (Hockey et al. 2005, Taylor et al. 2015). One factor that is mentioned in literature is the effect of grain spillage from trucks on their populations from vehicle collisions (Ansara 2004, Taylor et al. 2015). There is however the possibility that because of their elusive behaviour and nocturnal habits, they are under recorded (Taylor et al. 2015).

The barn owl, marsh owl and grass owl use a method of hunting called quartering, where they fly low to the ground to look for prey and then swoop down to catch their prey (Tarboton and Erasmus 1998, Oberprieler and Cillie 2002, Hockey et al. 2005). This method of hunting, however, is often associated with roads, close to the ground, which increases their risk of vehicle collisions.

These owl species are mostly easy to tell apart from each other, except for the barn owl and African grass-owl. However, these owls can be told apart by the barn owl's golden colour above while the grass-owl is a dark brown above (Kemp and Kemp 1998, Hockey et al. 2005, Sinclair and Ryan 2010). Also, as said above, grass-owls are very elusive and difficult to spot except when flushed and are thus easily overlooked (Kemp and Kemp 1998, Taylor et al. 2015).

From a prey perspective there are a number of small mammals that can be expected to be trapped in this study area. I compiled a list of small mammals that can be expected to be trapped in this study area based on small mammals caught in live traps, small mammal remains found in owl pellets in previous studies done in the area, the preferred diets of owls in the area and the distribution and preferred habitat of these small mammals (Ansara 2004, Vanroy 2018, Wei 2018). These species are *Mastomys* species (Ansara 2004, Hockey et al. 2005, Vanroy 2018, Wei 2018), *Rhabdomys dilectus* (Ansara 2004, Hockey et al. 2005, Vanroy 2018), *Mus minutoides* (Ansara 2004, Vanroy 2018), *Otomys irroratus* (Ansara 2004, Hockey et al. 2005, Chittenden et al. 2016, Wei 2018), *Gerbilliscus brantsii* (Ansara 2004, Wei 2018), *Rattus rattus* (Wei 2018) and *Micaelamys namaquensis* (Ansara 2004).

Mastomys species or multimammate mice, inhabit a wide range of habitats throughout their distribution but require a rainfall of more than 400mm per year (De Graaff 1981, Apps 2000). *Mastomys* species are often found in close contact with humans and are commonly caught but can be differentiated from *Rattus rattus* as they are significantly smaller than *R. rattus* (De Graaff 1981). They are also easy to identify by the large number of teats on females, which is normally between 8 and 12 teats (De Graaff 1981, Leirs et al. 2010). The two species in the region, *Mastomys natalensis* and *M. coucha* are indistinguishable in the field, but both are recognised as agricultural pests (Apps 2000, Smit et al. 2001, Stenseth et al. 2003). They are also considered one of the first small mammals to inhabit an area after some kind disturbance to the environment such as fires (De Graaff 1981). They are often then followed by *Rhabdomys dilectus* later during succession, and then much later by *Otomys* species (De Graaff 1981). *Mastomys* species are also considered to be one of the rodent pest species in sub-Saharan Africa with the most negative impact on agriculture (Leirs et al. 2010, Mulungu et al. 2013). *Mastomys* species are omnivorous, eating both seeds and insects, with a particular interest in grains, which often make them pests in agricultural areas (Apps 2000). They are often found near water but do not rely on it (De Graaff 1981). Their population irruptions are due to them being prolific breeders under favourable conditions and can breed throughout the year, but will generally breed less when the weather is cold, and have an average of 10-16 pups per litter, with up to 27 pups in a litter when there is above average or unseasonably high rainfall (De Graaff 1981, Apps 2000, Leirs et al. 2010). Multimammate mice are generally nocturnal and will nest in any crevices, including in burrows they have dug themselves or taken over from other species (De Graaff 1981, Apps 2000). They are reported prey for all four owl species found in the area (De Graaff 1981).

Rhabdomys delictus are also commonly associated with a variety of vegetation types, provided there is adequate grass cover (Apps 2000, Monadjem et al. 2015). They are easy to identify as they are conspicuously marked with stripes along their backs (De Graaff 1981, Apps 2000). *Rhabdomys dilectus* eat green vegetation, seeds and insects, making them another common rodent pest (De Graaff 1981, Apps 2000). They are often found in maize fields, where they feed on fallen grain after it is harvested but will not climb mature plants for grain before they are harvested (De Graaff 1981). This species differs from *Mastomys* species in that it is diurnal and *Rhabdomys dilectus* mostly breeds from September to April (Apps 2000). They are not very dependent on water sources and may get sufficient water from dew and plants (De Graaff 1981). *Rhabdomys dilectus* often build their own burrows but will also use termite mounds or will nest in nests similar to birds' nests in the grass (De Graaff 1981, Apps 2000). They breed throughout the year and have an average of 5 pups per litter (De Graaff 1981). This species is often preyed on by barn owls, spotted eagle-owls and marsh owls (De Graaff 1981).

Mus minutoides is found across a variety of vegetation types (De Graaff 1981, Apps 2000, Monadjem et al. 2015). They are some of the smallest mammal species in the world (De Graaff 1981). They dig burrows in soft ground but will most often nest under logs and rocks (Apps 2000). They are considered nocturnal (Apps 2000). *Mus minutoides* are reported to be omnivorous and will eat both insects and vegetable matter (De Graaff 1981). This species has been known to increase its population when there is an increase of *Mastomys* species and *Rhabdomys dilectus* (De Graaff 1981). They are often hunted by barn owls, African grass-owls and marsh owls (De Graaff 1981). This rodent species can breed throughout the year but most young are born in the summer months, with an average of 4 pups in a litter and a gestation period of 19 days (De Graaff 1981). They are known to be attracted to agricultural areas and they can have population irruptions as reported for *Mastomys* species but because of their small size they are not considered pests (De Graaff 1981).

Otomys irroratus is a large species of rat which inhabits vlei areas (De Graaff 1981, Apps 2000, Monadjem et al. 2015). They prefer habitats that are well covered by grass and have defined tunnels and runways, which helps to find them (De Graaff 1981). They are considered herbivores and as such they are often pests in agricultural areas as they eat large amounts of plant matter (De Graaff 1981, Apps 2000). *Otomys irroratus* is a mostly diurnal species but is sometimes nocturnal (De Graaff 1981, Apps 2000). This means that they are vulnerable to being hunted by all owl species as they are active when all the owl species are active (De Graaff 1981). Vlei rats will nest in grass nests or in burrows and have distinct runways to where they feed (Apps 2000). They breed throughout the year but only have an average of three young in a litter and a gestation period of 40 days, and thus do not have population irruptions like *Mastomys* species (De Graaff 1981). However, because of their large size (approximately 120g) and their appetite for vegetable matter *Otomys irroratus* can become a problem in agricultural areas (De Graaff 1981)

Gerbilliscus brantsii are rodents that typically live in large communal burrow systems (De Graaff 1981, Apps 2000, Monadjem et al. 2015). They are nocturnal and eat grass, seeds and insects which often makes them pests (De Graaff 1981, Apps 2000). They are often found in areas with peaty soil around marshes and will avoid areas with very hard soil, as they live in burrows (De Graaff 1981). They are preyed on by barn owls as well as African grass-owls (De Graaff 1981). They breed throughout the year and thus have the potential to become agricultural pests, but only have around 3 pups per litter (De Graaff 1981).

Rattus rattus is a dark grey rat which is commonly found living in close proximity to people (De Graaff 1981). Originally not a rodent indigenous to South Africa, it has since become extremely prolific and has spread throughout the country (De Graaff 1981). It is an omnivorous rodent that is well known for becoming an agricultural and domestic pest (Apps 2000). They are nocturnal and can cause large amounts of damage to food stores, agriculture and even infrastructure, gnawing through walls and or packaging to get to food (De Graaff 1981, Apps 2000). *Rattus rattus* is preyed upon by many predators including barn owls and spotted eagle-owls (De Graaff 1981). This species breeds prolifically, with up to 17 pups in a litter and because of their close contact with humans, they often have enough nutrition to breed throughout the year (De Graaff 1981). Their gestation period is around 21-30 days (De Graaff 1981).

Micaelamys (Aethomys) namaquensis (Namaqua rock mouse) is a reddish-brown colour with a pure white belly (De Graaff 1981, Monadjem et al. 2015). This species of mouse prefers rocky areas, nesting under logs or in crevices and sometimes in burrows, retreating to burrows in the case of veld fires (De Graaff 1981, Apps 2000). They are also commonly found in ruined buildings (De Graaff 1981). They are omnivorous but are not always attracted to cultivated areas (De Graaff 1981, Apps 2000). *Micaelamys namaquensis* is nocturnal and will leave their nests at dusk to feed (De Graaff 1981). They have litters of 2 – 7 pups (De Graaff 1981). Not much is known about the predators of *M. namaquensis*, but they have been found in barn owl pellets in the study area before (De Graaff 1981, Ansara 2004).

Because of the wide range of feed that these small mammals eat and because of the large amount of food available to them in agricultural areas, they often become pests

(Stenseth et al. 2003, Leirs et al. 2010). They can also become pests as a result of the fact that many rodent species are r-strategy breeders and thus when there are favourable situations rodent populations can increase dramatically, sometimes to plague levels (Leirs et al. 2010). With small mammals making up more than 90% of these owls' diets, it is important to look further at these prey species and see how they could be affecting owl populations (Tarboton and Erasmus 1998, Hockey et al. 2005).

As we can see from the predator and prey species descriptions above, the owls and small mammals present in the area have an intimate relationship with one another. Small mammals are the primary food source of the owls in the area, while owls are the primary predator of the small mammals in the area. It can thus be suggested that the owls and small mammals in the area have a lagged predator-prey relationship like the predator-prey relationship described by Lotka-Volterra models (Lima et al. 2002). Simply, this implies that as small mammal populations increase, due to, for example, increased food sources, owl populations can increase. However, as the owl population grows, the small mammal population will begin to decline and as a result so will the owl population (De Graaff 1981). This is referred to as a "boom-bust" event (Tarboton and Erasmus 1998).

STUDY AREA

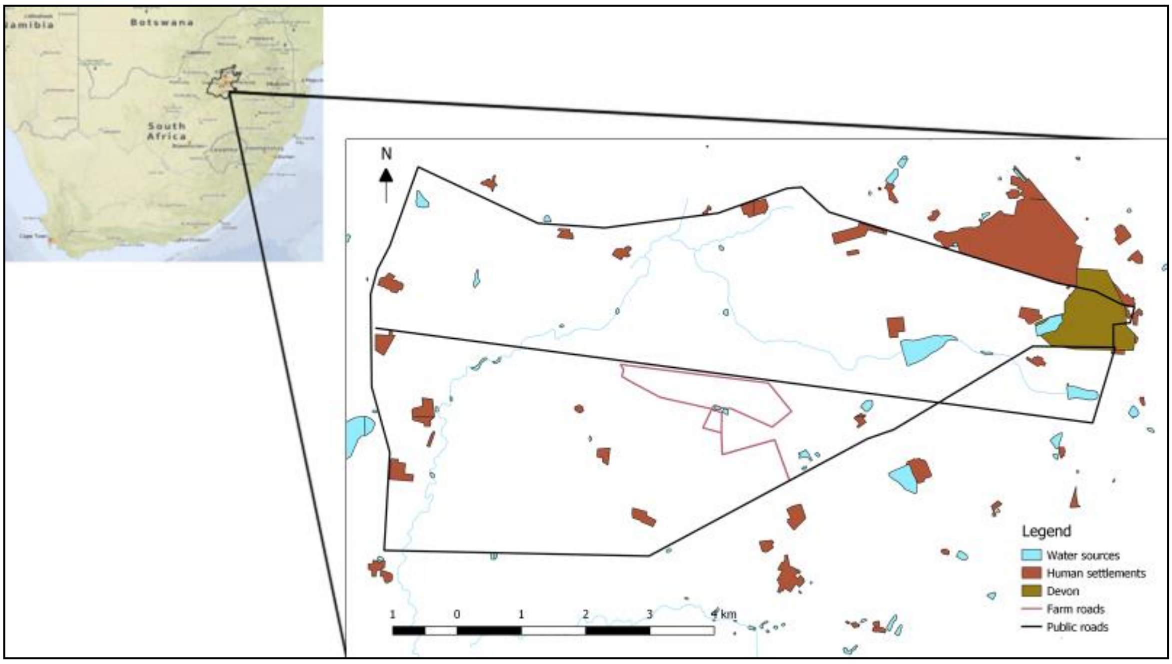

Figure 1.1: Study area for assessing the factors that are affecting owl occupancy and abundance in the east of Gauteng, South Africa. Gauteng province in the inset. Created in QGIS 3.0.1.

For this study I surveyed an area of around 50km^2 which included areas that are agricultural land and natural vegetation, with a few human settlements, along the N17 highway between Springs and Devon in the east of Gauteng (centroid GPS -26.370548°, 28.723736°). Approximately half of the study area (24km^2) is cultivated fields or human settlements. The remaining 26km^2 is made up of grassland, with a number of grass species. Specifically, the area is situated in the Boesmanspruit Highveld Grassland, near the Blesbokspruit Highveld Grassland, both of which are critically endangered ecosystems (SANBI 2013). The two main vegetation types in the area are the Gm8 Soweto Highveld Grassland and the Gm12 Eastern Highveld Grassland (Mucina et al. 2014), with small sections covered by the AZf3 Eastern Temperate Freshwater Wetlands (Mucina et al. 2014). This region of the grassland is known for receiving mainly spring-summer rainfall (±662 mm (Gm8) and 650-800 mm (Gm12))

(Mucina et al. 2006), with a cool temperate climate. Large differences between summer temperatures (highs) and winter temperatures (lows and frost) are reported for these two vegetation types (Mucina et al. 2006). Depending on the season, the area has approximately 79 hectares of surface water, either in natural wetlands or manmade water catchments, and is approximately 12 kilometres east of the Marievale Bird Sanctuary Nature Reserve. The main agricultural crop in this area is maize (*Zea mays*), soya beans (*Glycine max*) and cultivated veld (*Eragrostis tef*) crops for fodder. The natural vegetation in the area is made up of grass species such as *Eragrostis* and *Sporobolus* species, and *Themeda trianda* (Ansara 2004). Large portions of this area are routinely burned for management purposes (per. obs.). Pesticides are used in the area for insects in agricultural production (per. obs.).

LITERATURE CITED

Ansara, T. 2004. Determining the ecological status and possible anthropogenic impacts on the grass owl (*Tyto capensis*) population in the East Rand Highveld, Gauteng. MSc Thesis, Rand Afrikaans University, Johannesburg, South Africa.

Apps, P. 2000. Smithers' Mammals of Southern Africa, a field guide. Struik Publisher, Johannesburg, South Africa.

Avenant, N. L. 2005. Barn owl pellets: a useful tool for monitoring small mammal communities? The Belgian Journal of Zoology 135:39–43.

Avenant, N. L. 2011. The potential utility of rodents and other small mammals as indicators of ecosystem "integrity" of South African grasslands. Wildlife Research 38:626–639.

Beaudry, F., P. G. de Maynadier, and M. L. Hunter Jr. 2008. Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. Biological Conservation 141:2550-2563.

Brown, P. R., N. I. Huth, P. B. Banks, and G. R. Singleton. 2007. Relationship between abundance of rodents and damage to agricultural crops. Agriculture, Ecosystems and Environment 120:405–415.

Chittenden, H., G. Davies, and I. Weiersbye. 2016. Roberts' Bird Guide. The John Voelcker Bird Book Fund, Cape Town, South Africa.

Collinson, W., D. Parker, C. Patterson-Abrolat, G. Alexander, and H. Davies-Mostert. 2015. Setjhaba SA, South Afrika: a South African perspective on an emerging transport infrastructure. Pages 439–447 in. Handbook of road ecology. John Wiley & Sons, Chichester, West Sussex, UK.

Cowling, R. M., D. M. Richardson, and S. M. Pierce. 2004. Vegetation of southern Africa. Cambridge University Press, Cambridge, UK.

Crowder, D. W., T. D. Northfield, M. R. Strand, and W. E. Snyder. 2010. Organic agriculture promotes evenness and natural pest control. Nature 466(7302):109.

Gangadharan, A., S. Pollock, P. Gilhooly, A. Friesen, B. Dorsey, and C. C. St Clair. 2017. Grain spilled from moving trains create a substantial wildlife attractant in protected areas. Animal Conservation 20:391–400.

Geduhn, A., J. Jacob, D. Schenke, B. Keller, S. Kleinschmidt, and A. Esther. 2015. Relation between intensity of biocide practice and residues of anticoagulant rodenticides in red foxes (*Vulpes vulpes*). PLoS One 10:e0139191.

Gomes, L., C. Grilo, C. Silva, and A. Mira. 2009. Identification methods and deterministic factors of owl roadkill hotspot locations in Mediterranean landscapes. Ecological Research 24:355–370.

De Graaff, G. 1981. The rodents of Southern Africa: notes on their identification, distribution, ecology, and taxonomy. Butterworths, Durban, South Africa.

Grobler, C. H., G. J. Bredenkamp, and L. R. Brown. 2006. Primary grassland communities of urban open spaces in Gauteng, South Africa. South African Journal of Botany 72:367–377.

Hayman, P., N. Arlott, and W. Tarboton. 1994. Birds of Southern Africa: The Sasol Plates Collection. Struik Winchester, Cape Town, South Africa.

Hockey, P., W. Dean, and P. Ryan. 2005. Roberts' Birds of Souh Africa. John Voelcker Bird Book Fund, Cape Town, South Africa.

Hodara, K., and S. L. Poggio. 2016. Frogs taste nice when there are few mice: Do dietary shifts in barn owls result from rapid farming intensification? Agriculture, Ecosystems and Environment 230:42–46.

Jiguet, F., and A. Audevard. 2017. Birds of Europe, North Africa and the Middle East. Princeton University Press, Princeton, NJ, USA.

Kajtoch, Ł., M. Żmihorski, and P. Wieczorek. 2015. Habitat displacement effect between two competing owl species in fragmented forests. Population Ecology 57:517–527.

Kemp, A., and M. Kemp. 1998. Sasol Birds of Prey of Africa and its Islands. Struik Publisher, Cape Town, South Africa.

Kioko, J., C. Kiffner, N. Jenkins, and W. J. Collinson. 2015. Wildlife roadkill patterns on a major highway in Northern Tanzania. African Zoology 50:17–22.

Labuschagne, L. 2015. Determining the potential of Barn Owls, *Tyto alba*, as bio-control agent of agricultural rodent pests. MSc Thesis, University of Pretoria, Pretoria, South Africa.

Labuschagne, L., L. H. Swanepoel, P. J. Taylor, S. R. Belmain, and M. Keith. 2016. Are avian predators effective biological control agents for rodent pest management in agricultural system? Biological Control 101:94–102.

Leirs, H., V. Sluydts, and R. Makundi. 2010. Rodent outbreaks in sub-Saharan Africa. Pages 9–280 in. Rodent Outbreaks: Ecology and Impacts. International Rice Research Institute, Los Banos, Phillipines.

Lima, M., N. C. Stenseth, and F. M. Jaksic. 2002. Food web structure and climate effects on the dynamics of small mammals and owls in semi-arid Chile. Ecology Letters 5:273–284.

Loon, R., and H. Loon. 2005. Birds: the inside story. Struik Publisher, Cape Town, South Africa.

Mamba, M., N. J. Fasel, A. M. Themb'alilahlwa, J. D. Austin, R. A. McCleery, and A. Monadjem. 2019. Influence of sugarcane plantations on the population dynamics and community structure of small mammals in a savanna-agricultural landscape. Global Ecology and Conservation 20:e00752.

Mdangi, M., L. S. Mulungu, A. W. Massawe, S. Eiseb, V. Tutjavi, F. Kirsten, T. Mahlaba, P. Malebane, E. Von Maltitz, A. Monadjem, N. Dlamini, R. H. Makundi and S. R. Belmain. 2013. Assessment of rodent damage to stored maize (*Zea mays* L.) on smallholder farms in Tanzania. International Journal of Pest Management. 59:59-62.

Monadjem, A., P. J. Taylor, C. Denys and F. P. D. Cotterill. 2015. Rodents of Sub-Saharan Africa: A biogeographic and taxonomic synthesis. De Gruyter, Berlin, Germany.

Mucina, L., and M. C. Rutherford. 2006. The vegetation of South African, Lesotho and Swaziland. South African National Biodiversity Institute, Pretoria, South Africa.

Mucina, L., M. C. Rutherford, L. W. Powrie, A. Van Niekerk, and J. H. Van der Merwe. 2014. Vegetation field atlas of continental South Africa, Lesotho and Swaziland. South African National Biodiversity Institute, Pretoria, South Africa.

Muck, C., and U. Zeller. 2006. Small mammal communities on cattle and game grazing areas in Namibia. African Zoology 41:215–223.

Mulungu, L. S., V. Ngowo, M. Mdangi, A. Katakweba, P. Tesha, F. P. Mrosso, M. Mchomvu, P. M. Sheyo, and B. S. Kilonzo. 2013. Population dynamics and breeding patterns of multimammate mouse , *Mastomys natalensis* (Smith 1834), in irrigated rice fields in Eastern Tanzania. Pest Management Science 69:371–377.

Ojwang, D. O., and N. O. Oguge. 2003. Testing a biological control program for rodent management in a maize cropping system in Kenya. Aciar Monograph Series 96:251–253.

Parker, V. 2005. The Atlas of the Birds of Central Mozambique. Endangered Wildlife Trust and Avian Demography Unit, Johannesburg and Cape Town, South Africa.

Paz, A., D. Jareño, L. Arroyo, J. Viñuela, B. Arroyo, F. Mougeot, J. J. Luque-Larena, and J. A. Fargallo. 2013. Avian predators as a biological control system of common vole (*Microtus arvalis*) populations in north-western Spain: Experimental set-up and preliminary results. Pest Management Science 69:444-450.

Rands, M. R. W., W. M. Adams, L. Bennun, S. H. M. Butchart, A. Clements, D. Coomes, A. Entwistle, I. Hodge, V. Kapos, and J. P. W. Scharlemann. 2010. Biodiversity conservation: challenges beyond 2010. Science 329:1298–1303.

Saeki, M. and M. MacDonald. 2004. The effects of traffic on the raccoon dog (*Nyctereutes procyonoides viverrinus*) and other mammals in Japan. Biological Conservation

118:559-571.

SANBI. 2013. Grasslands Ecosystem Guidelines: landscape interpretation for planners and managers. Compiled by Cadman, M., de Villiers, C., Lechmere-Oertel, R. and D. McCulloch. South African National Biodiversity Institute, Pretoria, South Africa.

Scheun, J., N. C. Bennett, A. Ganswindt, and J. Nowack. 2015. The hustle and bustle of city life: monitoring the effects of urbanisation in the African lesser bushbaby. The Science of Nature 102:57.

Serieys, L. E. K., J. Bishop, N. Okes, J. Broadfield, D. J. Winterton, R. H. Poppenga, S. Viljoen, R. K. Wayne, and M. J. O'Riain. 2019. Widespread anticoagulant poison exposure in predators in a rapidly growing South African city. Science of the Total Environment 666:581–590.

Sinclair, I., and P. Ryan. 2010. Birds of Africa south of the Sahara. Struik Nature, Cape Town, South Africa.

Smit, A., H. van der Bank, T. Falk, and A. de Castro. 2001. Biochemical genetic markers to identify two morphologically similar South African Mastomys species (Rodentia: Muridae). Biochemical Systematics and Ecology 29:21–30.

Stenseth, N. C., H. Leirs, A. Skonhoft, S. A. Davis, R. P. Pech, H. Andreassen, G. R. Singleton, M. Lima, R. S. Machang'u, R. H. Makundi, Z. Zhang, P. R. Brown, D. Shi, and X. Wan. 2003. Mice, rats, and people: the bio-economics of agricultural rodent pests. Frontiers in Ecology and the Environment 1:367–375.

Swanepoel, L. H., C. M. Swanepoel, P. R. Brown, S. J. Eiseb, S. M. Goodman, M. Keith, F. Kirsten, H. Leirs, T. A. M. Mahlaba, R. H. Makundi, P. Malebane, E. F. Von Maltitz, A. W. Massawe, A. Monadjem, L. S. Mulungu, G. R. Singleton, P. J. Taylor, V.

Soarimalala, and S. R. Belmain. 2017. A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: Are we asking the right questions? PLoS ONE 12:e0176621.

Tarboton, W., and R. Erasmus. 1998. Owls and Owling in Southern Africa. Struik Publisher, Cape Town, South Africa.

Taylor, M. R., F. Peacock, and R. M. Wanless. 2015. The 2015 Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland. Birdlife South Africa, Johannesburg, South Africa.

Vanroy, T. 2018. Species richness of rodent populations in an agricultural matrix, and viability use on chew cards. MSc Thesis, University of Pretoria, Pretoria, South Africa.

Wei, M. 2018. The diet of owl community in a peri-urban and agricultural matrix, Gauteng East, South Africa. MSc Thesis, University of Pretoria, Pretoria, South Africa.

Wiens, J. D., R. G. Anthony, and E. D. Forsman. 2011. Barred owl occupancy surveys within the range of the northern spotted owl. Journal of Wildlife Management 75:531–538.

Wiens, J. D., R. G. Anthony, and E. D. Forsman. 2014. Competitive interactions and resource partitioning between northern spotted owls and barred owls in western Oregon. Wildlife Monographs 185:1–50.

Williams, S. T., W. Collinson, C. Patterson-Abrolat, D. G. Marneweck, and L. H. Swanepoel. 2019. Using road patrol data to identify factors associated with carnivore roadkill counts. PeerJ 29:e6650.

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Chapter 2: Assessing rodent community structures and densities in an agricultural matrix in the north-east of the Sedibeng district in Gauteng

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ABSTRACT To assess if food availability is a main driving variable contributing to high owl occupancy in the Devon area (Gauteng), I investigated the biology around the small mammal community in the study area. Using capture-mark-recapture, I determined the abundance of rodents in different crop types in three sampling periods in October 2018, January 2019 and April 2019. I found *Mastomys* species to be the most abundant, with only one other species trapped, *Rhabdomys dilectus*, in low abundance. Including the month of sampling, the current crop growing in the field and the crop that had previously been growing in the field into model assessment, I determined that fields where soya beans were being grown in April 2019 had the highest number of rodents up to 55 animals per hectare. Crop cycle, leading to increased coverage and food availability for the rodents in the crops, could have a strong influence, with *Mastomys* species able to take advantage of specific condition. Additionally, the height of the crop appears to have an effect on rodent abundances.

KEYWORDS *Mastomys*, N17 highway, owls, rodent pests, *Tyto alba*.

Rodents are considered one of the biggest problems in agriculture (Mulungu et al. 2013, Swanepoel et al. 2017). Some rodent species are closely associated with crop farms and due to the associated available food, population numbers are often higher than in natural vegetated areas (Stenseth et al. 2001, 2003, Swanepoel et al. 2017, Mamba et al. 2019). This increased availability of food can lead to an increase in rodents to an alarming degree (Stenseth et al. 2001, 2003, Swanepoel et al. 2017). These high numbers of rodents cause damage at various stages during the crop cycle, depending on the rodent species, for example, digging up and eating seeds that have been recently sown, eating seedlings, gnawing young plants, eating the crop pre-harvest and even eating the crop post-harvest in storage (Brown et al. 2007, Mulungu et al. 2011, Swanepoel et al. 2017). Rodents are also often associated with zoonotic diseases and can damage infrastructure (Mulungu et al. 2013, Swanepoel et al. 2017).

An example of these kinds of rodents in an African context, and in our study area, is the natal multimammate mouse, *Mastomys natalensis* (Mulungu et al. 2013, Swanepoel et al. 2017). A highly fecund rodent which can have up to 24 pups in a litter, this mouse is a generalist and can thus feed on a number of food items (De Graaff 1981, Mulungu et al. 2011, Swanepoel et al. 2017). Their populations are spurred on by an increase in food and when there is an excess of food, they produce larger litters (Stenseth et al. 2001, Mulungu et al. 2013). The increase of food from agricultural land can then spur these population increases on to the point of pest status.

Many farmers, from small scale to industrial scale, are required to deal with these rodent pest populations as best they can. Where farmers are able to, from a logistical or financial point of view, they will employ one or a number of techniques to deal with the pest species. This is often in the form of specific ploughing techniques and trapping to disrupt or reduce the rodent pest population (Swanepoel et al. 2017). However, most often chemical rodenticides are the management options relied upon (Stenseth et al. 2001, Paz et al. 2013, Swanepoel et al. 2017, Serieys et al. 2019).

Ecologically based rodent management (EBRM) is a very feasible option to use to assist in managing rodent pest populations (Palis et al. 2011, Paz et al. 2013, Labuschagne et al. 2016). EBRM relies upon a number of methods to control rodent populations, including using natural predator-prey relationships in an ecosystem. To do this it encourages natural predators of rodents to suppress rodent numbers, thereby helping ensure the perseverance of local predator species and keeping the number of rodents in the area at a manageable level. It also avoids problems for the local wildlife by avoiding secondary poisoning typically associated with chemical rodenticides and is less labour intensive and expensive than trapping or ploughing (Paz et al. 2013, Swanepoel et al. 2017, Serieys et al. 2019).

One of the most common species associated with EBRM is the western barn owl (*Tyto alba*) (Paz et al. 2013, Labuschagne et al. 2016). Avian predators are considered some of the best species for ecologically based rodent management as they are often not as persecuted as mammalian and reptilian predators such as cats and snakes (Labuschagne et al. 2016). They are also more mobile than mammalian and reptilian predators (Labuschagne et al. 2016). Owls in particular are very efficient hunters and most of their diet consists of rodents (Tarboton and Erasmus 1998, Ansara 2004, Hockey et al. 2005). In particular, western barn owls are extremely versatile when it comes to their environment and can eat up to a fourth of their body weight in rodents in a night (Hockey et al. 2005, Labuschagne et al. 2016). For this reason, owls are often encouraged in agricultural land and some farms even set up nest boxes and perches for owls to use to encourage them to stay in the area (Mohr et al. 2003, Paz et al. 2013, Labuschagne et al. 2016).

With this being said, it can be speculated that EBRM is a highly suitable system for the current study area. The interaction between the farmers and the owls in the study area mean that owls are able to hunt and reduce rodents in the area and farmers are able to control the number of rodents on their farms with ecologically responsible practises. Previous studies done in the area and on owls around the world have found that the main source of food for most owls, but specifically for the four owl species in the study area (see chapter 1 and chapter 3 of this thesis), is rodents and other small mammals (Tarboton and Erasmus 1998, Ansara 2004, Hockey et al. 2005). Food availability is one of the factors that can lead to a high density of owls in an area (Hockey et al. 2005), resulting in the reported high number of owls in the current study area between Springs and Devon, Gauteng (Ansara 2004).

I aim to assess the abundance of small mammals on a farm in the study area by assessing species richness and abundance of small mammals across different land use types within the study area, and to determine which factors are affecting their population numbers. I will use capture-mark-recapture survey data, through live trapping (Huysman et al. 2018).

STUDY AREA

The study area is a mixture of cultivated fields, natural fields used for grazing and road edges and a small number of human settlements. The area is approximately 50 km^2 and approximately 24 km^2 is cultivated fields or human settlements. The remaining 26 km^2 is made up of Highveld grassland, with a number of grass species. The area has approximately 79 hectares of surface water, depending on the season, and is situated approximately 12 kilometres east of the Marievale Bird Sanctuary. The water is made up of natural wetlands in the area as well as manmade water sources on farms in the area. The natural vegetation in the area is made up of grass species such as *Eragrostis* and *Sporobolus* species, and *Themeda trianda* (Ansara 2004).

The cultivated fields provide an overabundance of food for granivorous and herbivorous small mammals (De Graaff 1981, Stenseth et al. 2003, Swanepoel et al. 2017). I expected to mainly trap rodents and not many shrews. While shrews, make up part of the small mammal community, their diet is insectivorous, and will likely not be attracted to these fields, and likely not have a positive reproductive response to an overabundance in food like the rodents in these fields. This is because even though insects may be attracted to the crops, the crops in this area are sprayed for insect pests and thus there should not be many insects in the area. Therefore, we expected mostly rodents in the area as opposed to other small mammals. For more information on the study area, please see Chapter 1.

METHODS

For this part of the study I set up live traps in fields on two farms in the study area, Hanroux and Palmietskuil, bordering the N17 highway (Figure 2.1). These traps were set up in four separate fields with different crops and growth stages in the different months. I sampled on three different occasions, in October 2018, January 2019 and April 2019. This incorporated the fields pre-planting, mid growth cycle and pre-harvesting respectively. The fields are at various places on the farm (Figure 2.1).

The first field (Grid 1) was dominated by maize (*Zea mays*) from the end of 2017 and harvested in September 2018. In November 2018, soya beans (*Glycine max*) were planted there and replanted there in December 2018 after a hailstorm.

Grid 2 was planted with soya beans at the end of 2017 and harvested in May 2018. It was replanted with soya beans in November 2018 (no hail damage).

Grid 3 was placed in a cultivated field of *Eragrostis tef*, planted approximately 35 years ago and has since been routinely cut and fertilised to make animal feed.

Grid 4 is a field of natural veld with a number of grass species (e.g. *Eragrostis* species, *Sporobolus* species, *Themeda trianda*). This field is grazed by cattle (*Bos taurus*) for 2 – 3 weeks and is then rested for 3 weeks after this. Traps were set up in grid 4 for only January 2019 and April 2019 and not for October 2018.

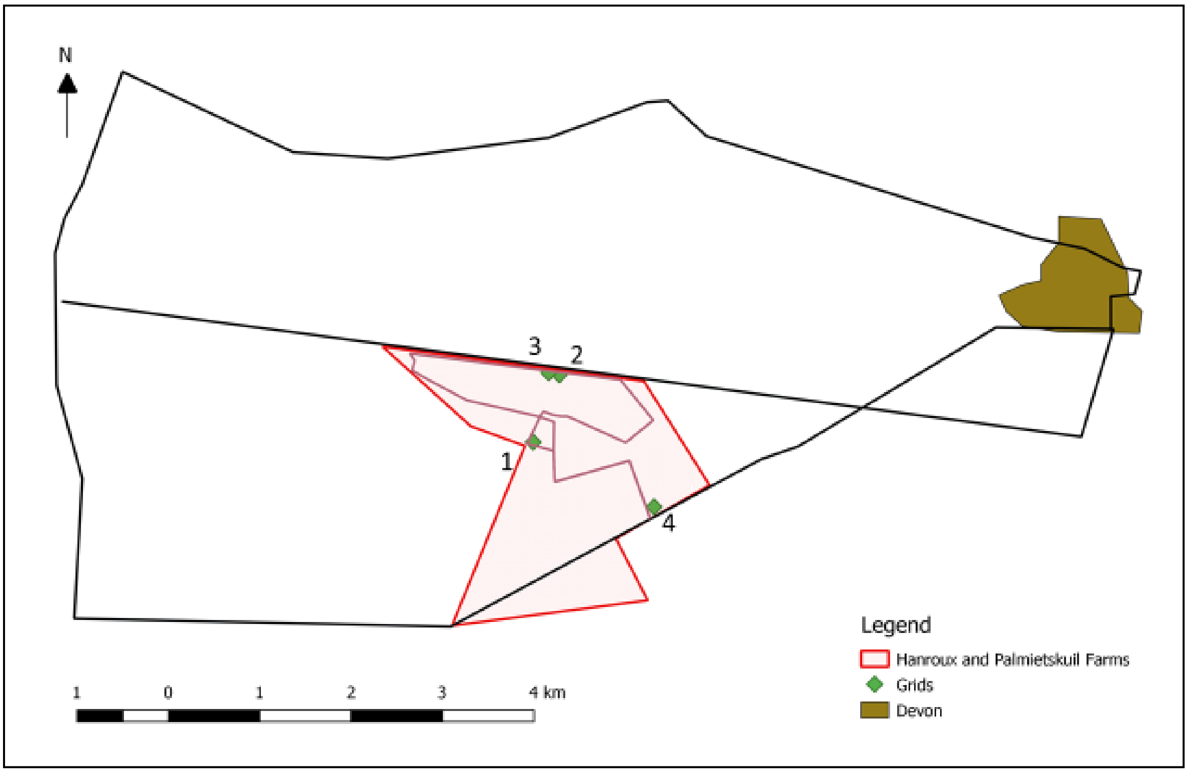

Figure 2.1: Grids where live traps are set out (green squares) on the Hanroux and Palmietskuil farms along the N17 highway (on the north border) near the human settlement Devon, Gauteng. From left to right: Grid 1 (-26.37377, 28.72012), Grid 3 (-26.36688, 28.72321), Grid 2 (-26.36686, 28.7241), Grid 4 (-26.37994, 28.73362) (see text for more details). These grids were used to determine the abundance of rodents in the different fields and to determine the factors that could be affecting abundance in the area. Created in QGIS (version 3.0.1).

These grids represent the general land use that is characteristic of the area between Springs and Devon, with maize and soya beans being the predominant crops planted for the two years that this study took place. The grids are along the route used for owl surveys at night (see chapter 3). The sites are replicate sites of sites used in a previous trial on the same farm and this could allow for comparison (Vanroy 2018).

In each grid there were 49 traps consisting of 7 rows with 7 traps in each row. These traps were set out approximately 15 metres apart, for an approximately 1 hectare sampling area. The traps were baited with a mixture of peanut butter and oats and during the winter, cotton wool was added to the trap to help reduce cold exposure (see Bronner and Meester 1987). Additionally, the traps were covered with cardboard to assist in insultation against wind and cold. As most of the small mammals in the area are nocturnal, traps were left open overnight for 4 nights, and checked every morning, closed for the day and opened in the late afternoon (Muck and Zeller 2006, Avenant and Cavallini 2007). Trapped animals were removed and put into a cotton capture bag. While in the bag, the animal was weighed using a Pesola scale (Micro-Line 100 g), and this was recorded. It was then scruffed through the bag and removed from the bag. This allowed for control over the rodent while ensuring the safety of the handler. Once out the bag the following were recorded from the animal: 1) species of the animal; 2) rough head-body length of the animal was measured with a Vernier caliper; 3) rough tail length of the animal was measured with a caliper; 4) sex of the animal; and 5) broad reproductive state of the animal (scrotal/non-scrotal, perforated/non-perforated vagina, lactating, etc.). I used field guides to identify all small mammals trapped (Apps 2000, Kirsten et al. 2010). *Mastomys* species were recorded to genus level as in the field *Mastomys natalensis* and *M. coucha* are indistinguishable (Smit et al. 2001). The animal was then given a unique marking using red hair dye (Inecto brand) and a cotton bud. The animal was marked on its ventral side. The animal was then put back in the capture bag. Recaptured animals were recorded but not remeasured. The trap that it came from was cleaned and rebaited and replaced in the field, and the marked animal was released. Traps were all closed for the duration of the day to avoid heat exposure. In the afternoons before the owl survey drives began (see Chapter 3), the traps were opened again.

Following the collection of this data, the Schnabel method for capture-mark-recapture (CMR) (following Conroy and Carroll 2009) was used to estimate the population of small mammals in these grids, using a formula in Microsoft Excel (365). These CMR numbers were compared between different months and different grids creating 11 samples (in October 2018, a sample was not taken in grid 4). These estimates were used as response variables with a number of predictor variables used to estimate what factors are affecting the populations of the rodents in the area in RStudio (version 1.1.423, R version 3.4.3, www.r-project.org, first accessed 27 March 2018). These predictor variables are as reported in Table 2.1. The results are presented in the form of a boxplot for the capture period (presented as month), the crop currently growing in the field and the crop previously growing in the field (Figures 2.3, 2.4 and 2.5). Weights of animals in the different sample groups, including sex are reported in Table 2.2 and the minimum number alive (MNA) in each field for each sampling period is reported in Table 2.3. MNA is calculated by tallying the individuals that were caught in a sample. Average weight was calculated for the two sexes for each species caught in each sample period. The predictor variables were recorded in each grid in each sampling occasion and were compared to the response variable of abundances calculated.

Ethics and landowner permission:

Animal Ethics Clearance from the University of Pretoria (ECO54-18) was obtained for this research and this work was undertaken under Gauteng Department of Agriculture and Rural Development (GDARD CPF6-211) permit. Research was undertaken with permission from the landowner, Dries Duvenhage.

Table 2.1: Variables and the reasons for their use in the testing of factors affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

Variable	Name	Description	Reason for testing
Month	October 2018 January 2019 April 2019	Pre-planting; late dry season Mid growth; early wet season Pre-harvesting; late wet season	Month can be indicative of a number of factors including, growth stage of the crops, season and rainfall (Leirs et al. 2010, Vanroy 2018).
Current crop	Soya beans Cultivated vegetation Natural vegetation	The crop that is currently growing in the field	Crop can be a factor affecting rodent abundance as it can be favoured by rodents for ease of access, cover or size of grain (Swanepoel et al. 2017).
Previous crop	Soya beans Maize Cultivated vegetation Natural vegetation	The vegetation that was planted in the field the previous season	Crops planted in previous seasons can leave a large amount of food behind which is easily accessible to rodents living in these fields (Price et al. 1996, Swanepoel et al. 2017).
Height of vegetation	-	Measured in centimetres	Crop height can reduce predation risk by avian predators. It can also shelter them from climatic elements such as sunlight and rainfall (Mohr et al. 2003, Leirs et al. 2010).

RESULTS

From the collective trapping over 12 nights, there were 2044 trap nights, from the 147 traps over 4 nights in October 2018 and the 182 traps over 4 nights in January 2019 and April 2019 respectively. From these 2044 trap nights, 270 rodents were captured resulting in an overall 13% trapping success. Twenty-three of these captures were in October 2018, 130 were in January 2019 and 117 were in April 2019. On a uniquely marked level, 17 individuals were caught in October 2018, 47 individuals were caught in January 2019, and 72 individuals were captured in April 2019. Of the total 136 animals captured, 125 (92%) were *Mastomys* species and 11 (8%) were *Rhabdomys dilectus*. All the *R. dilectus* were caught in either Grid 3 (cultivated veld) in October 2018 (10 individuals), or in Grid 4 (natural veld) in April 2019 (1 individual).

Table 2.2: Average weights (g) of the different species and sexes over the different sampling periods to determine which factors could be affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

Species	**Sex**	**October 2018**	**January 2019**	**April 2019**	**Overall**
***Mastomys* species**	**Male**	28.75 (n = 4)	47.00 (n = 21)	40.87 (n = 30)	42.32 (n = 55)
	Female	23.33 (n = 3)	35.38 (n = 21)	34.97 (n = 37)	34.45 (n = 61)
Rhabdomys dilectus	**Male**	34.50 (n = 8)	-	20.00 (n = 1)	32.89 (n = 9)
	Female	35.00 (n = 1)	-	-	35.00 (n = 1)

Table 2.3: Minimum number of animals alive (MNA) and abundance estimates for rodents caught in the different grids during the different sampling periods to determine which factors could have affected rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

Month	**October 2018**				**January 2019**				**April 2019**			
Grid	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
MNA	6	1	10	-	12	36	0	0	11	55	2	4
Abundance estimate (SE)	10 (0.3)	1 (1.0)	12 (0.3)	-	11 (0.3)	33 (0.2)	0 (0.0)	0 (0.0)	13 (0.3)	47 (0.1)	2 (0.7)	6 (0.4)

None of the months were significantly different from one another (boxplot overlap – see Figure 2.2). However, in April 2019 there was a relative increase in the maximum number of rodents caught (Figure 2.2). Crop type appeared to have an effect, specifically soya beans were different from the other crops growing in the fields having the highest abundances (Figure 2.3), and there was a large estimated abundance of rodents in fields where soya beans had been growing previously (Figure 2.4).

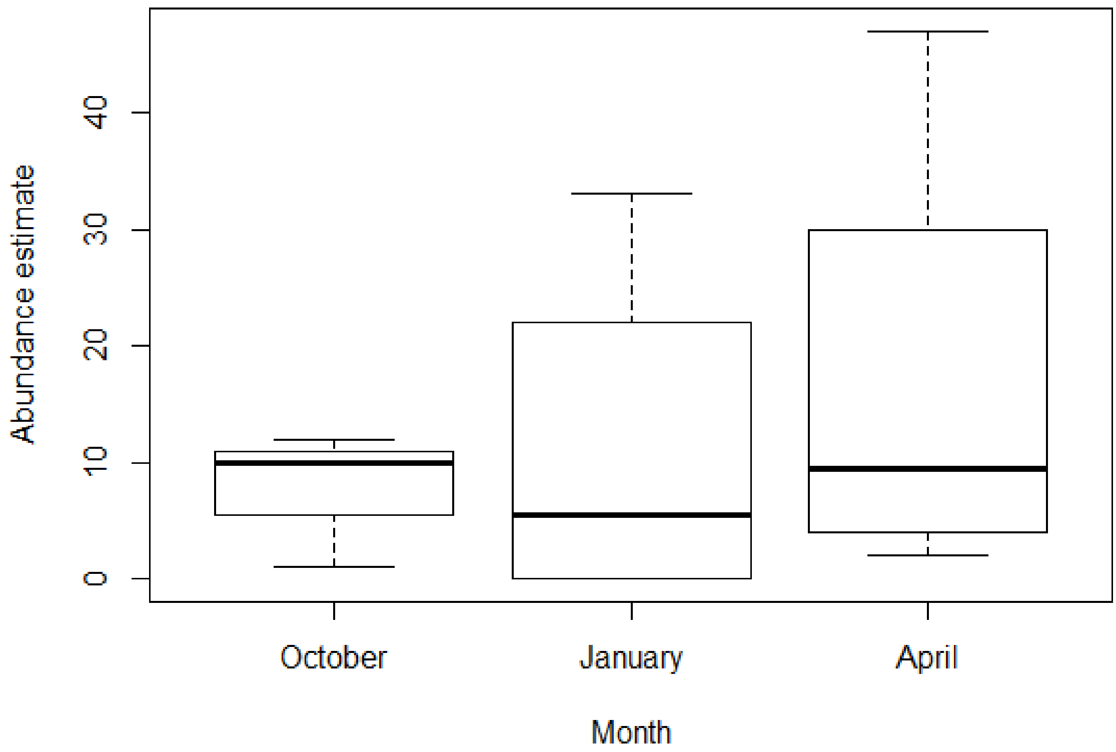

Figure 2.2: Comparison of rodent abundance estimates between the different sampling periods to determine which factors could be affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

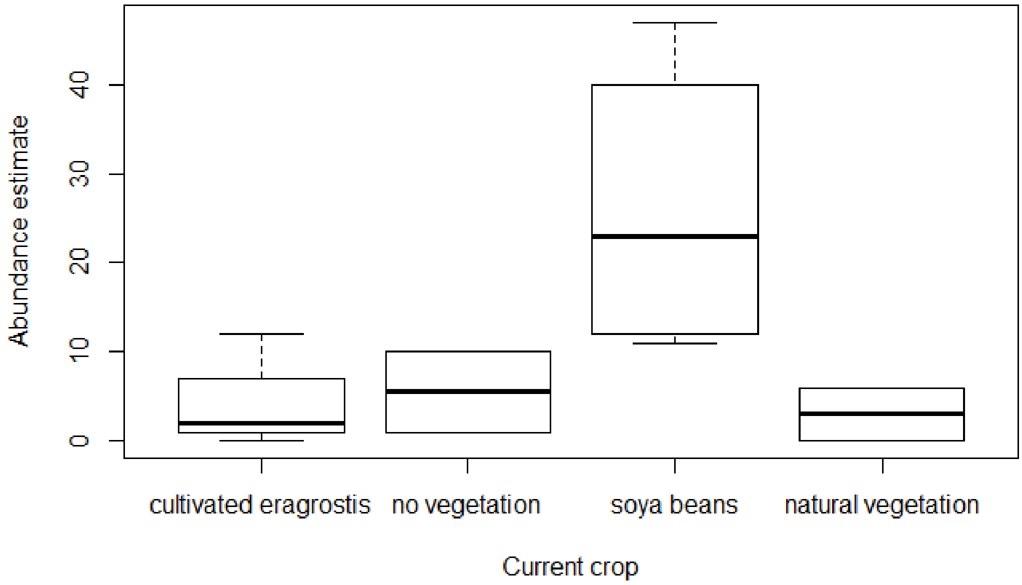

Figure 2.3: Comparison of rodent abundance estimates between fields with different crops or vegetation growing in them to determine which factors could be affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

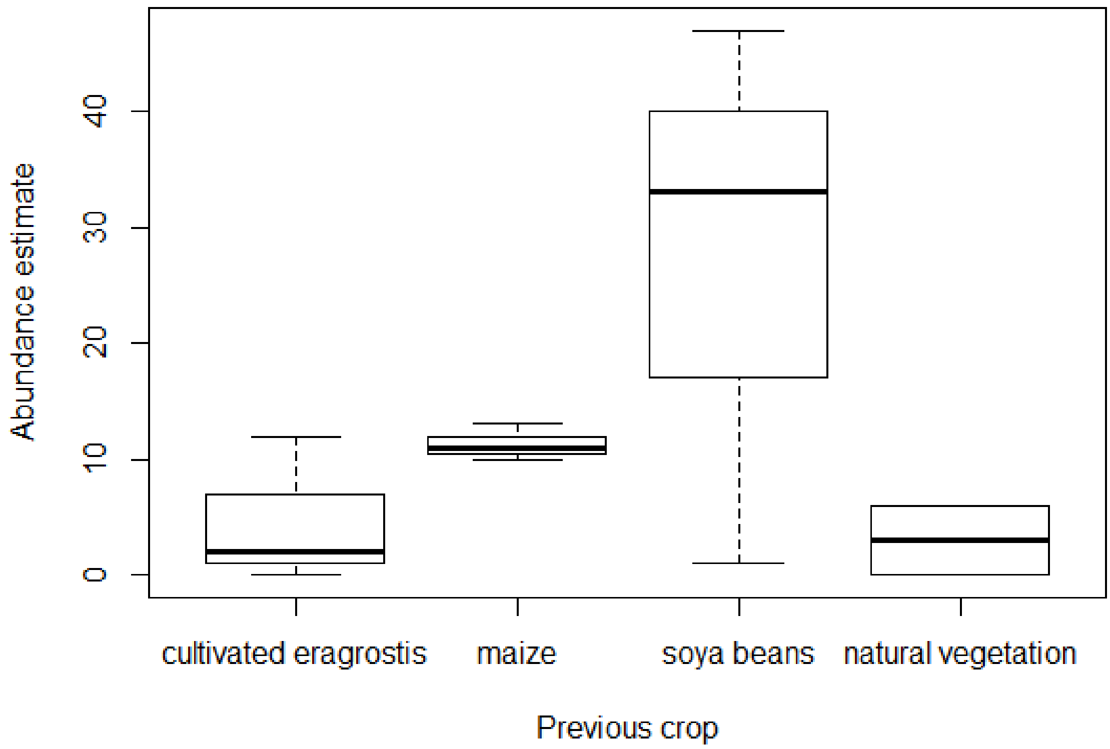

Figure 2.4: Comparison of rodent abundance estimates between the different crops or vegetation that were previously growing in the fields, to determine which factors could be affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

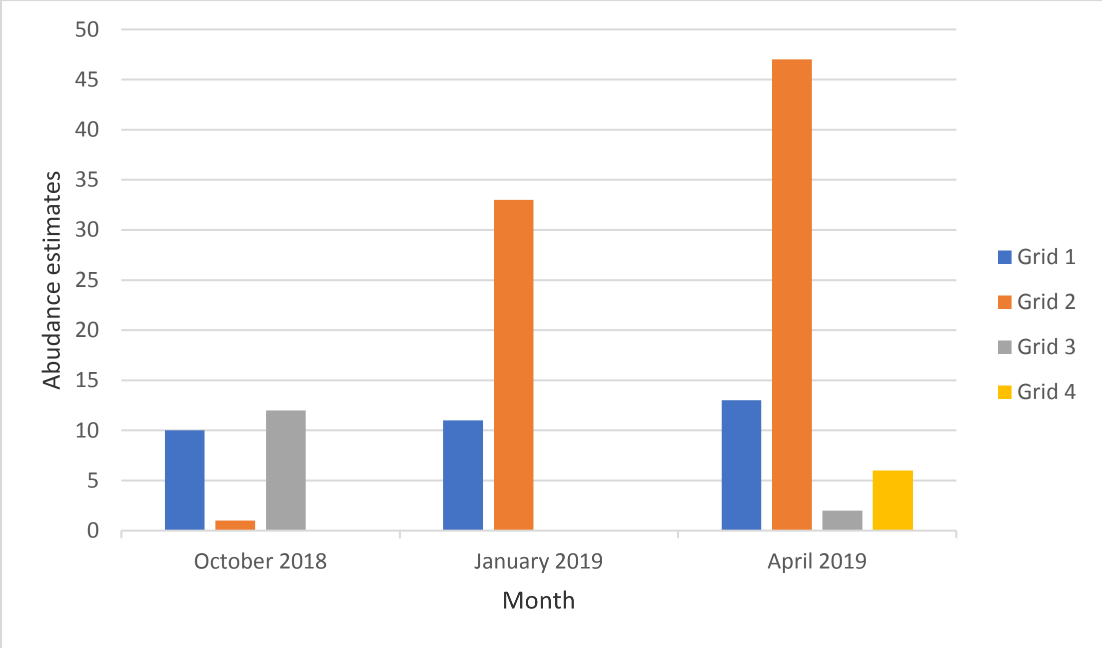

Figure 2.5: Abundance estimates for rodents caught in the different grids during the different sampling periods to determine which factors could be affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

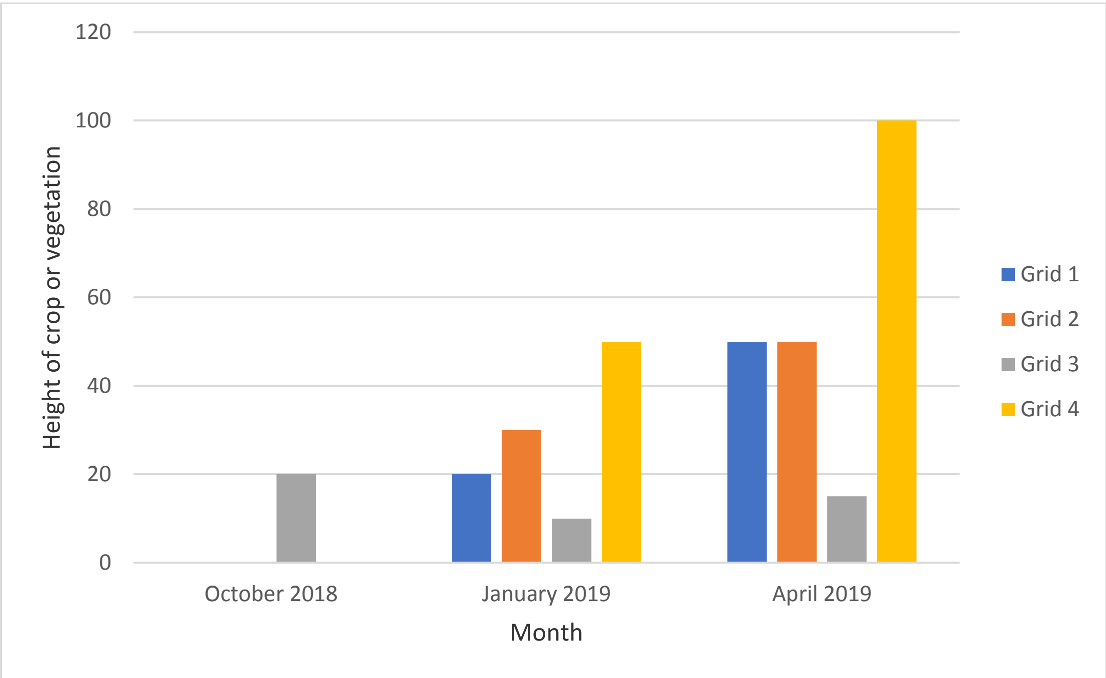

Figure 2.6: Height of the crop growing in the field of the grids during the different sampling periods to determine which factors could be affecting rodent abundance on the Hanroux and Palmietskuil farms along the N17 highway near Devon, Gauteng

Height of a crop across the trapping period is presented in Figure 2.6. Comparing this to Figure 2.5, representing how the rodent abundance estimates differed between the different sampling periods, there was an increase in the rodent abundance estimates over time, in grids 1, 2 and 4 (Figure 2.5). This responds similarly to the increase in the height of the crops or vegetation growing in the fields when the sampling took place. The height of the crop in grid 3 varied and did not increase over time and in comparison, neither did the estimated abundance of the rodents found in this field.

DISCUSSION

Rodent communities in this study were predominantly made up of *Mastomys* species, and the abundance estimates per hectare of these rodents varied across the different grids and across the different sampling occasions. The abundance estimates were highest in April 2019 in Grid 2 with 47 animals per hectare (minimum number alive = 55). According to literature, with the close link that rodent pest abundance and associated damage to crops have, one can extract a potential level of 5% damage to crops (Brown et al. 2007). Brown et al. (2007), suggests that when mouse populations are at 35-50 mice (*Mus domesticus*) per hectare it will likely result in approximately 5% damage to crops. It is also suggested that at this point a "tolerance" threshold is reached for farmers (Brown et al. 2007). With the 47 mice per hectare (MNA = 55 mice per hectare) (Table 2.3) reported in Grid 2 in April 2019, it can be suggested that the tolerance of farmers will be lower than the threshold. This could lead to farmers employing more extreme measures to resolve rodent pests, such as indiscriminate use of rodenticide to reduce the number of rodents (Singleton et al. 1999, Swanepoel et al. 2017).

Rhabdomys dilectus were also present on site (n = 11) but few individuals were caught in comparison to the number of *Mastomys* individuals caught (n = 125). This observation fits with the literature, as *Mastomys* species are pioneer species and are known to increase in population sizes when the environmental conditions are ideal (De Graaff 1981, Mulungu et al.

2013, Swanepoel et al. 2017). Being a species that is highly fecund, *Mastomys* species can have large litters, with up to 24 pups in a litter, leading to large and rapid population increases (De Graaff 1981, Leirs et al. 2010, Swanepoel et al. 2017). *Rhabdomys dilectus* is also a pioneer species but they are a diurnal species and no dedicated trapping was done during the day which is likely why their numbers were much lower (De Graaff 1981).

Considering the temporal changes across this study, there could be a number of reasons why April 2019 had the highest abundance estimates and October 2018 had the lowest abundance estimates. Firstly, rainfall is reported to have a great effect on rodent populations and that unseasonably high rainfall can result in population irruptions (Leirs et al. 2010, Buckle and Smith 2015). This is because of the increase in vegetation for the rodents to eat and because *Mastomys* species are able to breed so prolifically. This is especially prevalent when there has been a period of low population numbers (Leirs et al. 2010). This study did not include rainfall in the data analysis process as the available recorded rainfall numbers were from an area too far away (OR Tambo International Airport) for a locally accurate estimate about whether it had an effect or not, but there was an increase in rainfall in January 2019 which was so large it nearly postponed the sampling period and an increase in rainfall in April 2019 which was so large it did postpone the sampling period (per. obs.). It could thus be speculated that the increase in rodent populations in these months may thus have been due to the increase in rainfall, especially following the low population numbers in October 2018. However, no accurate conclusions about rainfall can be drawn from these observations.

The increase in rain could also mean an increase in available food for the rodents in the area and thus it is possible for more rodents to survive (Swanepoel et al. 2017). Additionally, the sampling periods also correspond with the natural vegetation/crop growing season with pre-planting (October 2018), mid growth stage (January 2019) and pre-harvesting

(April 2019). These seasons represent an increase in available food for the rodents in the field. More evidence of this can be seen in the increasing weight of the *Mastomys* species over the different sampling periods, as when food availability increases, body weight of the animal increases (see Table 2.2) (see Mamba et al. 2019).

Another factor associated with the different sampling periods and time, is that the changing growing season for crops in fields also represents a change in the height of the crops, as can be seen by the results. This increase in height provides an increase of cover of the rodents in the field. Cover has been found to be a main driver in rodent species presence and abundance, linked to reduction in predation risk from avian predators, and thus they are more likely to give up food resources in areas that are less covered (Mohr et al. 2003, Leirs et al. 2010).

Crop type seems to have contributed to rodent population abundance, in this case soya beans. This could be for a number of reasons. It has been found that when there are cultivated vegetation fields available and non-cultivated vegetation fields available, rodents will choose the cultivated vegetation (Houtcooper 1978). In a study done in the USA in maize and soya bean fields, the diet of rodents caught in these fields was made up mostly of maize and soya beans (Houtcooper 1978). This aligns with the current study as most rodents were found in cultivated fields, and while Grid 3 was a field with a cultivated crop with very few captures, it is a native grass species. The height of the *Eragrostis tef* in Grid 3 likely did not provide the rodents with enough of a reduction in predation risk in the form of cover.

The difference between Grid 1 and Grid 2's rodent abundance remains unclear as they were both soya bean fields for this study period. Again, the height of the soya bean crop in the different fields was different and this may have led to the differences in the abundance of rodents. In January 2019 the soya beans in Grid 1 were lower than in Grid 2 (20 cm and 30 cm, respectively), due to the fact that there was a hailstorm in December 2018 and thus replanting in Grid 1. This could have contributed to the lower abundance of rodents (Mohr et al. 2003, Muck and Zeller 2006, Leirs et al. 2010, Mamba et al. 2019).

In April 2019, even though the heights of the soya beans in Grid 1 and Grid 2 were equal, the age of the plant was different. Because of the replanting in Grid 1, the soya beans in Grid 2 were slightly older. The age of the plant affects the drying of the legume pods and could have resulted in increases in soya beans available for the rodents in Grid 2. A survey in June 2019 (Hannweg unpubl.) found that Grid 2 had the highest average wastage per square metre at 8.75 g of soya beans, compared to 2.38 g in Grid 1. This increase in food wastage could lead to an increase of rodent populations from an increase in available food.

With the low captures in Grid 4, in addition to low vegetation cover, research indicates that trampling by large herbivores affects rodent abundance levels (Muck and Zeller 2006, Avenant and Cavallini 2007). The larger abundance of food for rodents in the agricultural fields as opposed to in the natural veld, may also play a role (Mulungu et al. 2015, Mamba et al. 2019). This supports evidence that agriculture in an area would increase the rodent populations (Mulungu et al. 2015, Mamba et al. 2019). This is especially true for an irruptive species like the *Mastomys* species (De Graaff 1981).

The field with cultivated *Eragrostis tef,* (Grid 3) yielded several *Rhabdomys* individuals in October 2018 (n = 10), no rodents in January 2019 and one rodent in April 2019. As previously mentioned, *R. dilectus* being diurnal, could possibly still be moving about but are not captured due to the sampling protocol where I closed the traps during the day. However, movement across the landscape is also possible (Dickman et al. 1995, Leirs et al. 2010). A small distance migration is also possible for the *Mastomys* species individuals that were found in grid 3 in October 2018, and a study done in 2018 showed an individual had moved from grid 2 to grid 1 when grid 2 was harvested (Leirs et al. 2010, Vanroy 2018). In the same study, only four individuals were caught in grid 3 in April 2018, but in June 2018, after the soya beans in grid 2 had been harvested and there were no more crops in that field, there was an increase in the number of individuals in Grid 3 (n = 36) (Vanroy 2018). Additionally, rodents, being sensitive to environmental conditions and having a short life cycle, are able to have large population fluctuations, and are thus able to become locally extinct in an area and then re-inhabit an area within months (De Graaff 1981, Stenseth 2001, Avenant and Cavallini 2007, Previtali et al. 2009).

CONCLUSION

There are a number of factors that are affecting rodent populations and causing their numbers to increase dramatically (Muck and Zeller 2006, Mulungu et al. 2015, Swanepoel et al. 2017). Most notable is the season, which correlates to rainfall, stage of the crop cycle and the height of the crops (Mohr et al. 2003, Leirs et al. 2010, Buckle and Smith 2015, Mulungu et al. 2015, Mamba et al. 2019). Additionally, soya beans appear to be the crop that is most attractive for *Mastomys* species in this study as well as other works (Houtcopper 1978). Vegetation structure and cover have a significant impact on rodent populations and in this study, this seems to be the case. The vegetation structure of an agricultural field could limit aerial predators (Mohr et al. 2003, Leirs et al. 2010, Mamba et al. 2019).

The high abundance of rodents reported in Grid 2 and Grid 1 in January 2019 and April 2019 are likely contributing as a plentiful food source for owl populations in the larger area. The likely impact that high rodent numbers can have on farmers tolerance of damage to their crops, could lead to non-ecologically friendly rodent management strategies. With the high abundance of owls, owls can be a valuable source of rodent suppression (Paz et al. 2013, Labuschagne et al. 2016). However, owls are sensitive to secondary poisoning (Labuschagne et al. 2016, Serieys et al. 2019). Therefore, it is important that the factors that have been identified as having the most effect on rodent population increases in the area are considered in these rodent management decisions as well.

LITERATURE CITED

Ansara, T. 2004. Determining the ecological status and possible anthropogenic impacts on the grass owl (*Tyto capensis*) population in the East Rand Highveld, Gauteng. MSc Thesis, Rand Afrikaans University, Johannesburg, South Africa.

Apps, P. 2000. Smithers' Mammals of Southern Africa, a field guide. Struik Publisher, Johannesburg, South Africa.

Avenant, N. L., and P. Cavallini. 2007. Correlating rodent community structure with ecological integrity, Tussen-die-Riviere Nature Reserve, Free State province, South Africa. Integrative Zoology 2:212-219.

Bronner, G., and J. Meester. 1987. Comparison of methods for estimating rodent numbers. South African Journal of Wildlife Research 17:59–63.

Brown, P. R., N. I. Huth, P. B. Banks, and G. R. Singleton. 2007. Relationship between abundance of rodents and damage to agricultural crops. Agriculture, Ecosystems and Environment 120:405–415.

Buckle, A. P., and R. H. Smith. 2015. Rodent pests and their control. CABI, Wallingford, UK.

Conroy, M. J., and J. P. Carroll. 2009. Quantitative Conservation of Vertebrates. Wiley-Blackwell, Oxford, United Kingdom.

De Graaff, G. 1981. The rodents of Southern Africa: notes on their identification, distribution, ecology, and taxonomy. Butterworths, Durban, South Africa.

Dickman, C. R., M. Predavec, and F. J. Downey. 1995. Long-range movements of small mammals in arid Australia: implications for land management. Journal of Arid Environments 31:441-452.

Hockey, P., W. Dean, and P. Ryan. 2005. Roberts' Birds of Souh Africa. John Voelcker Bird Book Fund, Cape Town, South Africa.

Houtcooper, W. C. 1978. Food Habits of Rodents in a Cultivated Ecosystem. Journal of Mammalogy 59:427–430.

Huysman, A., D. St George, M. Johnson, M. Charter, C. Wendt, S. Hindmarch, G. Rozman, P. Rivadeneira, and E. Phillips. 2018. A Review of Research Methods for Barn Owls in Integrated Pest Management. Technical Report of the BARD Conference on the Use of Barn Owls for Agricultural Pest Control, 5-7 March 2018 at University of California Agricultural and Natural Resources. <http://www.barnowlpestcontrol.com/uploads /1/1/7/3/117396152/Huysman_et_al_2018.pdf>.

Kirsten, F., E. J. Richardson, and C. Peplow. 2010. Key to small mammals commonly found in agricultural areas in eastern and southern Africa. <http://projects.nri.org/ecorat/docs /Ecoratkeyagricrodents.pdf>. Accessed 1 October 2018.

Labuschagne, L., L. H. Swanepoel, P. J. Taylor, S. R. Belmain, and M. Keith. 2016. Are avian predators effective biological control agents for rodent pest management in agricultural systems? Biological Control 101:94-102.

Leirs, H., V. Sluydts, and R. Makundi. 2010. Rodent outbreaks in sub-Saharan Africa. Pages 9–280 in. Rodent Outbreaks: Ecology and Impacts. International Rice Research Institute, Los Banos, Phillipines.

Mamba, M., N. J. Fasel, T. A. M. Mahlaba, J. D. Austin, R. A. McCleery, and A. Monadjem. 2019. Influences of sugarcane plantations on the population dynamics and community structure of small mammals in a savanna-agricultural landscape. Global Ecology and Conservation 20:e00752.

Mohr, K., S. Vibe-Petersen, L. L. Jeppesen, M. Bildsøe, and H. Leirs. 2003. Foraging of multimammate mice, *Mastomys natalensis*, under different predation pressure: cover, patch-dependent decisions and density-dependent GUDs. Oikos 100:459–468.

Muck, C. and U. Zeller. 2006. Small mammal communities on cattle and game grazing areas in Namibia. African Zoology 41:215-223.

Mulungu, L.S., T. A. Mahlaba, A. W. Massawe, J. Kennis, D. Crauwels, S. Eiseb, A. Monadjem, R. H. Makundi, A. A. S. Katakweba, H. Leirs, and S. R. Belmain. Dietary differences of the multimammate mouse, *Mastomys natalensis* (Smith 1834), across different habitats and seasons in Tanzania and Swaziland. Wildlife Research 38:640-646.

Mulungu, L. S., V. Ngowo, M. Mdangi, A. Katakweba, P. Tesha, F. P. Mrosso, M. Mchomvu, P. M. Sheyo, and B. S. Kilonzo. 2013. Population dynamics and breeding patterns of multimammate mouse , *Mastomys natalensis* (Smith 1834), in irrigated rice fields in Eastern Tanzania. Pest Management Science 69:371–377.

Mulungu, L. S., V. Ngowo, M. E. Mdangi, A. S. Katakweba, P. Tesha, F. P. Mrosso, M. Mchomvu, A. W. Massawe, A. Monadjem, B. Kilonzo, and S. R. Belmain. 2015. Survival and recruitment of the multimammate mouse, *Mastomys natalensis* (Smith 1834), in a rice agro-system. Mammalia 80:205-210.

Palis, F. G., G. R. Singleton, P. R. Brown, N. H. Huan, C. Umali, and N. T. D. Nga. 2011. Can humans outsmart rodents? Learning to work collectively and strategically. Wildlife Research 38:568–578.

Paz, A., D. Jareño, L. Arroyo, J. Viñuela, B. Arroyo, F. Mougeot, J. J. Luque-Larena, and J. A. Fargallo. 2013. Avian predators as a biological control system of common vole (*Microtus arvalis*) populations in north-western Spain: Experimental set-up and preliminary results. Pest Management Science 69:444-450.

Previtali, M. A., M. Lima, P. L. Merserve, D. A. Kelt, and J. R. Gutierrez. 2009. Population dynamics of two sympatric rodents in a variable environment: rainfall, resource availability, and predation. Ecology 90:1996-2006.

Price, J. S., R. N. Hobson, M. A. Neale, and D. M. Bruce. 1996. Seed losses in commercial harvesting of oilseed rape. Journal of Agricultural Engineering Research 65:183–191.

Serieys, L. E. K., J. Bishop, N. Okes, J. Broadfield, D. J. Winterton, R. H. Poppenga, S. Viljoen, R. K. Wayne, and M. J. O'Riain. 2019. Widespread anticoagulant poison exposure in predators in a rapidly growing South African city. Science of the Total Environment 666:581–590.

Singleton, G. R., H. Leirs, L. A. Hinds, and Z. Zhang. 1999. Ecologically-based management of rodent pests – re-evaulating our approach to an old problem. Pages 17-29 in. Ecologically based management of rodent pests. Australian Centre for International Agricultural Research, Canberra, Australia.

Smit, A., H. van der Bank, T. Falk, and A. de Castro. 2001. Biochemical genetic markers to identify two morphologically similar South African Mastomys species (Rodentia: Muridae). Biochemical Systematics and Ecology 29:21-30.

Stenseth, N. C., H. Leirs, S. Mercelis, and P. Mwanjabe. 2001. Comparing strategies for controlling an African pest rodent: an empirically based theoretical study. Journal of Applied Ecology 38:1020–1031.

Stenseth, N. C., H. Leirs, A. Skonhoft, S. A. Davis, R. P. Pech, H. Andreassen, G. R. Singleton, M. Lima, R. S. Machang'u, R. H. Makundi, Z. Zhang, P. R. Brown, D. Shi, and X. Wan. 2003. Mice, rats, and people: the bio-economics of agricultural rodent pests. Frontiers in Ecology and the Environment 1:367–375.

Swanepoel, L. H., C. M. Swanepoel, P. R. Brown, S. J. Eiseb, S. M. Goodman, M. Keith, F. Kirsten, H. Leirs, T. A. M. Mahlaba, R. H. Makundi, P. Malebane, E. F. Von Maltitz, A. W. Massawe, A. Monadjem, L. S. Mulungu, G. R. Singleton, P. J. Taylor, V. Soarimalala, and S. R. Belmain. 2017. A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: Are we asking the right questions? PLoS ONE 12:e0176621.

Tarboton, W., and R. Erasmus. 1998. Owls and Owling in Southern Africa. Struik Publisher, Cape Town, South Africa.

Vanroy, T. 2018. Species richness of rodent populations in an agricultural matrix, and viability use on chew cards. BSc Honours Thesis, University of Pretoria, Pretoria, South Africa.

Chapter 3: The biological and environmental factors affecting owl occupancy in an agricultural matrix in the north-east of the Sedibeng district of Gauteng

INTRODUCTION

Agricultural environments often hold a large number of rodents due to the easy and abundant food available to them in these environments (Stenseth et al. 2001, 2003, Swanepoel et al. 2017). This often leads to them become troublesome for farmers as rodents can damage crops in a number of ways (Mulungu et al. 2003, Brown et al. 2007). A method that has grown in popularity over the years to help combat rodent pests is ecologically based rodent management (EBRM) (Singleton et al. 1999, Palis et al. 2011, Paz et al. 2013). This incorporates natural predators of rodents into the system to help control the levels of rodents on a farm. A species that is commonly part of the EBRM approach is the western barn owl (*Tyto alba*) (Paz et al. 2013, Labuschagne et al. 2016). Barn owls are adaptable to the area, and as such are often found in agricultural areas already, all over the world (Tarboton and Erasmus 1998, Oberprieler and Cillie 2002, Labuschagne et al. 2016).

The agricultural matrix in the east of Gauteng is somewhat unique in its characteristics in that it includes the Boesmanspruit Highveld Grassland and the Blesbokspruit Highveld Grassland which includes the Blesbokspruit, a Ramsar Wetland Site (Roychoudhury and Starke 2006, SANBI 2013). Owls are regularly found in agricultural environments, but this particular area and its wetlands has made it important for the vulnerable African grass-owls (*Tyto capensis*), an owl that needs rank grass near water for nesting sites (Tarboton and Erasmus 1998, Taylor et al. 2015). Therefore, while many agricultural environments do attract owls due to the increased availability of food sources, there is an even larger number of owls in the study area due to the ideal nesting opportunities, not only for African grass-owls, but also for other grass nesting owl in the area, the marsh owl (*Asio capensis*) (Taylor et al. 2015). Both the Boesmanspruit Highveld Grassland ecosystem that the study area falls in, and the Blesbokspruit Highveld Grassland ecosystem which is nearby, are critically endangered ecosystems meaning that they are threatened due to previous and ongoing transformation and loss in terms of original extent and ecological state and condition (SANBI 2013). This puts additional pressure on the species in the area, including the vulnerable African grass-owl (SANBI 2013).

There are other downfalls associated with owls relying on rodent populations in agricultural matrices for food. Firstly, using only biological control measures on a farm to control rodents is not an optimal system. Owing to boom and bust periods of rodent prey populations, owl populations will increase as rodent populations increase, at a lagged rate. When the rodent population begins to decline again (bust phase) due to environmental constraint (e.g. food shortage) the owl population will experience food source shortage. The boom-bust cycle will then reach a second critical point where the owl population cannot keep the rodent population in control any longer and the rodent population will be begin to increase (Korpimaki and Krebs 1996). This delay in response and the fact that the effect is not permanent often does not satisfy farmers' needs (Brown et al. 2007).

Another issue that presents itself when owls rely on farmland for food sources is the fact that when species such as marsh owls and grass-owls rely on cultivated grasslands for nesting, their nests can be disturbed by the farming practises (e.g. harvesting) of natural vegetation for animal feed. In grassland that is being kept natural for grazing purposes, nests run the risk of being disturbed by grazing cattle (Scholer et al. 2014, Taylor et al. 2015). Fire is also often used in these fields for a number of reasons, such as for keeping parasites at bay, encouraging regrowth or for flushing other agricultural pests such as seed eating birds and this has also been found to disturb owls (Scholer et al. 2014, Taylor et al. 2015). Fires and grazing are natural parts of the grassland ecosystem, however improper use of fire and heavy grazing can have negative effects on grasslands (SANBI 2013). The African grass-owl is extremely sensitive to nest disturbances and will often not return to the site for months or years once the area has been disturbed (Taylor et al. 2015). Being in themselves a vulnerable species this can be a problem.

Finally, an issue that is very prevalent in the study area in the east of Gauteng along the N17 highway, is the issue of roadkill deaths of owls (Ansara 2004, Collinson et al. 2015). The current research area has been reported to have extremely high owl roadkill deaths for nearly two decades (Ansara 2004). During harvest season, crops are transported from farms to grain silos by trucks travelling along the national and regional roads in the area. It has been noted that an issue has arisen with grain being spilled by these trucks and thus attracting animals such as rodents to the roads (Ansara 2004, Collinson et al. 2015, Gangadharan et al. 2017). This in turn attracts owls to the road where they are sometimes hit by vehicles (Ansara 2004, Collinson et al. 2015). They are also sometimes caught on the road, quartering (Hockey et al. 2005). Being nocturnal animals, owls are often the victims of being dazzled by headlights and are thus not able to move in time before being struck. Drivers are also often not as able to see them before it is too late. This is a problem consistent throughout nocturnal animals (Tarboton and Erasmus 1998, Kioko et al. 2015, Williams et al. 2019).

With the issues strongly associated with anthropogenic factors listed above and with the vulnerable African grass-owl being one of the four owl species found in the area, this research chapter was undertaken. Research on owls in an agricultural matrix is a topic that has been fairly well researched, but not in developing countries, such as South Africa, where biological rodent control is a relevant topic (Swanepoel et al. 2017, Williams et al. 2019). With these owls being important for the control of rodents in the area, it is important to assess what factors are affecting owl occupancy in the area as well as species richness, to ensure that relevant scientific information is made available to allow for good management decisions by relevant management authorities (Santos et al. 2013, Fattebert et al. 2018).

The aim of this study is to assess the underlying ecological and anthropogenic factors affecting owl occupancy in the study area by 1) assessing the species presence of owls in the area, based on road count data, and 2) quantifying factors affecting owl presence or absence in the study area, using occupancy estimates and covariates derived from remote sensing data.

STUDY AREA

For more information on the study area, please see the study area section of Chapter 1.

METHODS

To conduct this research, I sampled the study area during 3 different periods; October 2018, January 2019 and April 2019, using a road count survey methodology for a 5 night duration per sampling occasion (Malan 2009). Road counts were used as opposed to spot counts for practicality (Wiens et al. 2011, Scholer et al. 2014). Roads counts were conducted for approximately two hours each night using a 4 x 4 vehicle, in a team of two, with one person driving and the other using a spotlight to search for owls. The surveys began 30 minutes before sunset to ensure that all owl species were accounted for as some species begin hunting at dusk, some before dusk and some after dusk (Tarboton and Erasmus 1998, Oberprieler and Cillie 2002, Labuschagne et al. 2015).

I travelled approximately 51 kilometres each night at a speed of 40 km/hour, following similar methodology to Labuschagne (2015). When an owl was spotted, the vehicle was stopped and the GPS position and species of owl (where possible) was recorded. This route covered most of a 50 km^2 area in the Devon area in east Gauteng. The route included sections on the N17 highway, the regional roads, the R550, the R29 and R548, an unnamed tar road connecting the R29 and the R550 and farm roads we had access to from the rodent study (Figure 3.1). Each night the starting point was randomised to avoid bias from starting at the same point. To allow for adequate sample sites without the risk of counting an owl twice in two separate sites (MacKenzie et al. 2017), I created a 2 x 2 kilometre grid in QGIS (version 3.0.1). It is recommended that grid sizes are kept as small as possible to avoid counting an owl twice in two separate sample sites, but it is also important to keep the practicality of sampling a very large number of sites in mind (MacKenzie et al. 2017). Therefore, the 2 x 2 kilometre grid is the smallest possible grid taking into account all the ranges of all 4 owl species (Labuschagne 2015).

To determine which factors may be affecting owl occupancy in the study area I used occupancy models with a number of covariates. The covariates I analysed for these occupancy models were spatial data extracted using QGIS (version 3.0.1). I considered the following covariates; 1) percentage of transformed land in the site, 2) percentage of water sources in the site, 3) proportion of human settlements in the site, 4) an NDVI (Normalised Difference Vegetation Index (Fung and Siu 2000)) for each grid extracted from spatial data (USGS), and 5) estimated distance of the different road types in each grid (see Table 3.1 for more details). Choices for covariates were based on the fact that habitat, nesting opportunities and prey availability are considered the most important factors for owl occupancy (Labuschagne 2015).

Not all the sample sites were recorded equally due to the grid having to be laid over the route that we sampled. For this reason, it was necessary to include survey effort. I used length of road per grid as a percentage of the route covered and thus created an estimate of survey effort for the occupancy models. This was another covariate for detection in my original null model to then build a new null model. I then also used survey effort as a covariate for detection in every other model to account for possible survey bias. I did not include any of the grids without any road travelled as sample sites.

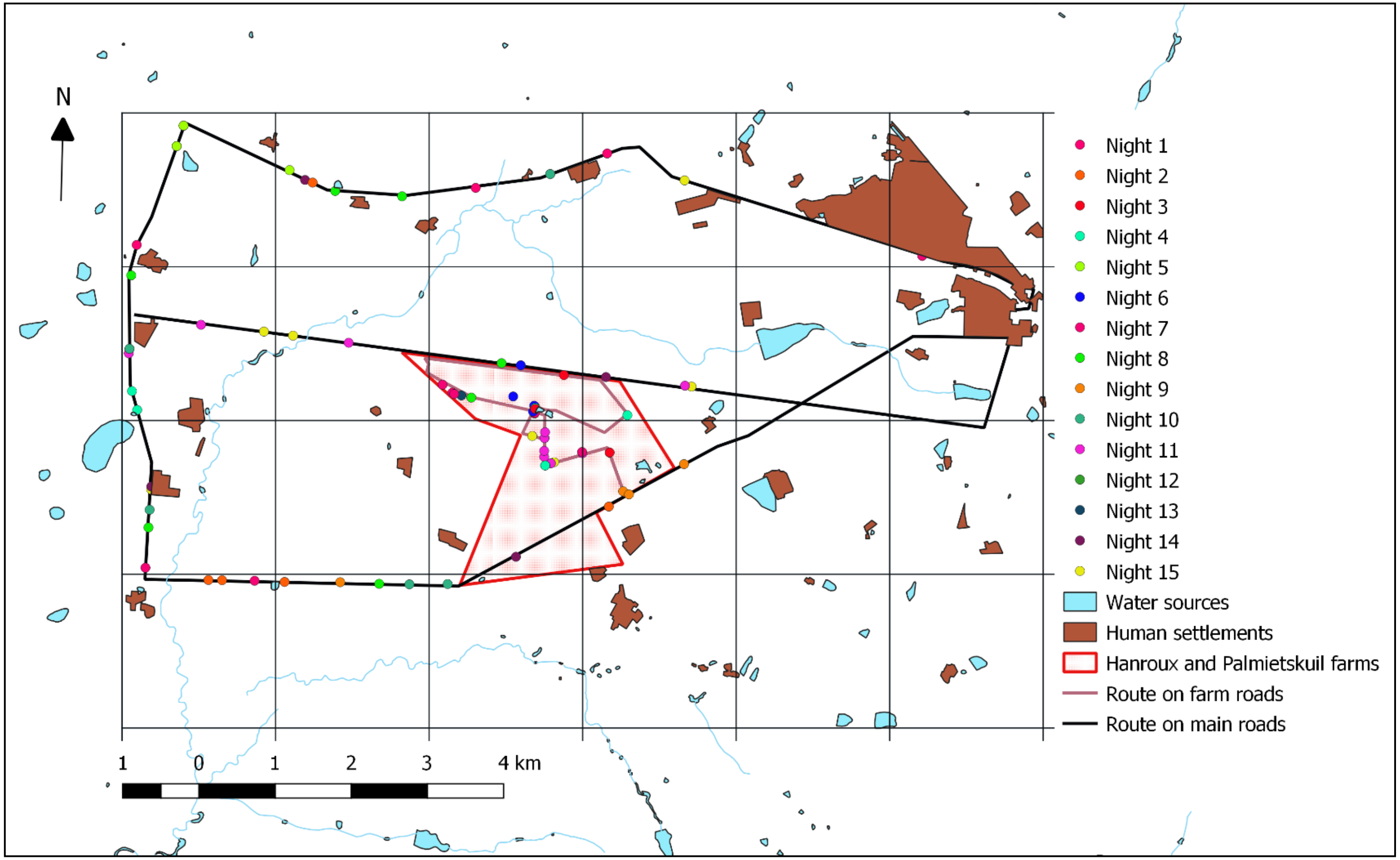

Figure 3.1: The Devon area along the N17 highway, Gauteng, South Africa, showing routes driven for the 15 nights surveyed, as well as all the sites where owls were sighted. Water sources and human settlements as well as the farm where the rodents were studied for the project is also included. Each grid is 2km x 2km and makes up a sample site. Created in QGIS 3.0.1.

Program R (version 3.4.3, www.r-project.org) and RStudio (version 1.1.423, first accessed 27 March 2018) were used to model a single-species single-season model for all three seasons (15 nights) and I ran a model for each of the covariates affecting occupancy and detection (Ihaka and Gentleman 1996). For this I used the R package unmarked (version 0.12-2) (Fiske and Chandler 2011), to estimate occupancy probability and detection probability (Wiens et al. 2011, Labuschagne 2015). I used the occuRN function on the unmarked package of R to determine an owl abundance estimate for the study (Fiske and Chandler 2011).

Table 3.1: Different covariates used in occupancy models of owls in an agricultural matrix in the east of Gauteng, as well as the reason for their use in this study.

Covariate	**Reason for use**
Proportion of untransformed land	Human settlements and agricultural land can have an effect on the occupancy of owls in an area (Scholer et al. 2014, Labuschagne 2015, Taylor et al. 2015, Fattebert et al. 2018). Polygons were drawn around all identifiably farmed land, human settlements and roads, in each grid. The total was subtracted from the 4km^2 in the grid (source Google Maps 2019).
Proportion of transformed land	Human settlements and agricultural land can have an effect on the occupancy of owls in an area (Scholer et al. 2014, Labuschagne 2015, Taylor et al. 2015, Fattebert et al. 2018). Polygons were drawn around all identifiably farmed land, human settlements and roads, in each grid. (source Google Maps 2019).
Proportion of water sources	African grass-owls can be extremely sensitive to and thus rely on water sources (Taylor et al. 2015, Williams et al. 2019). Polygons were drawn around all water sources in each grid. (source Google Maps 2019).

Proportion of human settlements	Barn owls and spotted eagle-owls can make use of these areas for nesting or hunting, but owls can sometimes be persecuted near these settlements and some prefer habitat further away from human settlements (Labuschagne 2015, Fattebert et al. 2018). Polygons were drawn around all human settlements in each grid. (source Google Maps 2019).
Distance of N17	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). Lines were drawn along the length of the N17 in each grid. (source Open Street Map 2018).
Distance of R550	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). Lines were drawn along the length of the R550 in each grid. (source Open Street Map 2018).
Distance of R29	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). Lines were drawn along the length of the R29 in each grid. (source Open Street Map 2018).
Distance of R548	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). Lines were drawn along the length of the R548 in each grid. (source Open Street Map 2018).
Distance of unnamed tar road	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). Lines were drawn along

	the length of the unnamed tar road in each grid. (source Open Street Map 2018).
Distance of farm road	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). Lines were drawn along the length of the farm roads in each grid, as mapped by the GPS co-ordinates taken at each corner of the road. (source Open Street Map 2018).
Distance of regional roads (R550, R29, R548)	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). The sum of the length of the R550, R29 and R548 was found in each grid (source Open Street Map 2018).
Distance of tar roads (R550, R29, R548, unnamed road, N17)	Roads can have a negative impact on wildlife especially nocturnal animals such as owls. The speed at which vehicles travel on roads and the number of vehicles on the road, may play a role in this (Santos et al. 2013, Williams et al. 2019). The sum of the length of the R550, R29, R548, unnamed tar road and N17 was found in each grid (source Open Street Map 2018).
NDVI (May 2018)	Owls can be more attracted to natural vegetation and undisturbed sites (Santos et al. 2013, Fattebert et al. 2018, Williams et al. 2019). (source United States Geological Survey 2019)

My first step with my models was to reduce the number of models that were to be run by reducing the number of covariates. To do this I used the Microsoft Excel (365) extension NumXL (version 1.65). This extension uses VIF (variance inflation factor) to test for multicollinearity. I then ran two models for each covariate, one with an effect on probability and one with an effect on detection with survey effort. With the different models that I ran I then used an Akaike Information Criterion (AIC) for the model selections (Burnham and Anderson 2002). Further, model selection was based on the lowest AIC value and models within a 2 value difference of the lowest AIC were considered to be similar in support. (Burnham and Anderson 2002). I then extracted the occupancy and detection estimates for the models that best fit the data.

RESULTS

Over the 15 nights that surveys were conducted, 84 owls were sighted. Of these, 36 (43%) were marsh owls, 23 (27%) were barn owls, 9 (11%) were spotted eagle-owls and 16 (19%) were unidentified. In total, 15 of the 20 sites had an owl present at least once. Twenty-seven (32%) of these owls were seen in October and 10 of the 20 sites had an owl present at least once. 32 (38%) of these owls were seen in January and 11 of the sites had an owl present at least once. 25 (30%) of these owls were seen in April and 9 of the 20 sites had an owl present at least once. Over all of the three surveys (15 nights sampled) no African grass-owls were observed.

The naïve occupancy for the data was 0.75 for the study area. Once the “detection” was accounted for at 0.207 (SE = 0.028), the occupancy adjusted to 0.774 (SE = 0.101). To reduce and account for bias, I then added survey effort to the null model as a covariate for detection, and made this my new null model. This changed my detection estimate to 0.076 (SE = 0.028) and thus changed my occupancy estimate to 0.817 (SE = 0.102). With this new occupancy probability, using the occuRN function yielded an estimate of 2 owls per site (SE = 1.21).

I found that the factor which best explained the response data was “the surface area of water sources” at the sites where owls were seen (Table 3.3).

Table 3.2: Numbers of identified and unidentified owl species seen over five nights in the three sampling periods for the study of the biology of owls in an agricultural matrix in the east of Gauteng

Species	**October 2018**	**January 2019**	**April 2019**	**Total**
Marsh owls (*Asio capensis*)	8	12	16	36
Western barn owls (*Tyto alba*)	8	10	5	23
Spotted eagle-owls (*Bubo africanus*)	2	6	1	9
Unidentified	9	4	3	16
Total	27	32	25	84

Table 3.3: Occupancy models, and their occupancy estimates, detection estimates, AIC (Akaike Information Criterion) values and delta AIC, used in analysing the factors that are affecting owl species in an agricultural matrix in the east of Gauteng. WS = surface area of water sources in the site, SEff = survey effort in the site, R548 = length of R548 in the site, SE = standard error

Model	**Occupancy estimate (SE)**	**Detection estimate (SE)**	**AIC value**	**Delta AIC**
psi(WS)p(SEff)	1 (3.427 x 10^{-16})	0.079 (0.026)	234.95	0.00
psi(.)p(SEff + WS)	1 (0.001)	0.035 (0.015)	237.61	2.66
psi(.)p(SEff + R548)	0.903 (0.089)	0.078 (0.028)	245.32	10.37
psi(R548)p(SEff)	0.898 (0.090)	0.077 (0.028)	245.32	10.37
psi(.)p(SEff)	0.817 (0.102)	0.076 (0.028)	249.43	14.48

Considering the occupancy and detection estimates of the owls for each of the sampling seasons separately, namely October 2018, January 2019 and April 2019 (Table 3.4). October 2018 is pre-planting, late dry season; January 2019 is early growth, early wet season; and April 2019 is pre-harvest, late wet season.

Owl occupancy was highest in October 2018 and lowest in April 2019. This is the opposite of the detection probability which was highest in April 2019 and lowest in October 2018.

Table 3.4: occupancy and detection estimates for each sampling season from occupancy models with survey effort as factor affecting detection probability, to determine which season is affecting owl species the most in an agricultural matrix in the east of Gauteng. Overall occupancy and detection probability are included for comparison. SE = standard error

Season	**Naïve occupancy**	**Occupancy probability (SE)**	**Detection probability (SE)**
October 2018	0.50	0.996 (0.155)	0.051 (0.033)
January 2019	0.55	0.722 (0.167)	0.126 (0.072)
April 2019	0.45	0.526 (0.173)	0.156 (0.128)
Overall	0.75	0.817 (0.102)	0.076 (0.028)

DISCUSSION

The number of species in the study area remained constant for the duration of the study, with three owl species identified only, and no African grass-owls spotted. The most common owl species in the area is the marsh owl. This could be due to a number of reasons. Firstly, they are less territorial than the other owl species found in the area (i.e. barn owls and spotted eagle-owls) and sometimes considered gregarious (Hockey et al. 2005). This allows for more marsh owl individuals to occupy a smaller area. Secondly, the area is conducive to marsh owls and grass-owls nesting as there are a number of water sources in the area including the Marievale Bird Sanctuary approximately 12 kilometres away (Tarboton and Erasmus 1998, Hockey et al. 2005, Williams et al. 2019). Another reason why we may have observed so many more of this species than the other species is because their behaviour allows for easier observations. They are more diurnal than the other species which allows us to see this species more easily than the other species (Tarboton and Erasmus 1998, Oberprieler and Cillie 2002). With no African grass-owls recorded for the duration of the study and in early 2018 (Hannweg 2018), in total 5 driven periods, I acknowledge that grass-owls are notoriously elusive and, are a grass dwelling species, to a much greater degree than marsh owls (Tarboton and Erasmus 1998). The best method to observe this species is to flush them from their nests in the grass (Tarboton and Erasmus 1998, Ansara 2004), which was not part of this studies methodology. African grass-owls are extremely sensitive to any disturbance to their habitat, which includes drought, improper fire usage and heavy grazing (Tarboton and Erasmus 1998, SANBI 2013, Taylor et al. 2015). A recent drought in the area has had a major effect on agriculture and thus may have had an effect on grass-owl populations too (Baudoin et al. 2017). During the October 2018 survey, fires were observed and in January 2019 and April 2019 grazing was observed. Fire and grazing are a regular occurrence and are key factors affecting and disturbing African grass-owls and their nests (Tarboton and Erasmus 1998, Taylor et al. 2015). As mentioned before, the Blesbokspruit Highveld Grassland close to the study area and the Boesmanspruit Highveld Grassland that falls within the study area are both critically endangered ecosystems, and this may also have an effect of grass-owl populations (SANBI 2013).

Owl abundance estimates for the basic model presented as an average 2 owls per 2 x 2 kilometre site (SE = 1.21). When water source was added to the model the abundance of owls per site increased to an average of 6 owls per site. This fits with the behaviour of the three owl species seen during this study. The barn owl population is known to increase when there are favourable circumstances, such as increased food and nesting opportunities (Tarboton and Erasmus 1998, Hockey et al. 2005), and spotted eagle-owls have been reported to nest 1.44 km apart in favourable circumstances (Hockey et al. 2005). Marsh owls are the least territorial of these owls and can nest as close to 33 metres apart (Hockey et al. 2005). These numbers fit with what has been found in the past (Hockey et al. 2005). Spotted eagle-owls have been found nesting as close as 1.44 km apart, marsh-owls as close as 33m apart, and barn owls in pairs with ranges of approximately 2.5 km^2, in various parts of the country, however these numbers are the high end of the abundance scale (Hockey et al. 2005). The data presented here is supported by findings (Hockey et al. 2005), and an increase in owl abundances is strongly associated with an increase in water available and the owls in the area are less territorial when there is an increase in water sources. The other species of owls can to an extent eliminate the number of grass-owls (Wiens et al. 2011, Wiens et al. 2014, Kajtoch et al. 2015).

The occupancy models suggest the most important factor affecting owl occupancy is water sources. With marsh owls being reliant on grass near water for nesting sites, an increase in water sources will mean an increase in marsh owl populations. While grass-owls and marsh owls are often found nesting in the same area, because marsh owls are more generalist than grass-owls, they can be found in ratios of approximately 10 marsh owls to 1 grass-owl (Hockey et al. 2005). Additionally, when there is an increase in water sources in an area, it can mean an increase in rodents, birds, reptiles, amphibians and other prey for owl species (De Graaff 1981, Tarboton and Erasmus 1998, Leirs et al. 2010, Hodara and Poggio 2016). This increase in water in the area which increases primary productivity, benefits primary consumers such as rodents. The recent drought in the area may also mean that water is a limiting factor on owl occupancy and why it was lower than usual (Thibault et al. 2010, Taylor et al. 2015, Baudoin et al. 2017).

Comparing occupancy between the different seasons we can see that occupancy appears to be highest in October 2018 (0.996 ± 0.155) during the late dry season, before planting has begun. This observation suggests that it is likely not food, but more likely habitat that is driving the occupancy of owls in the area. In chapter 2, findings showed that rodents were the most abundant in April 2019 (47 ± 0.1) during the late wet season, pre-harvesting, compared to the abundance in October 2018 (1 ± 1.0) during the late dry season, pre-planting, in the same grid. It is also possible that the reason for this observation is a lagged boom-bust fluctuation where the owls may be reducing as a result of not enough rodents from the previous season and therefore the rodent population begins to increase again (Korpimaki and Krebs 1996).

Egg laying of the owl species present in the area, takes place between March and May for barn owls, marsh owls and grass-owls, and between August and September for spotted eagle owls (Tarboton and Erasmus 1998). Hatchlings then take between 35 and 50 days to leave the nest (Tarboton and Erasmus 1998). This means that any young owls that are new to the population will only be present in October and may have left the area by January and April before the new breeding season starts and pairs are established.

Fire in African grassland systems is one of the key drivers (Koerner and Collins 2014) and is a dominant landscape driver in July to October in Gauteng (as observed during the October 2018 survey), when owl occupancy was highest. This is at odds with the fact that fire often disturbs owls nesting in the grass. However, it could be suggested that the controlled burning of these fields may be driving rodents out of fields, into open areas where it is easier for the owls to hunt them (Shaffer and Laudenslayer 2006). It has been previously reported that some avian predators will even follow fires, increasing in abundance during active fires (Tarboton and Erasmus 1998, Shaffer and Laudenslayer 2006).

Forty-eight regurgitated owl pellets were collected in October 2018 from a barn owl roost (Hannweg unpubl. data). Fifty-seven skulls were found in these pellets. Fifteen of these skulls were identifiable as either *Otomys* species (n = 6), *Gerbilliscus* species (n = 4) and *Myosorex* species (n = 5) using de Graaff (1981). With the large numbers of *Mastomys* species that were available in the fields and only *Rhabdomys dilectus* caught in these fields otherwise, it is surprising that this number is so high (see Chapter 2). The estimated abundance from trapped rodents in the sampling sites (Chapter 2) does not correspond with the species of rodents found in the owl pellets processed. This suggests that although there is a high number of these *Mastomys* individuals in the fields they are not necessarily being preyed upon by the owls in the area (Hodara and Poggio 2016).

A final observation comes from a study done in April 2018 and June 2018 in the same area (Hannweg 2018), where owl occupancy was determined in April 2018 and June 2018 with an occupancy of 1 (SE = 0.007) and 0.943 (SE = 0.127), respectively. With occupancy in October 2018 being 0.996 (SE = 0.155) and 0.722 (SE = 0.167) and 0.526 (SE = 0.173) in January 2019 and April 2019, respectively, owl occupancy seems to be decreasing over time in 2019. Ansara (2004) found an abundance of approximately 13 owls per 1.5 km^2. The reason for the reduction in occupancy between October 2018 and January 2019 remains unclear. The rodent abundance increases from October 2018 to January 2019 and April 2019 (see Chapter 2) and the owls recorded did not reflect a similar trend. However, the owls and rodents in the area may be following a lagged boom-bust trend.

Values of occupancy and detection estimates were constant when no covariates were used on them. Similarly, abundance estimates were constant when no covariate was used of occupancy. When covariates were introduced into the models for occupancy or detection estimates, the estimates were reported at the average of the covariate. When covariates were used for abundance estimates, the estimates were reported at the average of the occupancy covariates (Fiske and Chandler 2019).

All of the detection probabilities to come from this analysis are less than 0.5. This is an indication that this study could have benefited from more sampling occasions. However, the increase in occupancy from the naïve occupancy probability shows that there were sites that had owls present but not detected (Conroy and Carroll 2009). Specifically, the null model with occupancy probability 0.817 suggests that approximately 16 sites had owls present in them. However, when the appropriate covariates are added to the models, the occupancy probability goes up to 1. This suggests that in every site where owls were recorded as “absent” they were actually “present but not detected” (Conroy and Carroll 2009).

CONCLUSIONS

There are many owls present in the agricultural matrix of east Gauteng, with at least three different species, namely marsh owls, spotted eagle-owls and barn owls. My estimates indicate a boom-bust fluctuation community of owls in the east of Gauteng with various factors that are driving the occupancy of owls in the area at all times (Ansara 2004, Hockey et al. 2005, Shaffer and Laudenslayer 2006, Taylor et al. 2015, Baudoin et al. 2017). Some key factors are likely the time of the year and water sources, with resource availability, biology and behaviour of owls pointing to being fundamental covariates driving population abundances, however, the anthropogenic factors, such as management in the fields, in the area are likely a critical set of factors affecting owl persistence (Ansara 2004, Hockey et al. 2005, Shaffer and Laudenslayer 2006, Taylor et al. 2015, Baudoin et al. 2017) .

It is speculated that the species that are persisting in the area are still facing threats in the form of anthropogenic effects such as, improper burning and heavy grazing, as well as main roads (Tarboton and Erasmus 1998, Hockey et al. 2005, SANBI 2013, Taylor et al. 2015). Besides these factors, the vulnerable African grass-owl is conspicuous in its absence. As the most sensitive and threatened owls in area, and one of the two species most threatened in the country, it is important that we take special notice of their absence (Taylor et al. 2015). It is likely that the factors that are affecting the absence of these owls are closely linked with the factors that are causing the grassland ecosystems in the area to be critically endangered (SANBI 2013). It is also possible that the African grass-owl was not detected due to its cryptic nature (Tarboton and Erasmus 1998). The study conducted did not allow for other methods to be used to detect for these owls but they have been detected in the area using a roped dragged through the fields to flush them (Ansara 2004). Further studies should be done on whether the African grass-owls are in fact present in the area.

It is important that the areas around roads and in the land surrounding the roads is managed in the manner that allows the owls to breed and survive successfully, with factors that may be affecting owl occupancy kept in mind to ensure their persistence in the environment. If owls are under threat from grazing or burning during certain times in the year, it may be a good idea to create management programs that centre around when owls are nesting and when there are still chicks in the nests, to avoid disturbing them. It must also be considered that the owls are not suppressing rodent populations sufficiently and thus a pest management system that does not affect owl populations negatively should perhaps be included in the area (Swanepoel et al. 2017). Additionally, owl populations should be encouraged further in the area to ensure that their effect on rodents is substantial enough if this is the only method that will be used to control rodent pests.

LITERATURE CITED

Ansara, T. 2004. Determining the ecological status and possible anthropogenic impacts on the grass owl (*Tyto capensis*) population in the East Rand Highveld, Gauteng. MSc Thesis, Rand Afrikaans University, Johannesburg, South Africa.

Baudoin, M.-A., C. Vogel, K. Nortje, and M. Naik. 2017. Living with drought in South Africa: lessons learnt from the recent El Niño drought period. International Journal of Disaster Risk Reduction 23:128–137.

Brown, P. R., N. I. Huth, P. B. Banks, and G. R. Singleton. 2007. Relationship between abundance of rodents and damage to agricultural crops. Agriculture, Ecosystems and Environment 120:405–415.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference. Springer-Verlag, New York, New York, USA.

Collinson, W., D. Parker, C. Patterson-Abrolat, G. Alexander, and H. Davies-Mostert. 2015. Setjhaba Sa, South Afrika: A South African perspective of an emerging transport infrastructure. Pages 439-447 in. Handbook of road ecology. John Wiley and Sons, Chichester, West Sussex, UK.

Conroy, M. J., and J. P. Carroll. 2009. Quantitative Conservation of Vertebrates. Wiley-Blackwell, Oxford, UK.

De Graaff, G. 1981. The rodents of Southern Africa: notes on their identification, distribution, ecology, and taxonomy. Butterworths, Durban, South Africa.

Fattebert, J., V. Michel, P. Scherler, B. Naef-Daenzer, P. Milanesi, and M. U. Grüebler. 2018. Little owls in big landscapes: Informing conservation using multi-level resource selection functions. Biological Conservation 228:1–9.

Fiske, I., and R. Chandler. 2011. unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. Journal of Statistical Software 43:1–23.

Fiske, I., and R. Chandler. 2019. Overview of Unmarked: An R Package for the Analysis of Data from Unmarked Animals. <https://cran.r-project.org/web/packages/unmarked /vignettes/unmarked.pdf>. Accessed 18 February 2019.

Fung, T., and W. Siu. 2000. Environmental quality and its changes, an analysis using NDVI. International Journal of Remote Sensing 21:1011–1024.

Gangadharan, A., S. Pollock, P. Gilhooly, A. Friesen, B. Dorsey, and C. C. St Clair. 2017. Grain spilled from moving trains create a substantial wildlife attractant in protected areas. Animal Conservation 20:391–400.

Hannweg, C. G. 2018. Factors Affecting Owl Occupancy in an Agricultural Matrix in the North-East of the Sedibeng District, Gauteng. BSc Honours Thesis, Univerisity of Pretoria, Pretoria, South Africa.

Hockey, P., W. Dean, and P. Ryan. 2005. Roberts' Birds of Souh Africa. John Voelcker Bird Book Fund, Cape Town, South Africa.

Hodara, K., and S. L. Poggio. 2016. Frogs taste nice when there are few mice: Do dietary shifts in barn owls result from rapid farming intensification? Agriculture, Ecosystems and Environment 230:42–46.

Ihaka, R., and R. Gentleman. 1996. R: a language for data analysis and graphics. Journal of Computational and Graphical Statistics 5:299–314.

Kajtoch, L., M. Zmihorski, and P. Wieczorek. 2015. Habitat displacement effect between two competing owl species in fragmented forests. Population Ecology 57:517-527.

Kioko, J., C. Kiffner, N. Jenkins, and W. J. Collinson. 2015. Wildlife roadkill patterns on a major highway in Northern Tanzania. African Zoology 50:17–22.

Koerner, S. E., and S. L. Collins. 2014. Interactive effects of grazing, drought, and fire on grassland communities in North America and South Africa. Ecology 95:98-109.

Korpimaki, E., and C. J. Krebs. 1996. Predation and population cycles of small mammals. Bioscience 46:754–764.

Labuschagne, L. 2015. Determining the potential of Barn Owls, *Tyto alba*, as bio-control agent of agricultural rodent pests. MSc Thesis, University of Pretoria, Pretoria, South Africa.

Leirs, H., V. Sluydts, and R. Makundi. 2010. Rodent outbreaks in sub-Saharan Africa. Pages 9–280 in. Rodent Outbreaks: Ecology and Impacts. International Rice Research Institute, Los Banos, Phillipines.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. Bailey, and J. E. Hines. 2017. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier, San Diego, California, USA.

Malan, G. 2009. Raptor survey and monitoring: a field guide for African birds of prey. Briza Publications, Pretoria, South Africa.

Mulungu, L. S., R. H. Makundi, H. Leirs, A. W. Massawe, S. Vibe-Petersen, and N. C. Stenseth. 2003. The rodent density-damage function in maize fields at early growth stage. Pages 301-303 in. Rats, Mice and People: Rodent Biology and Management. ACIAR Monograph No. 96, 564.

Oberprieler, U., and B. Cillie. 2002. Raptor identification guide for southern Africa. Rollerbird Press, Johannesburg, South Africa.

Palis, F. G., G. R. Singleton, P. R. Brown, N. H. Huan, C. Umali, and N. T. D. Nga. 2011.

Can humans outsmart rodents? Learning to work collectively and strategically. Wildlife Research 38:568–578.

Paz, A., D. Jareño, L. Arroyo, J. Viñuela, B. Arroyo, F. Mougeot, J. J. Luque-Larena, and J. A. Fargallo. 2013. Avian predators as a biological control system of common vole (*Microtus arvalis*) populations in north-western Spain: Experimental set-up and preliminary results. Pest Management Science 69:444-450.

Roychoudhury, A. N., and M. F. Starke. 2006. Partitioning and mobility of trace metals in the Blesbokspruit: Impact assessment of dewatering of mine waters in the East Rand, South Africa. Applied Geochemistry 21:1044–1063.

SANBI. 2013. Grasslands Ecosystem Guidelines: landscape interpretation for planners and managers. Compiled by Cadman, M., de Villiers, C., Lechmere-Oertel, R. and D. McCulloch. South African National Biodiversity Institute, Pretoria, South Africa.

Santos, S. M., R. Lourenço, A. Mira, and P. Beja. 2013. Relative effects of road risk, habitat suitability, and connectivity on wildlife roadkills: The case of tawny owls (*Strix aluco*). PLoS ONE 8:e79967.

Scholer, M. N., M. Leu, and J. R. Belthoff. 2014. Factors Associated with Flammulated Owl and Northern Saw-Whet Owl Occupancy in Southern Idaho. Journal of Raptor Research 48:128–141.

Shaffer, K. and W. Laudenslayer. 2006. Fire and animal interactions. Pages 118-143 in. Fire in California Ecosystems. University of California Press, Oakland, California, USA.

Stenseth, N. C., H. Leirs, S. Mercelis, and P. Mwanjabe. 2001. Comparing strategies for controlling an African pest rodent: an empirically based theoretical study. Journal of Applied Ecology 38:1020–1031.

Stenseth, N. C., H. Leirs, A. Skonhoft, S. A. Davis, R. P. Pech, H. Andreassen, G. R. Singleton, M. Lima, R. S. Machang'u, R. H. Makundi, Z. Zhang, P. R. Brown, D. Shi, and X. Wan. 2003. Mice, rats, and people: the bio-economics of agricultural rodent pests. Frontiers in Ecology and the Environment 1:367–375.

Swanepoel, L. H., C. M. Swanepoel, P. R. Brown, S. J. Eiseb, S. M. Goodman, M. Keith, F. Kirsten, H. Leirs, T. A. M. Mahlaba, R. H. Makundi, P. Malebane, E. F. Von Maltitz, A. W. Massawe, A. Monadjem, L. S. Mulungu, G. R. Singleton, P. J. Taylor, V. Soarimalala, and S. R. Belmain. 2017. A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: Are we asking the right questions? PLoS ONE 12:e0176621.

Tarboton, W., and R. Erasmus. 1998. Owls and Owling in Southern Africa. Struik Publisher, Cape Town, South Africa.

Taylor, M. R., F. Peacock, and R. M. Wanless. 2015. The 2015 Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland. Birdlife South Africa, Johannesburg, South Africa.

Thibault K. M., S. K. M. Ernest, E. P. White, J. H. Brown, and J. R. Goheen. 2010. Long-term insights into the influence of precipitation on community dynaminccs in desert rodents. Journal of Mammalogy 91:787-797.

Wiens, J. D., R. G. Anthony, and E. D. Forsman. 2011. Barred owl occupancy surveys within the range of the northern spotted owl. Journal of Wildlife Management 75:531–538.

Wiens, J. D., R. G. Anthony, and E. D. Forsman. 2014. Competitive interactions and resource partitioning between northern spotted owls and barred owls in western Oregon. Wildlife Monographs 185:1-50.

Williams, S. T., W. Collinson, C. Patterson-Abrolat, D. G. Marneweck, and L. H. Swanepoel. 2019. Using road patrol data to identify factors associated with carnivore roadkill counts. PeerJ 29:e6650.

Chapter 4: Conclusions and management implications

This research highlights important biological and management factors for the owls in an agricultural matrix, and specifically in the critically endangered Boesmanspruit Highveld Grassland ecosystem (SANBI 2013). Anthropogenic affects do appear to have an effect on owl occupancy in the study area and it is important to determine what that effect is on the owl assemblage. As mentioned throughout this thesis, it is important for us to know what factors are affecting the spaces owls in the agricultural matrix around Devon, Gauteng, occupy so that appropriate management decisions can be made. The conservation of these owls is important as the apex predators in this ecosystem, but it is especially important in the study area as not only is the ecosystem critically endangered, but the African grass-owls (*Tyto capensis*) which use this ecosystem are also vulnerable. In the human context, it is also important that these owls persist in the area as an ecologically responsible way to manage rodent pests.

There are three important points that come out of this research, specifically, the species richness of owls in the area, the occupancy and abundance of owls in the area and the factors that are affecting owls in the area.

Three of the four expected owl species were found in the area. Unfortunately, this did not include the vulnerable African grass-owl, and this is a cause for concern. While study methods may not have been conducive to the analysis of grass-owl occupancy, it is also possible that the more generalist species (western barn owl (*Tyto alba*) and spotted eagle-owl (*Bubo africanus*)) are possibly competitively excluding grass-owls (Scholer et al. 2014). Marsh owls (*Asio capensis*) and grass-owls have extensive habitat preference overlap and marsh owls are reportedly less sensitive to the anthropogenic pressures, such as fire regimes and heavy grazing (Tarboton and Erasmus 1998, Oberprieler and Cillie 2002, Hockey et al. 2005). A recent drought in the area may also have affected the number of grass-owls in the area as they require rank grassland for nesting (Ansara 2004, Taylor et al. 2015). The overall owl occupancy for the study area was as high as 0.996 (0.155) in October 2018 and owl abundance was estimated at an average of 2 owls per $4km^2$. Including water sources as a covariate to the model, the abundance increased to 6 owls per $4km^2$. This abundance fits with the literature, but it is at the low end of the scale of the number of owls in an area (Malherbe 1963, Hockey et al. 2005). The low owl abundances and the absence of grass-owls needs to be explored further, as it can be driven by anthropogenic threats or potentially excluded by the other three species (Scholer et al. 2014).

The current research provided evidence that in this area it is not only food that is driving the occupancy of owls in the area. Rodent abundances were found to be high and highest in April 2019 and lowest in October 2018. This is the inverse of owl occupancy estimates with the highest in October 2018 and the lowest in April 2019. Additionally, a preliminary analysis of owl pellets showed an increased species richness with at least four species of rodents while rodent trapping showed only two species, dominated by *Mastomys* species. An alternative to food sources being the main driver is habitat preference and nesting availability, apparent in the owl occupancy changing during the different months (Labuschagne et al. 2016). With water sources appearing to be the main driver of owls in the area, it is likely that the rank grassland which is ideal for marsh owl nests is what is driving the high owl occupancy (Tarboton and Erasmus 1998, Hockey et al. 2005). Further evidence is provided with marsh owls being the species that was most often seen in the area. The height of crops also appears to be affecting rodent populations, with higher crops having higher rodent abundance. This is line with literature as higher vegetation height is ideal for rodents as it provides cover from predators (Labuschagne 2015, Mamba et al. 2019). This could be why owl occupancy was lower in April 2019 even though rodent abundance was high.

The high number of owl roadkills in the area in early 2000 (Ansara 2004) initially raised awareness and contextualised the plight of owls. To alleviate the pressures of roadkill on owl populations it is important to keep the factors that are affecting them in mind in making farming management and road management decisions (Ansara 2004). If new roads are built, it is important that areas near water and wetlands are avoided, as owls are being killed in roadkill incidents and it is thus important that their habitat is avoided when implementing roads in the area (Ansara 2004, Williams et al. 2019). This should help ensure that more vulnerable owls like the African grass-owl are being considered and protected by allowing space for them in the environment where they are not disturbed.

Time of year appeared to strongly affect the abundance of owls and rodents in the study, and certain agricultural practises could possibly be done during specific times of the year that will help to minimise the impact on the owls. Burning of natural vegetation and heavy grazing are likely the factors with the biggest impact on the vegetation for the owls, and time of year for owlets to fledge and leave the nest should be considered when burning or grazing takes place in areas where owls may be nesting. Both grazing and burning are natural processes and part of healthy ecosystem processes, but done improperly, they can have a negative effect on the grassland carrying capacity and also owl populations in the area (SANBI 2013). Seeing as conducive habitat is important for the persistent of grass-owl populations in the area, it is important that places where they may be nesting are taken into consideration and that they are given sufficient opportunities to successfully breed. It is also important to consider factors such as fencing in the area as this also has a negative impact on the owls, and therefore fencing should be kept to a minimum where possible.

African grass-owl and marsh owl habitats are typically wetland and grassland areas with pans (Hockey et al. 2005). Extensive water extraction and use, and drainage of wetlands negatively impact species relying on these wetland areas (SANBI 2013, Davidson 2014).

Water pollution is another factor that could impact species reliant on healthy and clean water sources (SANBI 2013). With grass-owls being a species with a very narrow habitat niche, pristine unaffected, unaltered areas are required. To preserve and conserve populations, land use decisions and management decisions must accommodate these requirements for grass-owls if populations are to persist in agricultural landscapes. The ideal situation might include efforts to keep water sources healthy with surrounding grassland as a buffer zone on a farm (SANBI 2013), surrounded by soya bean fields with perches in these soya bean fields. This could help to alleviate the rodent populations in soya beans by planting the soya beans in spaces near high owl populations. Additionally, when there are few mice in the fields – for example, when the fields have no crops growing in them – the water sources and surrounding grassland could provide the owls with enough prey sources to avoid the potential lag phase of owls when rodent populations start to increase again, which is a key issue in whether or not owls and other predators are suitable for the control of rodent pests (Korpimaki and Krebs 1996, Leirs et al. 2010, Hodara and Poggio 2016).

The live trapping of rodents suggests that the level of rodents in some fields is reaching pest levels. Comparing this to the owl occupancies over time, it suggests that EBRM is unlikely to be a sole successful rodent pest management system in the area. Unlike most areas where ecological based rodent management is being implemented, such as in Tanzania and Portugal, I would suggest the focus is not placed on nest boxes for barn owls (Mohr et al. 2003, Paz et al. 2013). This species of owl is able to nest in a variety of places, including human built structures and if too many nesting opportunities are provided for them this may create too much competition for the other owls in the area and drive them out (Scholer et al. 2014). The use of nest boxes can be helpful to help reduce rodent populations, but it should not solely be relied upon. If the population of rodents continues to rise, it may cause some farmers to resort to chemical rodenticides which could negatively affect the owl population through secondary poisoning (Brown et al. 2007, Swanepoel et al. 2017). It is therefore important that another ecologically responsible management system is sought out so that management systems that negatively impact other wildlife like owls, are not relied upon.

This research has suggested what is affecting the owls specifically, as well as finding an effective ecologically responsible way to manage the rodents in the agricultural areas. This is especially important in the critically endangered Boesmanspruit Highveld Grassland ecosystem. It is important that this research is continued to ensure that good agricultural and infrastructure management decisions are made regarding owls and other wildlife in the area to further help mitigate the anthropogenic effects on wildlife in this sensitive ecosystem.

LITERATURE CITED

Ansara, T. 2004. Determining the ecological status and possible anthropogenic impacts on the grass owl (*Tyto capensis*) population in the East Rand Highveld, Gauteng. MSc Thesis, Rand Afrikaans University, Johannesburg, South Africa.

Brown, P. R., N. I. Huth, P. B. Banks, and G. R. Singleton. 2007. Relationship between abundance of rodents and damage to agricultural crops. Agriculture, Ecosystems and Environment 120:405–415.

Davidson, N. C. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research 65:934-941.

Hockey, P., W. Dean, and P. Ryan. 2005. Roberts' Birds of Souh Africa. John Voelcker Bird Book Fund, Cape Town, South Africa.

Hodara, K., and S. L. Poggio. 2016. Frogs taste nice when there are few mice: Do dietary shifts in barn owls result from rapid farming intensification? Agriculture, Ecosystems and Environment 230:42–46.

Korpimaki, E., and C. J. Krebs. 1996. Predation and population cycles of small mammals. Bioscience 46:754–764.

Labuschagne, L. 2015. Determining the potential of Barn Owls, Tyto alba, as bio-control agent of agricultural rodent pests. MSc Thesis, University of Pretoria, Pretoria, South Africa.

Labuschagne, L., L. H. Swanepoel, P. J. Taylor, S. R. Belmain, and M. Keith. 2016. Are avian predators effective biological control agents for rodent pest management in agricultural systems? Biological Control 101:94–102.

Leirs, H., V. Sluydts, and R. Makundi. 2010. Rodent outbreaks in sub-Saharan Africa. Pages 9–280 in. Rodent Outbreaks: Ecology and Impacts. International Rice Research Institute, Los Banos, Phillipines.

Malherbe, A. P. 1963. Notes on birds of prey and some others at Boshoek north of Rustenburg during a rodent plague. Ostrich 34:95-96.

Mamba, M., N. J. Fasel, A. M. Themb'alilahlwa, J. D. Austin, R. A. McCleery, and A. Monadjem. 2019. Influence of sugarcane plantations on the population dynamics and community structure of small mammals in a savanna-agricultural landscape. Global Ecology and Conservation 20:e00752.

Mohr, K., S. Vibe-Petersen, L. L. Jeppesen, M. Bildsøe, and H. Leirs. 2003. Foraging of multimammate mice, *Mastomys natalensis*, under different predation pressure: cover, patch-dependent decisions and density-dependent GUDs. Oikos 100:459–468.

Oberprieler, U., and B. Cillie. 2002. Raptor identification guide for southern Africa. Rollerbird Press, Johannesburg, South Africa.

Paz, A., D. Jareño, L. Arroyo, J. Viñuela, B. Arroyo, F. Mougeot, J. J. Luque-Larena, and J.

A. Fargallo. 2013. Avian predators as a biological control system of common vole (*Microtus arvalis*) populations in north-western Spain: Experimental set-up and preliminary results. Pest Management Science 69:444-450.

SANBI. 2013. Grasslands Ecosystem Guidelines: landscape interpretation for planners and managers. Compiled by Cadman, M., de Villiers, C., Lechmere-Oertel, R. and D. McCulloch. South African National Biodiversity Institute, Pretoria, South Africa.

Scholer, M. N., M. Leu, and J. R. Belthoff. 2014. Factors Associated with Flammulated Owl and Northern Saw-Whet Owl Occupancy in Southern Idaho. Journal of Raptor Research 48:128–141.

Swanepoel, L. H., C. M. Swanepoel, P. R. Brown, S. J. Eiseb, S. M. Goodman, M. Keith, F. Kirsten, H. Leirs, T. A. M. Mahlaba, R. H. Makundi, P. Malebane, E. F. Von Maltitz, A. W. Massawe, A. Monadjem, L. S. Mulungu, G. R. Singleton, P. J. Taylor, V. Soarimalala, and S. R. Belmain. 2017. A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: Are we asking the right questions? PLoS ONE 12:e0176621.

Tarboton, W., and R. Erasmus. 1998. Owls and Owling in Southern Africa. Struik Publisher, Cape Town, South Africa.

Taylor, M. R., F. Peacock, and R. M. Wanless. 2015. The 2015 Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland. Birdlife South Africa, Johannesburg, South Africa.

Williams, S. T., W. Collinson, C. Patterson-Abrolat, D. G. Marneweck, and L. H. Swanepoel. 2019. Using road patrol data to identify factors associated with carnivore roadkill counts. PeerJ 29:e6650.