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Estimation of the Leopard (*Panthera pardus*) population density in the Nama Karoo, Southern Namibia

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Estimation of the Leopard (*Panthera pardus*) population density in the Nama Karoo, Southern Namibia" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

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Acknowledgements

Abstract

The leopard (*Panthera pardus*) a species which is affected by habitat loss and fragmentation throughout its global range, so that the species is now listed as "Vulnerable" by IUCN. Assessing its local population status is therefore a key step in order to gain more knowledge about this species and to operate in a meaningful way for its conservation. This study assesses the leopard population density in South-Eastern Namibia, in a landscape dominated by the Nama Karoo biome. In this region the human population density is extremely low, however this species is sharing the space with local farmers, and shepherding and game ranching are the main sources of incomes for the local population. In this context, coexistence can result in human-leopard conflict, which could threaten the local population of leopards.

We set 20 camera trap stations across the study area. Two camera traps were placed in each station, in order to maximise the chances to individually recognise individual leopards. In total, we captured 5 males and 2 females. Leopard density was estimated using Spatially Explicit Capture-Recapture models implemented in the "secr" package in RStudio. We tested different models involving sex as a covariate, and we found significant difference between males and females home range sizes. The population density estimation in this region is 0.46-0.67 leopards per 100 km², confirming this region has one of the lowest leopard densities in the World.

The capture rate of mesocarnivorans in the area was extremely low, and further research is advisable in order to assess how the leopard presence is affecting the whole community composition, as well as the actual home range sizes of leopard by use of telemetry, since our data suggests a very large extent of home ranges.

Key words: Leopard, secr, density, Namibia, camera trap

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List of the abbreviations used in the thesis

CTS: Camera Trap Station

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IUCN: International Union for the Conservation of Nature

RAI: Relative Abundance of Species

SE: Standard Error

SECR: Spatially Explicit Capture-Recapture

1.   Introduction and Literature Review

Nowadays, the almost totality of the biologist community agree on the fact that Earth is currently facing a concerning biodiversity crisis, which consist of an alarming extinction rate of the species living on the planet, so that we can state that we are experiencing the "Sixth mass extinction" (Elredge 2005). The IPBES Global Assessment Report on Biodiversity and Ecosystem Services in 2019 highlighted the fact that the extinction rate is currently increasing as a direct result of human activities and it constitutes a threat not only to biodiversity itself, but also to human well-being in all regions of the world.

Increasing awareness of the gravity of the current situation led to the promotion to effective area-based conservation measures at different levels (United Nations 2019). However, growing human population makes it challenging to effectively take action to tackle this negative trend, since the expanding of urban areas, and human activities in general, is competing with the preservation of natural ecosystems (Kondratyeva et al. 2020). In addition to that, sharing the space with wild animals often leads to conflicts between local people and animals posing a threat to their livelihood or personal safety (IUCN 2022).

The leopard (*Panthera pardus*) is a well-known example of a species which is affected by habitat loss and fragmentation throughout its global range (Jacobson et al. 2016), so that the species is now listed as "Vulnerable" by IUCN. In Namibia, leopards still occur in large numbers outside of protected areas (Odden et al. 2014; Stein et al. 2012) and conflicts with local farmers are common (Inskip and Zimmermann 2009), so that those felids are often persecuted by humans (Ripple et al. 2014).

Effective conservation measures cannot disregard a deep knowledge of local population abundance and density of this species (Allen et al. 2020): camera traps are, in this sense, very useful tools which allow for the detection of cryptic species and can dramatically facilitate the efforts required to estimate population parameters of a wide variety of mammalian species (Hernandez-Blanco et al. 2013).

1.1.   Leopard's biology

1.1.1.   Distribution and conservation status

The leopard is one of the five representatives of the genus Panthera of the Felidae family (Kitchener et al. 2017) and it occurs in a wide range of habitats in the African and Asian continents: it is the most widely distributed of all felids (Nowell and Jackson 1996).
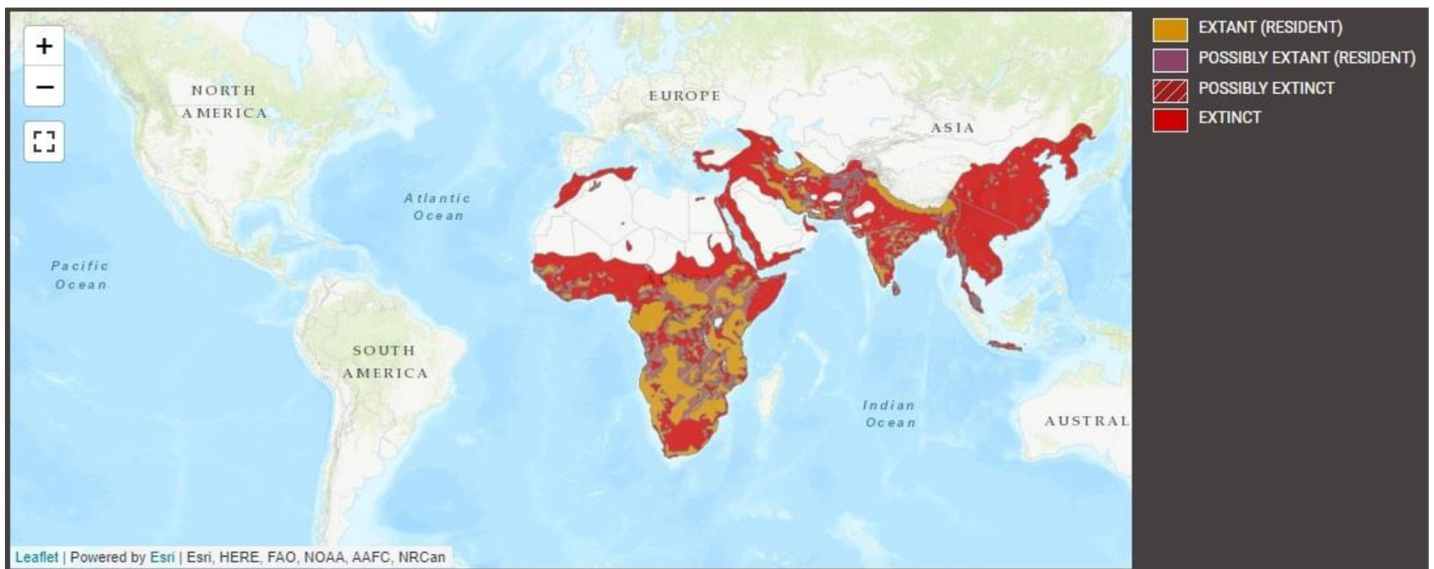
Figure 1: Leopard global distribution (IUCN, 2015)

It inhabits desertic and semi-desertic regions of Southern Africa (Namibia, Botswana, South Africa) and Middle East; some small populations still exist in the arid regions of Northern Africa (Egypt). Leopards are found in mountain environment up to an altitude of 5200 m in the Himalayas and 4600 m on Mt. Kenya. They flourish in rainforests in southern Asia and Western and Central Africa. The subspecies known as Amur leopard (*P. p. orientalis*) still inhabits the Russian Far-East, where snow is perennial, being perfectly adapted to the cold climate (IUCN, 2015).

In their habitat use, leopards somehow showed a tolerance towards human settlements, as they were lately reported in suburban and urban environment, where however they tend to reduce the size of their home ranges, given the acute anthropogenic pressure (Singh 2005, Athreya et al. 2013).

Anthropogenic pressure is also the main threat for the leopard's global conservation, which is now surviving only in the 25% of its historical range (Jacobson et al. 2016; Williams et al. 2017). Main threats for leopard's conservation include habitat fragmentation, decline in prey abundance and conflicts with farmers (Nowell and Jackson 1996, Ray et al. 2005, Hunter et al. 2013). Those conflicts are more acute where natural prey occurrence is lower and/or in areas where leopards and people are sharing a common space. Farmers may kill leopards in response to a real or perceived threat for either their livestock's safety or for that of themselves (Stein et al. 2010, Athreya et al. 2011). Carnivores, in general, can account for considerable economical loss for farmers even when predation affects only a relatively little percentage of the total stock holding. This is particularly true in developing countries: a study which was carried out in Namibia in 2014 among 147 local farmers, reported an annual economic loss of roughly US$ 3461 per person (Rust & Marker 2014).

In the Indo-Malayan region and China, leopards are victims of illegal skin and bones trade and some reports estimated an alarming poaching rate at four individuals per week for at least 10 years (Raza et al. 2012).

Given the listed threats and the dramatic habitat loss they suffered, combined with the fact that the global leopard population is currently declining, leopards are listed as "Vulnerable" by IUCN (2015).

In Namibia the leopard population was determined to be 11.733 with a root mean square error of 5.949 (Richmond-Coggan, 2019).

1.1.2. Morphological features

Leopard's morphological features vary between different subspecies and populations and are related to the diversity of environments in the regions it inhabits (Nowell & Jackson 1996). Its fur colour varies between pale cream to ochraceous and rufous; it always shows black rosettes whose pattern is unique per each individual (Allen et al. 2010). This feature is crucial as it allows for individual recognition of different animals. Melanistic individuals (black panthers) occur in the wild and are considered rare, being more common in moist forests, where this mutation may even be locally

predominant (Kawanishi et al. 2010). The white tip of the tail, along with the white spots on the top of the ears, is a diagnostic feature which may function as a "follow me" signal in interspecific communication, however this aspect is still under study and not completely clear (Ortolani 1999).

Sexual dimorphism is evident as males are usually larger and heavier than females (Stein & Hayssen 2010). Taking into account that it exists a broad variation in body size depending on latitude and subspecies, as already mentioned (Nowell & Jackson 1996), male leopards' weight 37-90 kg and females 28-60 kg (Stein & Hayssen 2010). The prominent dewlap is another important feature which allows for the recognition of mature males and can even provide information about the age of the individual (Taylor 2018).

Figure 2: Prominent dewlap indicates this leopard is a mature male (Credits: Craig Taylor)

1.1.3.   Behaviour and social structure

Leopards are typically solitary and territorial animals: their territory size is mostly regulated by prey density; adult individuals associate only during mating season (MacDonald 1983).

Home ranges differ between sexes, with males' usually overlapping with a few female home ranges, sometimes completely embracing them. Overlapping of home ranges usually does not happen with individuals of the same sex (Hunter, 2013; Jenny 1996). Home ranges sizes are affected by various factors such as habitat features (especially rainfall rate), prey abundance and anthropogenic impact (Marker & Dickman 2005). Interactions between leopards and other large felids occurring in the same area and possible competition/predation avoidance is still subject of debate, as studies highlighted different results (Steinmetz et al. 2013; Rafiq et al. 2020)

Given the heterogeneity of the above-mentioned features across the leopard's global distribution, home ranges may greatly vary in size. For females, Seidensticker et al. (1990) reported a home range of roughly 6 km² in Chitwan National Park in Nepal, which is the minimum known size for the species; whereas Bothma et al. (1997) reported a home range size of more than 1200 km² in the Southern Kalahari. Home range sizes for males are notably larger, and in the case of Southern Africa they can reach up to 2700 km² in the driest areas. In more rainy regions of Southern Africa, the smallest recorded adult female home range size was 30 km² in South Africa (Fattebert 2013) and 40 km² in Namibia (Stein et al. 2011).

Population density, on the other hand, is reported to be low in southern Namibia, with 1.2 individuals per 100 km² according to the last Namibian National Leopard Survey (Stein et al. 2011). Even lower estimates were provided more recently by Richmond-Coggan (2019) for the same area, reporting 0,5-1 individuals per 100 km². These results reflect the larger home ranges reported for Southern Namibia in other studies, which are directly correlated with lower population densities (O'Brien et al. 2003).

Activity pattern may vary between seasons (Jenny & Zuberbuhler 2005) but leopards are primarily nocturnal, being active from dusk till dawn (Estes 1991; Mills & Briggs 1993).

1.1.4. Diet and ecological role

The leopard is an hypercarnivore with a notably broad diet, perhaps the broadest among large felids (Hayward et al. 2006). Among the largest leopard's preys reported in the

Southern Africa region, we can mention the common eland (*Taurotragus oryx*) and the giraffe (*Giraffa camelopardalis*), however it may even supplement its diet with large insects (Hayward et al. 2006). It mainly hunts at night (Estes 1991) and it shows a preference for ungulates living in small herds and weighting around 23-25 kg on average (Hayward et al. 2006).

In the driest areas of its distribution in Sub-Saharan Africa, such as Kalahari, leopards manage to drink every two to three days by meeting their water requirement by succulent plants which are consumed at times (Bothma 2005).

The renowned habit to drag its preys on trees is one of the strategies that allow the leopard to be sympatric with other African big carnivores such as hyenas (Hyenidae), cheetahs (*Acinonyx jubatus*) and lions (*Panthera leo*), preventing them from stealing its kills (Palomares & Caro 1999; Nowell & Jackson, 1996). Interpecific killings with other predators and snatching of carcasses by lions are occasionally reported (Schaller 1972; Owens & Owens 1980).

Being large carnivorans, leopards trigger a top-down cascading effect upon the whole ecosystem (Winnie Jr & Creel 2017), by regulating densities of mammalian herbivores either by direct predation or by affecting their physiology and therefore re-shaping the environment in terms of its vegetation component. This, in turn, influences the presence of other taxa such as birds, insects and other mammals (both herbivores and carnivores) (Ripple & Beschta 2012; Gallagher et al. 2017). When a high dietary overlap between leopards and mesocarnivores which are sharing the same area exists, the leopard's presence can suppress the pressure that mesocarnivores are exerting on preys, resulting in higher abundance of ungulates (Suraci et al. 2017).

This is particularly true when preys are easily accessible, therefore consequences on the leopard's perception in the frame of human-leopard conflicts are relevant. Since mesocarnivorans showed to avoid the areas where big carnivorans are occurring, showing little spatial overlap in the short term between them (Zhao et al. 2019; Sarmento et al. 2021), leopards can, in fact, limit the spread of black-backed jackals and other mammals which are the main causes of livestock losses among farmers (See **Chapter 1.1.6**).

1.1.5. Leopard trophy hunting in Namibia

Leopards are popular targets in trophy hunting, a practice which is still widely discussed. It can be detrimental to local populations if poorly managed, for example by over-harvesting or corruption which may lead in the lack of reinvestment in conservation and development of local communities (Balme et al. 2010; Ripple et al. 2016). Those pitfalls risk to make the hunting unsustainable and threaten the population (Lindsey et al. 2007). Another side-effect of trophy hunting is the biased sex ratio which may lead to higher infanticide rate by dispersing males which occupy the vacuum left by the removed individual (Davidson et al. 2011).

Leopards are included in CITES Appendix I. Trade of Leopard Skins and Products (CITES resolution 10:14) which is restricted to 2,483 individuals in 11 countries across sub-Saharan Africa (CITES 2018a). Stein et al. (2011) suggested a quota of 250 individuals for Namibia (CITES Resolution Conf. 10.14 (Rev. CoP16)), along with an intensive monitoring programme to ensure that permits are distributed across Namibia according to the variation of the leopard density. Quotas should be regulated as follows:

- High density areas (0.5 adult male leopards/100 km² / year) = 5.5 permits/10,000 km²
- Medium density areas (0.35 adult male leopards/100 km² / year) = 3.5 permits/10,000 km²
- Low density areas: (0.21 male adult leopards/100 km² / year) = 2.1 permits/10,000 km²

Maximum harvesting was never reached in the last 18 years, except for the year 2008 (Richmond-Coggan, 2019).
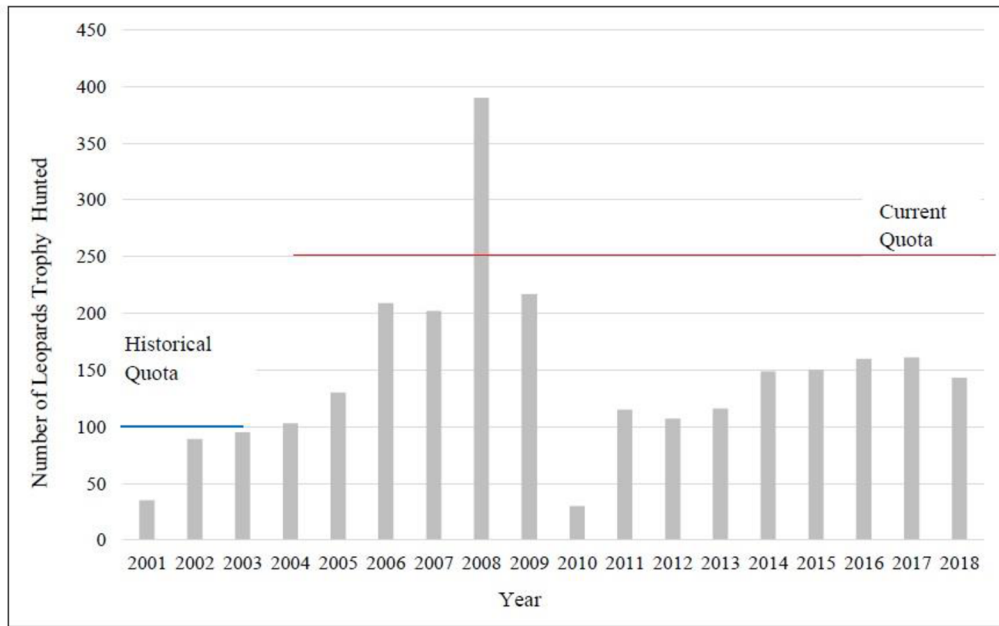
Figure 3: Numbers of leopards trophy hunted in Namibia between 2001 and 2018 (Richmond-Coggan, 2019)

1.1.6.   Human-Leopard conflict in Namibia

A national survey carried out by Richmond-Coggan (2019) highlighted a general negative attitude among farmers towards the leopard presence in their property, or in the proximity of it. In only one region (Kavango East) leopards were seen positively; Erongo, Kunene, Otjozondjupa and Zambezi regions showed a neutral attitude and the remaining five regions had a negative attitude towards its presence. Karas, the southernmost region, showed the most negative disposition. Farmer's attitude was reflected by the livestock loss rate, which was significantly higher in Karas.

The leopard was the second most removed carnivoran (after the black-backed jackal) in the farmer's properties between October 2016 and December 2018, with a total number of 342 individuals (6,1 % of the total removals of carnivores). Most respondents removed leopards by shooting or cage traps (82 % of the removed leopards). Some utilised the opportunity to trophy hunt (12 % of the removed leopards) a leopard in response to loss of livestock and/or game (Richmond-Coggan 2019).

Despite the negative attitude of farmers towards leopard, the 53% of them declared that they wanted the leopard to be present in their property. The reason for

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that is to be found in leopard's aesthetic value, its ecosystem service, such as the baboon control, and its economic value for trophy hunting and/or tourism (Richmond-Coggan 2019).

Between 2005 and 2018 a total of 1.589 leopards listed as problematic individuals were removed in Namibia. 449 were males, 176 were females and for 942 individuals sex was not stated. Actual numbers of removed individuals by farmers are considerably higher, since not all farmers applied to MET for the permit: in Richmond-Coggan survey, only half of the interviewed affirmed to apply for the request before the removal (Richmond-Coggan 2019).

Between 2001 and 2017, in ten regions across 75 communal conservancies, 5,718 incidents of human-leopard conflict were catalogued by the Namibian Association of the Community Based Natural Resource Management activities (NACSO, 2018). The average number of incidents logged per year was 336.

Stein et al. (2010) highlighted the fact that farmer's attitude towards leopard is linked to the farm's incomes, and they are less likely to tolerate its presence when they depend on subsistence farming. Other factors such as age, culture, and religious beliefs were proven to have an influence on people's disposition towards carnivores in general (Kellert 1985; Schumann et al. 2012; Thorn et al. 2015).

Leopard's predation on livestock is related to calving season, seasonal grazing patterns and land degradation in communal area. Leopards showed to have a preference for domestic equids like horses and donkeys (Constant et al. 2015).

Records of leopard's attack towards human are very rare in Southern Africa but may occur at times. Big felids may especially cause a threat to humans once they lose fear of humans due to habituation, which may be caused for intentional or unintentional feeding of the animal (Constant et al. 2015). This was the case of a recent attack by a leopard on two German tourists in the Kuiseb Canyon (The Namibian, 2018). Between India and Nepal, where leopards are often living in suburban areas, attacks on humans are more common: in Kruger National Park only 5 fatalities were reported in eleven years (1992-2003) (News24 2003), whereas in India the Forest Department reported 902

human injuries and 201 deaths between 1999 and 2005 in the state of Maharashtra only (Athreya et al. 2011).

1.2.   Application of camera traps in wildlife ecology studies

Camera traps are nowadays very powerful tools in wildlife ecology, behaviour, and conservation studies, allowing for the detection of cryptic species which are difficult to contact by direct methods (O'Connel 2011). Their basic functioning consists of a camera recording videos or photos, which is triggered by a motion sensor. Therefore, placing the camera in a proper position in the study area allows for the detection of animals which would otherwise be difficult to record. Various camera trap models exist on the market, and almost the totality of them is suitable for recording night footage, thanks to the leds which illuminates the image (Rovero & Zimmermann 2016).

There are two types of lights that are normally built on cameras, namely LED white-flash or infrareds. Recent studies highlighted that there is no evidence that the type of flash have an impact on the detection probabilities of species (Henrick et al. 2020), even though this aspect is still object of debate (Herrera et al. 2021); LED white-flash cameras produce photographs which are generally of higher quality and better suit for identification of individual animals when unique markings are present (Herrera et al. 2021).

Camera traps are particularly helpful in recording carnivorans due to their low density, elusive nature and mainly nocturnal activity. Over the last years, many studies used camera trapping as the main method to assess carnivorans populations status (Kauffman et al. 2007; Gerber et al. 2010; Pettorelli et al. 2010).

Camera traps usually have cryptic colouration, so they are better hidden in the chosen placement spot. The main obtainable benefit using camera traps is the minimum disturbance caused to animals, so that it can be defined as a non-invasive way to study wildlife. This is particularly true if compared to other methods such as direct observation or trapping. Those tools allow not only to the adoption of more ethical surveying methods, but also dramatically limit the bias caused by the avoidance of humans by

animals. Despite a relatively high initial cost, camera traps allow prolonged data collection in more stations at the same time, being active uninterruptedly for 24 hours/day, and they can be left in the field for weeks - and even months - depending on the battery duration. Recorded data are accurate evidence which can be analysed by other scientists, if needed, and can also provide precious photo-video material which could be viable for communication campaigns (O'Connell et al. 2011; Rovero & Zimmermann 2016).

On the other hand, the main disadvantage of camera trap use, as already mentioned, is the high initial cost for the materials, which include not only camera traps but also batteries, SD cards and possibly a locker per camera to prevent theft. A wrong camera placement may determine the ineffectiveness of the survey effort, and relevant economic loss if cameras are located in remote areas (which is often the case). Common problems in camera traps placement include vegetation triggering the motion sensor (and eventually filling the SD card with empty footage), low battery level, mechanical problems that may affect the motion sensor or the infrared flash, theft and camera damage which may be caused by animals, fire, floods or severe weather conditions (O'Connell et al. 2011).

Calculation of species' densities without their direct capture and labelling became possible with the appearance of standardized methods which profit from camera traps and enable individual identification of animals (Karanth, 1995). Other possible outcomes of standardized camera trap surveys are occupancy estimates, population abundance and activity patterns, among others.

Camera trapping rate (CTR) is an index that measures the total number of independent events in which a species is detected during the sampling period. It could be also referred to as relative abundance index, as it can provide information about the animals' abundance, assuming that the studied species will trigger cameras in relation to its density (Rovero & Zimmermann 2016; Amin et al. 2017). Carbone et al. (2001) showed that the camera trapping rate was correlated with density estimates of tigers that were performed independently with the capture-recapture technique.

Over the last 15 years, spatially explicit capture-recapture (SECR) models have been widely used to estimate animal densities (Efford 2011; Royle et al. 2013; Wilton et al. 2014). It is a more solid method that uses the captures' spatial locations to estimate each individual's centre of activity within the study area. SECR method is based on the key assumption that states that the probability of detecting an individual at a specified detector is a function of the distance of this detector from the individual's activity centre (Gardner et al. 2010). Consequently, the unequivocal identification of each individual within the species in the sampling effort is fundamental for the correct functioning of the model (Efford 2011; Royle et al. 2013; Wilton et al. 2014).

SECR models are flexible and they can incorporate individual covariates, such as sex (Efford 2011).

2.   Aims of the Thesis

The main objective of this thesis was to assess the leopard population density in the Nama Karoo biome of South-Eastern Namibia by means of camera traps. The final goal was to provide insight abut leopard's population in this environment. Effective conservation and management measures, in fact, depend on solid knowledge on key population parameters such as density and abundance.

The leopard presence is confirmed in the study area, which is a system of private farms in the Karasburg constituency, at the border with South Africa. Given the type of biome and the aridity of the region, we predicted that leopard's density could be among the lowest ever recorded in literature. By use of camera trap stations, we aim to calculate the density of this carnivoran with the spatially explicit capture-recapture methodology, in order to have a reliable estimate of this parameter.

Information on leopard's population density is crucial in assessing quotas in trophy hunting, since they are regulated according to different brackets of the species' population densities. A good evaluation allows to lower the error threshold and to allocate the most appropriate harvesting quota for the local population. It is vital to manage trophy hunting in a proper way, if we don't want to risk aggravating the conservation status of leopards, which are already classified as "Vulnerable" according to IUCN.

Findings about leopard population parameters may also help in the human-wildlife conflict mitigation, as the number of attack towards domestic animals may be correlated with population density and/or abundance, as already proven in many instances.

Moreover, since big carnivorans presence implies a top-down regulation towards other species in the ecological pyramid, assessing their density can help to have a better understanding of the whole community of species. Leopard presence can be considered as an indicator of prey abundance; ecosystem's health influences and is influenced by the presence of this felid.

3.   Methods

3.1.   Study Area

The study area is located in the southern part of Namibia, more precisely in the Karasburg constituency, which is part of the Karas region. The Orange River separates this district from the bordering South Africa.
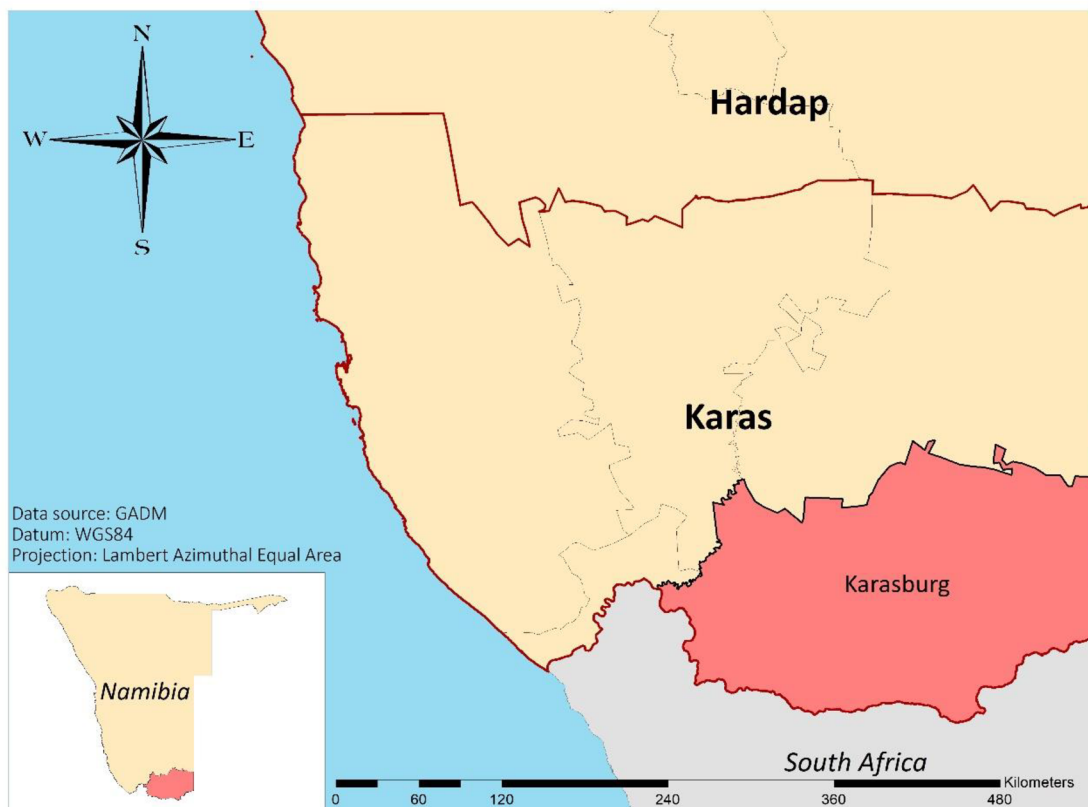
Figure 4: Location of the Karasburg constituency in Namibia.

This area is characterised by the predominance of the Nama Karoo biome. The climate of this region is typically continental, with little or no climate mitigation by the action of the oceans. According to the The Köppen-Geiger classification system, the climate of this region can be described as arid, with very low precipitation concentrated in the winter, and hot arid temperature (Beck et al. 2018). In the Nama Karoo most of the rivers are seasonal. In this specific region, an exception is constituted by the Orange River, which is one of the few perennial ones (Mucina et al. 2006).

The mean temperature reaches its maximum in the months of January and February, when 35°C are recorded on average during the day and 18-19°C at night. The coldest months are June and July, with a mean temperature of 22°C during the day and 8°C at night (WorldWeatherOnline 2022).

The mean annual rainfall was measured as 19.55 mm in the last ten years, with February being the month with the highest mean rainfall (28.3 mm) along the year (WorldWeatherOnline 2022). In the Nama Karoo there is a relevant variation in annual rainfall rates, which can go up to 40%, with unpredictable droughts that can last for months (Booysen & Rowswell 1983) (See **Figure 5**).
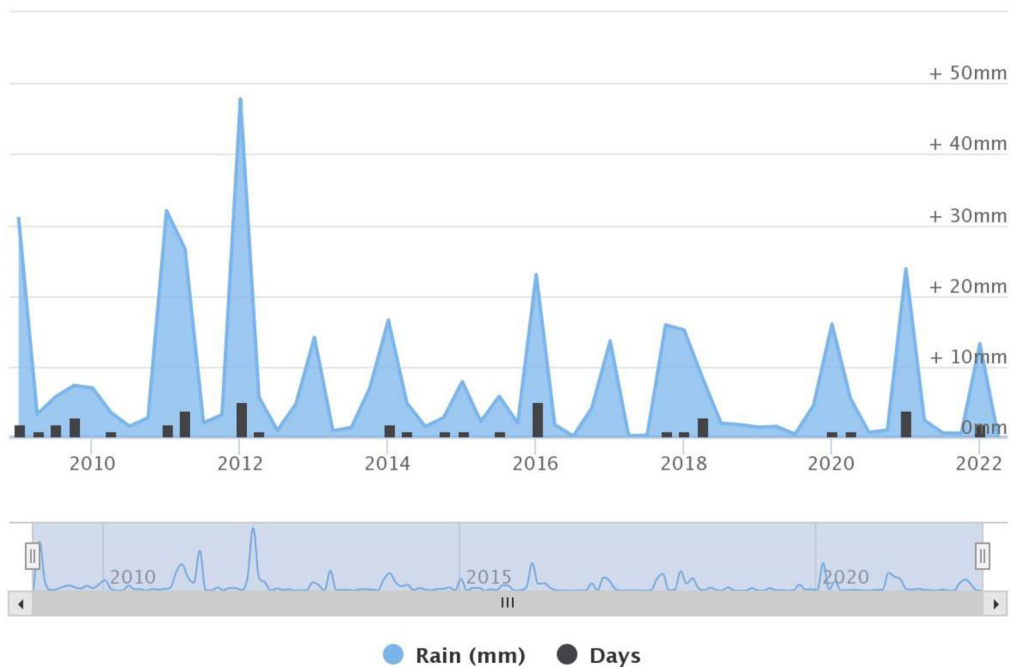
Figure 5: Mean annual rainfall in the Karasburg constituency, years 2010-2022
(WorldWeatherOnline, 2022)

The research was carried out in a territory which embraces several farms, owned by different persons. The whole area was once used as game ranch for hunting activity in the past, but since 2012 all the properties were converted in their land management, with the aim to create an extensive nature reserve (Mikslová 2019). The sampling effort took place in the two farms called "KumKum" and "Pelgrimrust", with an extension of 187 km² and 105 km² respectively, and an approximate altitude range of 600 - 900 m,

with higher mountain reaching up to 1050 m in altitude (Hernández Alonso 2020) (See Figure 6).
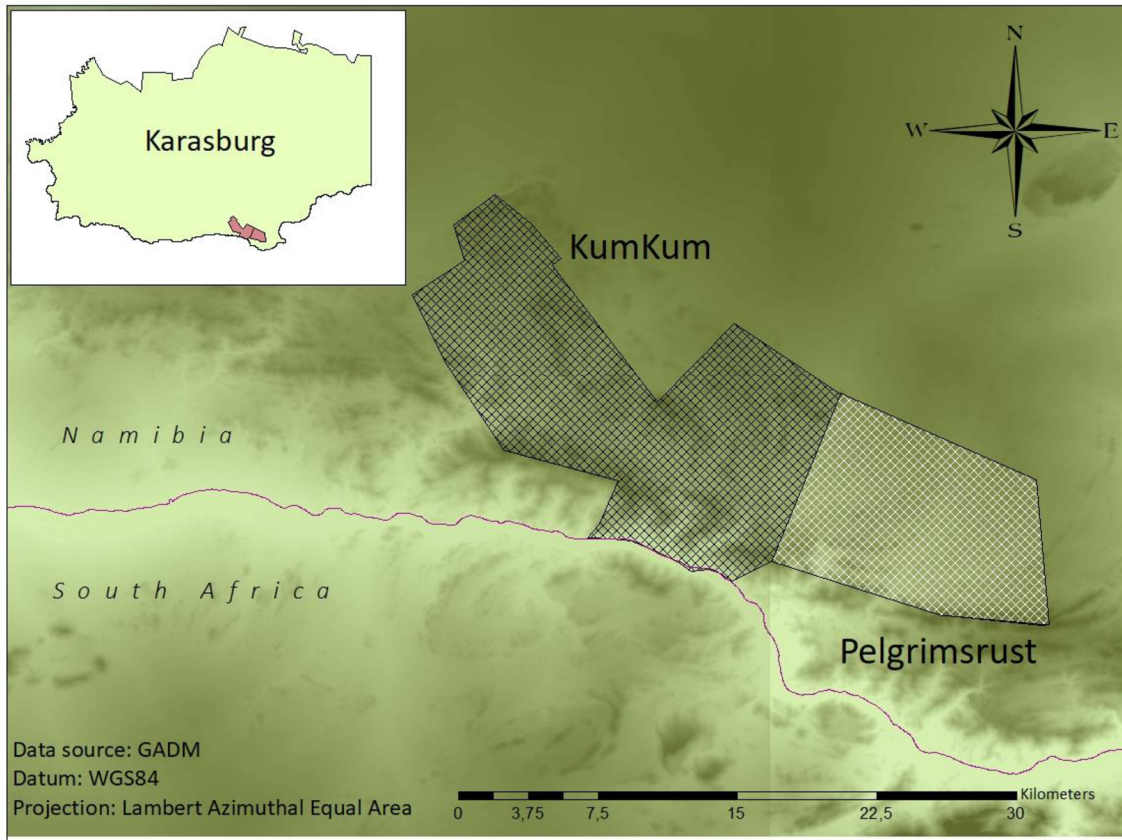
Figure 6: Location of KumKum and Pelgrimrusts farms in the Karasburg constituency.

The area holds an heterogeneous landscape which varies from mountainous abrupt regions to the drainage line of the Orange River. KumKum area presents an enormous gabbroidal formation which creates a large mountain massif, while Pelgrimrust is characterised by plains and metamorphic mountain ridges (Hernández Alonso 2020).

3.1.1.   Microhabitats and Flora

The area is characterised by extensive plains with typically low shrubs. In common with floras of other arid and semi-arid areas, Asteraceae, Fabaceae and Poaceae are dominant plant families (Mucina et al. 2006).

Several microhabitats can be recognised in the study area. Sandy plains are composed by a compacted, uniform substrate made of sand, with scarce vegetation

mainly composed by sub-shrubs and annual plants. We can mention *Cadaba aphylla*, *Phaeoptilum spinosum* and *Boscia foetida* among the main shrub species; dominant grasses belonging to the Poaceae family include *Schmidtia kalahariensis*, *Stipagrostis ciliata*, *Stipagrostis obtusa* and *Cladoraphis cyperoides* (Koekemoer et al. 2014). Few isolated trees of the genus Acacia are also present along with the succulent *Aloidendron dichotomum* (Hernández Alonso 2020).

Rocky plains have higher altitudinal variation. They are characterised by soils rich in quartz and amphibolite, with coarser rocks and greater vegetation cover if compared with sandy plains. The landscape here is dominated by the presence of shrubs of the genus Euphorbia (Hernández Alonso 2020).

Dry riverbeds present less compact soil and variable presence of rocks. As it will be later explained, this landscape feature plays an important role in this research, as it is the elective microhabitat where camera traps were placed. A predominance of shrubs such as *Cadaba aphyla*, *Sarcostemma viminale*, *Tamarix usneoides* or *Parkinsonia africana* can be observed. Acacia trees find better conditions to grow here rather than in the plains, and therefore are more abundant (Andrés Criado 2020).

The last microhabitat which can be described in the area are the mountains, with a prevalence of coarse rocks and little presence of any vegetation, being the predominant species *Ailodendron dichotomum*, and scarce presence of some Euphorbiaceae or Crassulaceae (Hernández Alonso 2020).

The only area with abundant vegetation is represented by the immediate surroundings of the Orange River. A predominance of mesquite trees (*Prosopis* spp.) can be noticed here. Those plants are alien species coming from South America and are listed as highly invasive (Curtis & Mannheimer 2005). However, this area is also home to perennial grasses and reeds, which cannot be encountered elsewhere in the plains or mountains (Koch Jiménez 2021).

3.1.2. Fauna

Diversity of mammals counts with several ungulates' species, the most common ones being common elands (*Taurotragus oryx*), mountain zebras (*Equus zebra*), greater

kudus (*Tragelaphus strepsiceros*) and steenboks (*Raphicerus campestris*). Other species which are found in the area are the gemsbok (*Oryx gazella*) and the red hartebeest (*Alcelaphus caama*). Springboks (*Antidorcas marsupialis*) and klipspringers (*Oreotragus oreotragus*) are commonly encountered in mountainous and rocky areas, along with rock hyraxes (*Procavia capensis*).

Carnivorans are well represented, counting with leopards, black-backed jackals (*Canis mesomelas*), honey badgers (*Mellivora capensis*), striped polecats (*Ictonyx striatus*) and genets (*Genetta genetta*).

Among small mammals, we can mention the aardvark (*Orycteropus afer*), the Cape ground squirrel (*Xerus inauris*), the Cape hare (*Lepus capensis*), the South African springhare (*Pedetes capensis*), the Western rock sengi (*Elephantulus rupestris*), the Cape short-eared gerbil (*Desmodillus auricularis*) and the Egyptian slit-faced bat (*Nycteris thebaica*) (Koch Jiménez 2021; Hernández Alonso 2020).

The riparian habitat along the Orange River is home to a few species of primates, namely the chacma baboon (*Papio ursinus*), and vervet monkeys (*Chlorocebus pygerythrus*). African clawless otters (*Aonyx capensis*) can be found here as well (Hernández Alonso 2020).

Birds are well represented, especially birds of prey like the chanting goshawk (*Melierax canorus*), the black eagle (*Aquila verreauxii*) and vultures (namely *Torgos tracheliotus* and *Gyps africanus*). Among Strigiformes, we can mention the spotted eagle-owl (*Bubo africanus*). Passerines are abundant, especially sociable weavers (*Philetairus socius*) and southern masked weavers (*Ploceus velatus*), cape sparrows (*Passer melanurus*), cape buntings (*Emberiza capensis*), karoo scrub robins (*Cercotrichas coryphoeus*), the bokmakierie (*Telophorus zeylonus*), African red-eyed bulbuls (Pycnonotus nigricans), rock martins (*Ptyonoprogne fuligula*), pale-winged starlings (*Onychognathus nabouroup*) and mountain wheatears (*Myrmecocichla monticola*). Members of flycatchers (fam. Muscicapidae) and larks (fam. Alaudidae) are also common. Crows (namely *Corvus albus* and *Corvus capensis*) are frequent in the area, together with sandgrouses (*Pterocles* spp.), doves (*Columba* and *Streptopelia* spp.) and

korhaans (*Afrotis afraoides* and *Eupodotis vigorsii*) (Koch Jiménez 2021; Hernández Alonso 2020).

In the proximity of the Orange River the ornithological diversity increases dramatically, hosting a rich community of birds' species which are linked to water such as kingfishers (*Ceryle rudis*, *Corythornis cristatus*, *Megaceryle maxima*), ibises (*Bostrychia hagedash*, *Threskiornis aethiopicus*), various herons (fam. Ardeidae), African darters (*Anhinga rufa*), South African shelduck (*Tadorna cana*), spur-winged goose (*Plectropterus gambensis*) and Egyptian goose (*Alopochen aegyptiaca*), among others (Hernández Alonso 2020).

This arid area is home to several species of reptiles. The most common groups are geckos of the genuses *Chondrodactylus* and *Pachydactylus*, agamas (*Agama* spp.), lizards of the genus *Pedioplanis*, skinks (*Trachylepis* spp.) and snakes like viperids (*Bitis* spp.), cobras (*Naja* spp.) and various colubrids, especially *Psammophis* spp. (Franco-Polo 2020).

3.1.3. Socio-economic composition

The Karas Region counts with 77,421 inhabitants according to the most recent census, with a growth rate of 1.1% and a population density which is one of the lowest in the whole world (0.5 persons per km²). The median age in the region is 26 years (Namibia Statistics Agency 2011).

Almost the totality of the population (98%) is able to read and write, however the percentage of people older than 15 years who leave school is high (84%) and increasing (it was 77% in 2001). At the same time, unemployment is also relatively high (32.2%) (Namibia Statistics Agency 2011).

In the Karasburg constituency, the majority of the land ownership and management is private (Acacia Project 2002). The main activity of local people is ranching of small stock, which is possible in the area because of the presence of the relatively abundant shrub vegetation. Without perennial grasses, those plants constitute the main source of food for livestock, which focuses mainly on goats and sheep (Mendelsohn et al. 2002).

In the study area, several water points were built on farms to secure its availability along the year. Given the importance of the water supply, the most proximate area with the Orange River is the preferred grazing ground by farmers. This resulted in some anthropogenic transformation of the landscape in those areas, which are sometimes burned to keep predators away (Hernández Alonso 2020).

3.2. Data collection

PhD student Viktor Nešticky from the Faculty of Tropical AgriSciences in Prague was the person who carried out the fieldwork in the study area, planned the sampling design and actually placed the camera traps. At this point, he created an excel list of all captures from the camera traps. All further analysis was carried out by the author.

From the 1st of June to the 25th of July 2018, a pilot study was carried out in the area, in order to assess the most effective settings in the monitoring layout. The pilot study showed to be a crucial step for the optimization of the monitoring, as during this time frame camera traps failed to record the leopard's presence in the proximity of water points, which were thought to be the most suitable places to detect those felids. At the same time, tracks and scats were recorded in order to detect the best locations for the future camera trap placing.

The monitoring effort took place from the 27th of July until the 28th of September 2018, during Namibian winter. The study involved the usage of forty camera traps in total (28 UOVision UV 535 Panda, 11 Bushnell Trophy CamHD, 1 Browning Strike Force micro HD). Each camera station was composed by two camera traps that allowed for the recording of the animal on both its flanks. Without this array, individual recognition of animals would have been extremely difficult, if not impossible. Individual recognition, in fact, allows the possibility for recapture in the data analysis.

An important requisite for the study is the population closure assumption, which states that the studied population should not undergo changes such as births, deaths, immigration and emigration. This assumption was met by sampling for 58 days, which

in case of leopards is considered to be short enough to prevent such changes (Karanth & Nichols 2002).

At least two camera stations per 30 km² were placed in the field. This is, in fact, the smallest adult female home range size recorded in Southern Africa (Fattebert 2013). In that way we could be sure that all individuals had access to more than one station.

To optimize the monitoring effort, camera stations were placed in dry riverbeds, as these microhabitats showed the maximum presence of leopard's tracks and signs, other than various ungulates and other animals. No bait was used in this study, as the usage of attractants would have biased the detection probability of animals (Mills et al. 2019). Camera traps were placed at approximately 40 cm of height from the ground, secured to either a tree, a rock pile, or a pole. The vegetation in front of the camera was removed to prevent the wind from triggering the motion sensor by moving leaves.

Each camera was set with normal sensitivity and in video mode, with a video length of 10 seconds. This length was considered to be the best offset between the need to reduce the files' size for the memory storage, and the need to avoid the recording of blurry images, which is pretty common when the camera is set in photo mode, especially at night.

3.3. Data analysis

3.3.1. Data preparation

Due to the large volume of footage recorded, in this study we made use of the software called "Camera Trap Analysis Package" (CTAP) from the Zoological Society of London. This program is particularly designed to work with big volumes of data and to automatically calculate the key parameters in the research, such as trapping rates, species richness estimates, activity plots, spatial-temporal plots, occupancy and detection probability estimates (Amin et al. 2017).

In order to make the dataset readable by the CTAP software, an excel file was created prior to the analysis. This table contained information for every video recorded, that are date, time, camera station ID, camera trap number, the file source name and

whether the video was blank or if it recorded livestock, humans, or wildlife. In this last case, additional information about animals was provided in the excel sheet: species name, number of individuals, sex (if determination was possible), age class and any further written note that could be relevant for the analysis.

At this point, CTAP software only needed additional information about the basic configuration of camera traps and their location, before providing the needed outputs.

The excel table thus organised, resulted to be useful also for the density estimation which was carried out by the "secr" (Spatially-Explicit Capture Recapture) package in the software R Studio (see **Chapter 3.3.4**). This package, in fact, requires two text files as input files to run the analysis.

The first file contains the location of camera traps in cartesian coordinates (sometimes referred to as XY coordinates). The cartesian coordinate system is a right-hand, rectangular, three-dimensional, earth-fixed coordinate system with an origin at (0, 0, 0). For the sake of simplicity, we considered this system to be bi-dimensional and therefore to not take into account the Z-axis, which could be considered as the axis of rotation of the Earth (and would result in the altitude). In the field, coordinates of each camera trap station were recorded by use of the GPS and stored in the form of latitude and longitude. To convert such coordinates to the cartesian system we need to establish our ellipsoid of reference, which was set to the commonly used World Geodetic System 84 (WGS 84). At this point the formulae to obtain X and Y values, with a reasonable approximation, are the following:

$$x = R \cdot \cos(lat) \cdot \cos(lon)$$

$$y = R \cdot \cos(lat) \cdot \sin(lon)$$

Where R is the approximate radius of earth: 6371 km.

The first input file for the secr analysis in R studio was then organised as we can see in **Table 1**.

Detector	X	Y
CTS 1	6813958	290861
CTS 2	6816531	290492
CTS 3	6814440	304800

CTS 4	6813370	303435
CTS 5	6821501	291135
CTS 6	6821376	292794
CTS 7	6818428	294990
CTS 8	6813115	292317
CTS 9	6813442	300476
CTS 10	6807370	303753
CTS 11	6806136	307271
CTS 12	6808197	308972
CTS 13	6808363	300591
CTS 14	6807102	298905
CTS 15	6814650	295518
CTS 16	6813747	298545
CTS 17	6811804	294809
CTS 18	6810870	297754
CTS 19	6811610	305010
CTS 20	6811694	310053

Table 1: Location of each camera station with cartesian coordinates.

The second input file was the one containing the list of independent photographic events in which a leopard was recorded by any camera trap station. It is important to define what can be considered as independent event. A single animal can, in fact, spend some time around the camera station place and be recorded several times within a relatively short time frame. If each video counted as one event, this would be a source of bias in our research. For this reason, in our case we decided to set a minimum time of one hour between subsequent videos (of the same species), to define an independent event.

For this analysis, only records of leopards which were unequivocally identified were considered. This was not the case for all the photographic events, as we will later see. For each event, the second input file contained the name of the monitoring campaign, the ID of the animal (in this case an informal name which was given to the recognisable individuals), the camera station ID in which the leopard was recorded and the number of the day in which the event took place. The last value was calculated by counting the days since when the camera trap started to be operational, being the placing day the day zero and counting progressively. Since leopards are nocturnal animals, a single day was not counted from midnight to the midnight after, but rather

from noon until the noon after, as suggested in literature (Efford 2011; Royle et al. 2013; Wilton et al. 2014). The second input file resulted in the output shown in Table 2.

# Session	ID	Occasion	Detector	Sex
LeopardMonitoring	Pink	44	CTS20	M
LeopardMonitoring	Pink	47	CTS20	M
LeopardMonitoring	Pink	15	CTS20	M
LeopardMonitoring	Pink	15	CTS20	M
LeopardMonitoring	Pink	47	CTS20	M
LeopardMonitoring	Hunter	58	CTS17	M
LeopardMonitoring	Set	5	CTS16	M
LeopardMonitoring	Dark	4	CTS16	F
LeopardMonitoring	Set	5	CTS16	M
LeopardMonitoring	Dark	27	CTS16	F
LeopardMonitoring	Dark	27	CTS16	F
LeopardMonitoring	Set	23	CTS15	M
LeopardMonitoring	Hunter	5	CTS14	M
LeopardMonitoring	Hunter	24	CTS14	M
LeopardMonitoring	Hunter	37	CTS14	M
LeopardMonitoring	Hunter	53	CTS14	M
LeopardMonitoring	Hunter	5	CTS14	M
LeopardMonitoring	Hunter	24	CTS14	M
LeopardMonitoring	Paw	37	CTS13	M
LeopardMonitoring	Set	5	CTS13	M
LeopardMonitoring	Paw	37	CTS13	M
LeopardMonitoring	Hunter	58	CTS13	M
LeopardMonitoring	Estelle	2	CTS12	F
LeopardMonitoring	Pink	46	CTS12	M
LeopardMonitoring	Estelle	2	CTS12	F
LeopardMonitoring	Set	2	CTS12	M
LeopardMonitoring	Set	11	CTS11	M
LeopardMonitoring	Set	31	CTS11	M
LeopardMonitoring	Set	37	CTS11	M
LeopardMonitoring	Set	40	CTS11	M
LeopardMonitoring	Set	48	CTS11	M
LeopardMonitoring	Paw	19	CTS10	M
LeopardMonitoring	Paw	37	CTS10	M
LeopardMonitoring	Paw	27	CTS10	M
LeopardMonitoring	Paw	37	CTS10	M

Table 2: List of leopard records within the sampling effort.

3.3.2. Camera trapping rate and relative abundance

The first index that was calculated in the analysis is the camera trapping rate. There are several methods to calculate this value. The most common method is to count the number of independent photographs of a single species per 100 trap days, and this is the method that has been used in this work. Other options include to count the number of days in which the species is captured, or the number of photographs of the species per trap day. Another option is to consider the proportion of photos from the focal species compared with the total number of pictures of all animals. This is particularly used when the goal of the study is to assess and compare species components in communities (Palmer et al. 2018).

Camera trapping rate is considered to be an estimate of the relative abundance of species (RAI). Recent studied highlighted the limitations in correlating this index with the abundance of species, since it does not account for potential bias arising from imperfect detection (Lijun et al. 2019; Palmer et al. 2018). However, this index is still much in use in wildlife ecology studies, especially when assessing true abundance is very difficult or costly (Palmer et al. 2018).

Considering the above-mentioned method that was adopted to calculate the camera trapping rate, the final formula for the RAI calculation is the following:

$$RAI = \frac{E_i}{SC} \cdot 100$$

Where E_i is the number of independent photographic events of the species *i* and *SC* is the total number of trapping days in which cameras were operational.

3.3.3. Occupancy

Occupancy can be defined as the diffusion of a species within the study area. It is defined by two separate values, which are the naïve occupancy and the modelled occupancy. The first is given by the number of camera stations which recorded the focal species' presence, divided by the total number of camera stations in the study area. The second is given by the naïve occupancy corrected with the probability to detect that species (detectability).

In fact, naïve occupancy itself does not take into account the fact that a species may be present in the area where the camera stations is, but it could be not recorded in the study (MacKenzie et al. 2006; Amin et al. 2017). This value returns a detection (1), non detection (0) matrix for each species, considering each camera station.

The modelled occupancy is hence calculated with the formula:

$$\psi = \frac{s_d}{s \cdot p}$$

Where s_d is the number of sites in which the species was recorded; s is the total number of sampling sites within the study area and p is the detection probability.

Detection probability, in turn, is given by:

$$p = 1 - (1 - n)^t$$

Considering that n equals to the number of number of sites in which the species is recorded, divided by the total number of sampling sites in the study area; t equals to the number of surveys (MacKenzie et al. 2006).

3.3.4.   Population density

To calculate leopard's population density in the study area, we made use of the spatially explicit capture-recapture (SECR) modelling. The model was elaborated by use of the „`secr`" package in the software RStudio 2022.02.3+492.

This method is based on two assumptions (Borchers & Efford 2008), which are:

1) Individuals of the focal species have activity centers in their home ranges;
2) The probability to detect an individual grows by approaching the proximity of its activity center.

The encounter rate of an individual in a camera station is defined as a monotonically decreasing function of the distance from the focal individual's activity center to that station (Sarmento & Carrapato 2019). In other words, this detection function relates the probability of detection (g) or the expected number of detections (λ) for an animal with the distance of a detector from a point usually thought of as its home-range centre (Efford 2022).

The `secr` package allows to fit different detection functions in the model, however the choice of detection function is usually not critical, and the default 'HN' (halfnormal) is usually adequate. In this case, the number of times animal i is detected by trap j during a sampling occasion (y_{ij}) follows a Poisson distribution with mean λ_{ij} (Gardner et al. 2010):

$$[1]\ y_{ij} \tilde{P} oisson(\lambda_{ij})$$

The model assumes then a log-linear form:

$$[2]\ \log(\lambda_{ij}) = \log(g_0) - \left(\frac{1}{2\sigma^2}\right) d_{ij}^2$$

The index g_0 can be defined as the probability of capturing an animal in a camera station during an occasion j, when the activity centre of the individual coincides precisely with the trapping station. σ, on the other hand, define how the curve is skewed as the distance from the home range centre increases. More generally, since σ is the scaling parameter of the function, it is related with the home range size.

A buffer around each camera trap locations needs to be considered for the analysis. It should be large enough include potential home range centres of the captured individuals. In general, keeping a buffer value which equals to 4σ is appropriate (Efford 2022). Higher buffer values require more computational time, but bias for over-wide buffer sizes is negligible; on the other hand, too narrow buffers may result in relevant bias for estimated densities (Efford 2022). In this work we used a buffer of 12 km, since leopards can have very large home ranges in arid environment (Bothma et al. 1997; Steyn & Funston 2009; Stein et al. 2011). The `secr` package can automatically suggest the best buffer size when fitting the model. This is done by the `suggest.buffer` function in R Studio.

In order to apply this method, only records in which animals are individually recognisable can be used, and footage in which clear differentiation between individuals is not possible need to be discarded.

We tested various models in order to see which one is more accurate in our research by comparing both the AIC and AICc indexes and the detection probability curves. The first model did not take into account any covariate, and this can be defined

as an "empty" model where the influence of sex on the function is not considered (model ID: *fit0*). Then we tested other three models to see how males and females differed in the detection curve. Model *fitSex1* assumed g_0 was constant and σ was sex-dependent; model *fitSex2* assumed g_0 was sex-dependent, and σ was not; the last model *fitSexT* assumed both g_0 and σ were sex-dependent.

SECR models in RStudio automatically calculate the mask area that cover the sampling effort. Theoretically, it is possible to create a custom mask to exclude unsuitable habitat and integrate the mask in the density estimation. However, for free ranging species this process showed to be unnecessary, as centroids of core areas will not be located in unsuitable habitat if data are not supporting it (Nipko 2022, pers. com.).

As already mentioned, even though the study area creates a mosaic of different microhabitats, in our case the arid landscape is relatively homogeneous: given the lack of particular obstacles in the area such as lakes, large rivers, vertical slopes, etc., we decided not to consider any custom habitat mask and to consider the default area calculation which RStudio returned.

4.   Results

Camera traps deployed in the twenty stations were active for ~63 days on average and recording 10,548 photographs in total. The average spacing between camera trap was 2,234 m. The final number of trap nights was 2,536, and this value was obtained by considering only the days in which camera stations were operational.

More specifically, 267 events were attributable to the camera setup process, which could be either the camera placement, the station check-up or the camera recovery. 41 videos were triggered by persons passing by – researchers or shepherds. 189 videos were caused by the wind action; 111 events were related to the contrast given by the sunshine light that triggered the motion sensor; 132 videos were triggered by insects. More than half of the total video recorded (6,099) were caused by the vegetation moving. 1,042 videos were apparently empty and 16 events were classified as "unidentifiable" since it was not clear whether the motion sensor was triggered by an animal or either wind, insects, etc. All the rest of the footage (2,651 videos) were triggered by wildlife. Among those, 145 were classified as "unidentifiable" wildlife, resulting with 2,506 final records of identifiable species.
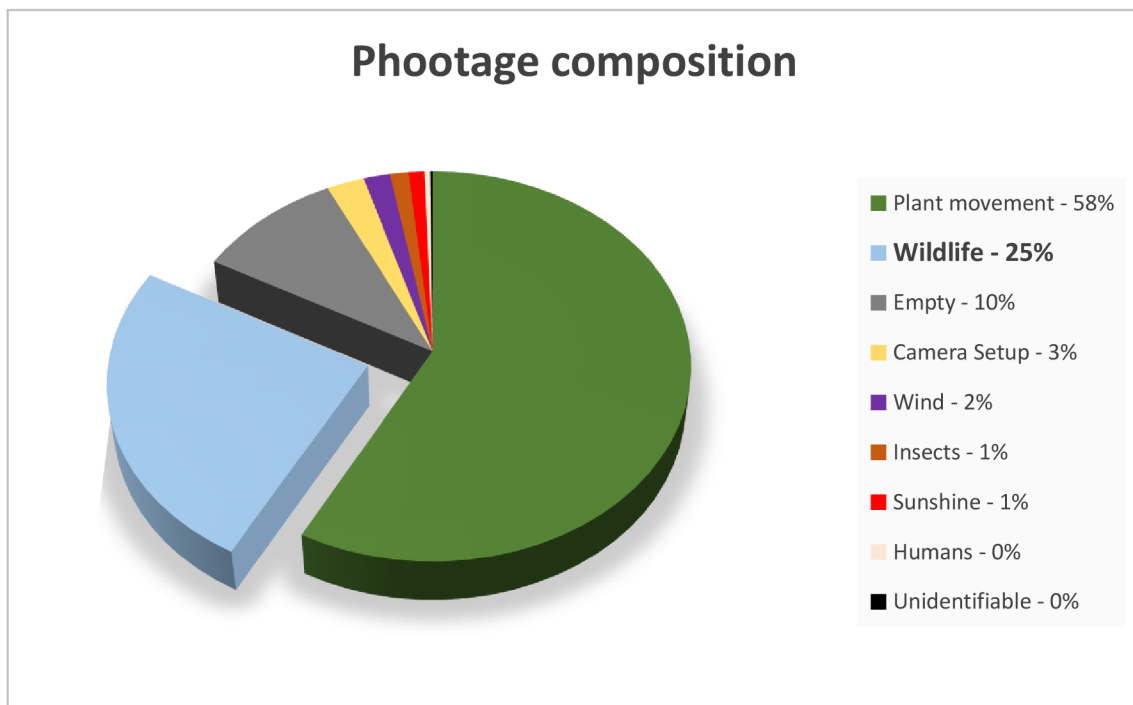
Figure 7: Percentages of the total footage composition in the camera trap stations.

For the purpose of this study, we were not interested in the identification of birds (103 records) and reptiles (1 record) which were also recorded by camera traps, and we focused on mammals. The most abundant species recorded was the common slender mongoose (*Galerella sanguinea*), with 210 records (8.4% of the total number of wildlife images recorded), followed by the rock hyrax with 159 records (6.3%) and the klipspringer with 90 records (3.6%). The complete list of mammals recorded by camera traps can be seen in **Figure 8**.
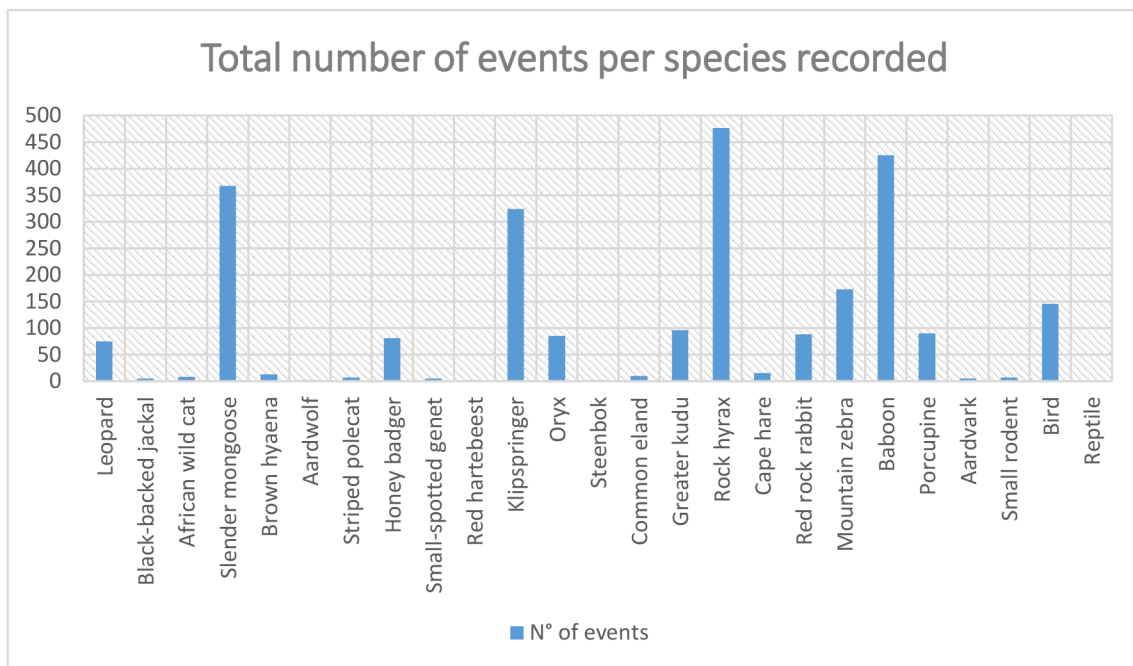
Figure 8: Total number of independent events per species recorded in the camera trap stations.

Leopards were recorded in 41 independent events, accounting for 75 total images in total. They appeared in 14 camera trap stations. Leopard was the eleventh most abundant species recorded among mammals (3% of the total number of wildlife images recorded).

4.1.1. Occupancy

Camera trapping rate for leopards was 1,62. Naïve occupancy was 0,7 and modelled estimate occupancy (ψ) was 0.762 (SE 0,116) with a detection probability (p) of 0.174 (SE 0.031). Akaike information criterion (AIC) index of the model resulted to be equal to 200.4.

Trapping rate, naïve and modelled occupancies of other carnivorans and ungulates can be seen in **Table 3**. It can be interesting to consider those parameters because of potential competition between leopards and other species, and to have an estimate of leopard's prey abundance, as we will later discuss.

Modelled occupancy can be calculated only for species whose naïve occupancy is higher than 0.1 and were detected more than 5 times, therefore some species lack those indexes.

Species			Occupancy		
Common name	Scientific name	Naïve Occupancy	Modelled Estimate (ψ)	Detection probability (p)	Standard Error
Aardvark	*Orycteropus afer*	0.05	-	-	-
Aardwolf	*Proteles cristata*	0.05	-	-	-
African wild cat	*Felis sylvestris*	0.3	0.993	0.027	0.274
Baboon	*Papio ursinus*	0.35	0.371	0.209	0.114
Black-backed jackal	*Canis mesomelas*	0.1	-	-	-
Brown hyaena	*Hyaenna brunnea*	0.15	-	-	-
Cape hare	*Lepus capensis*	0.05	-	-	-
Common eland	*Taurotragus oryx*	0.1	-	-	-
Greater kudu	*Tragelaphus strepsiceros*	0.35	0.402	0.152	0.127
Honey badger	*Melivora capensis*	0.55	0.641	0.14	0.14
Klipspringer	*Oreotragus oreotragus*	0.85	0.863	0.271	0.081
Leopard	***Panthera pardus***	**0.7**	**0.762**	**0.174**	**0.116**
Slender mongoose	*Galerella sanguinea*	0.95	0.95	0.434	0.049
Mountain zebra	*Equus zebra hartmannae*	0.4	0.519	0.111	0.161
Oryx	*Oryx gazella*	0.4	0.426	0.205	0.118
Porcupine	*Hystrix africaeaustralis*	0.55	0.784	0.089	0.207
Red hartebeest	*Alcelaphus caama*	0.05	-	-	-
Red rock rabbit	*Pronolagus rupestris*	0.7	0.709	0.275	0.104
Rock hyrax	*Procavia capensis*	0.8	0.801	0.414	0.09
Small-spotted genet	*Genetta genetta*	0.1	-	-	-
Steenbok	*Raphicerus campestris*	0.05	-	-	-
Striped polecat	*Ictonyx striatus*	0.15	-	-	-

Table 3: Naïve and model occupancy for the main species of animals recorded within the sampling effort.

4.1.2.   Species overlap

Being caught by camera traps predominantly at night, leopards showed a nocturnal/crepuscular habit. During the day (between 7 a.m. and 5 p.m.) we registered 5 records only (12%), out of 41. The 22% of the captures occurred at sunset (between 6 p.m. and 8 p.m.) with 9 events, while the majority (66%) occurred at night (between 8 p.m. and 7 a.m.), with 27 events (**Figure 9**).
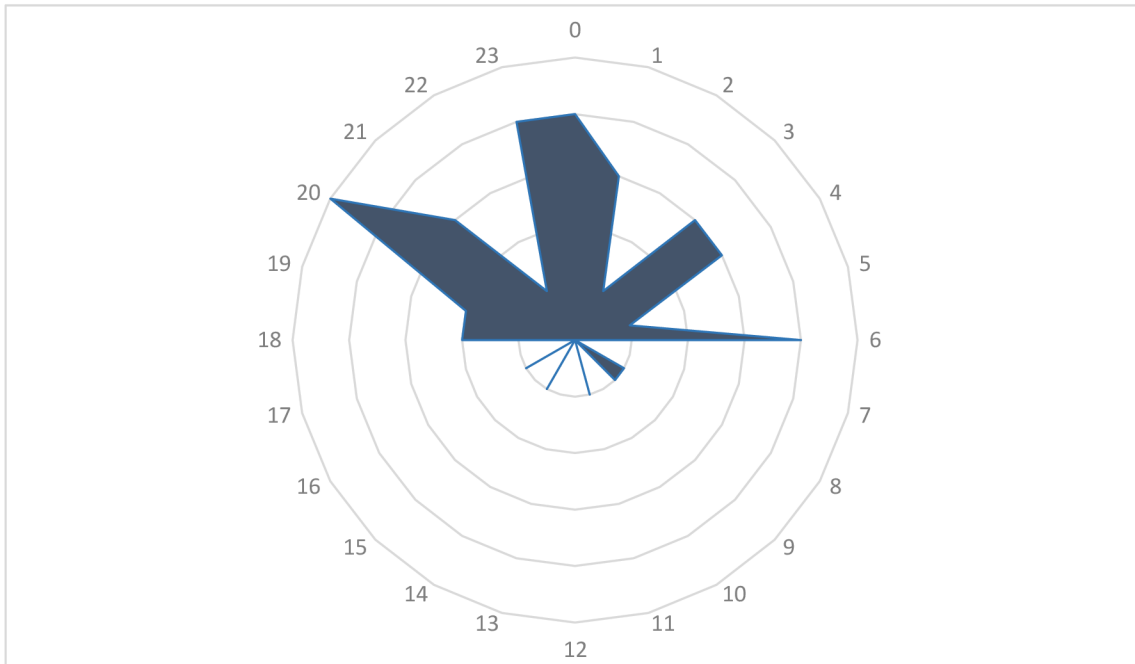
Figure 9: Leopard activity pattern given by the number of independent photographic event per hour of the day.

We observed which species overlapped the most and the least with leopards, according to the camera stations (CTS) in which both the species appeared. Slender mongooses, klipspringers and rock hyraxes were the species which were most observed in the same CTS as leopards; those species were also the most numerous in our sampling effort in general. The aardwolf, on the contrary, was observed only once, in a camera station where leopards did not appear (**Figure 10**).
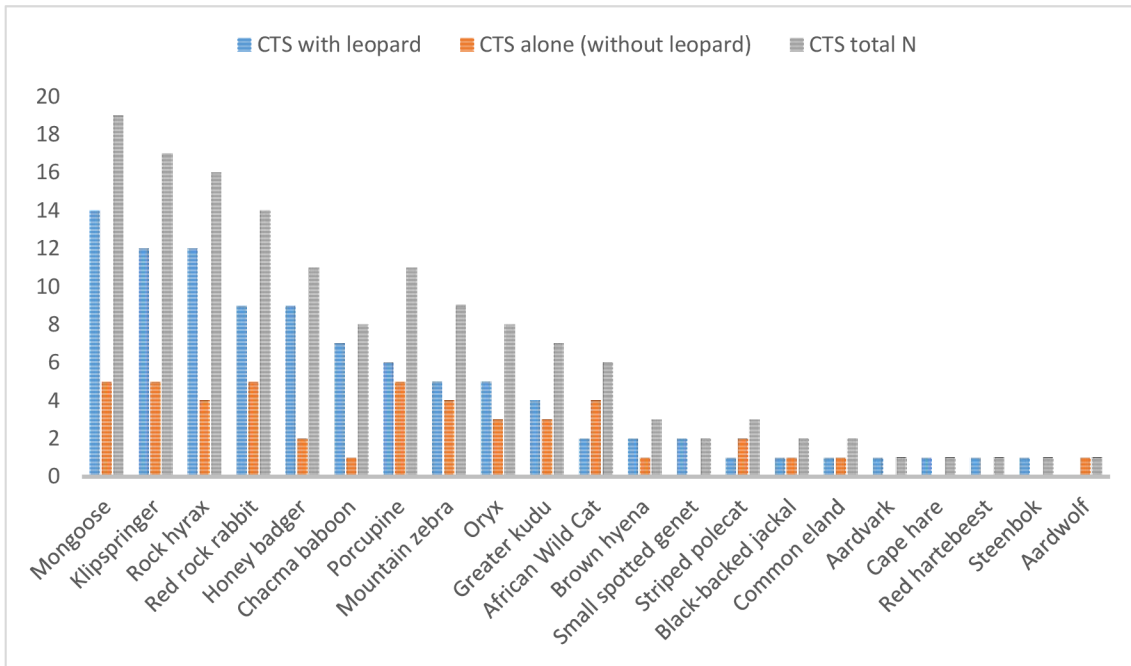
Figure 10: Overlap between leopards and other species in the same camera stations.

Activity pattern of the species listed above can provide a better view on the actual chances of encounter with leopards, since those animals may be more active in different times of the day. For this purpose, we considered only species with more than 20 events recorded. The most nocturnal species showed to be the porcupine, which was never recorded during the day and produced 19 nocturnal events and 6 crepuscular events (namely 76% and 24% of total events for the species), followed by the red rock rabbit, with 40 nocturnal events and 26 crepuscular events (namely 57% and 37% of total events for the species), which was recorded only 4 times during the day (6%).

Considering the most counted species, the slender mongoose was the most diurnal species (98% of its captures occurred by day), followed by the rock hyrax (96%) and the klipspringer (84%). Chacma baboon showed also a primarily diurnal habit, with 26 events out of 29 (90%) (Figure 11).
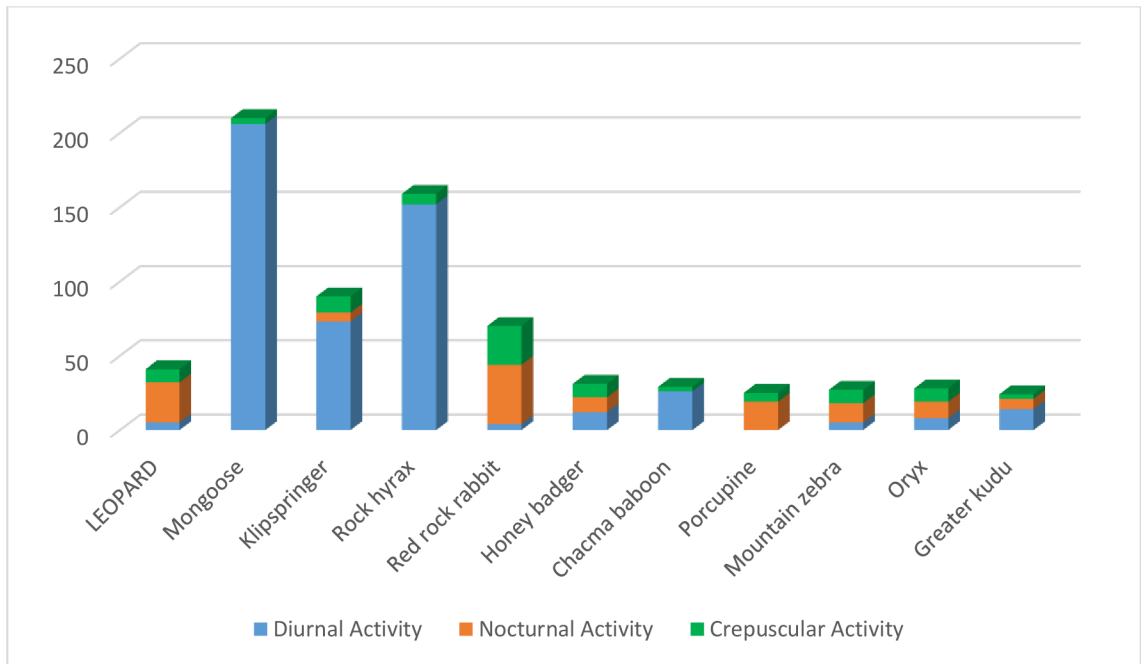
Figure 11: Activity patterns of species recorded in the camera trap stations with more than 20 photographic events.

4.1.3. Population density

For the population density estimation, we had to consider only those records in which individual leopards were unequivocally identified. We had to discard 6 events in which the subject resulted too blurry in the video, or where just a body part of the animal appeared – in that case allowing for the species recognition, but not of the single individual. Therefore, the final number of independent events considered was 35.

A unique ID was given to each leopard recorded. We decided to use common names, since the use of numerical codes could be a source of confusion when coding in RStudio. Camera traps recorded the presence of 6 different individuals, 2 females and 4 males. The two females were named "Estelle" and "Dark", while males were named "Set", "Hunter", "Pink" and "Paw".

In Table 4 we can see in which stations each individual appeared and the number of captures.

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Individual ID	Sex	N° of CTS seen	N° of captures
Pink	M	2	6
Hunter	M	3	8
Set	M	5	10
Dark	F	1	3
Paw	M	2	6
Estelle	F	1	2

Table 4: Number of camera trap stations in which individual leopard appeared and total number of captures.

Resulting models returned a mask area of ~1068 km² (106796 ha).

Results about the accuracy of each model tested is listed in **Table 5**. We can see that model *fitSex1* had the smallest AIC value (394.024). This model returns a detection function in which g_0 is constant and σ is influenced by sex.

Given the low sampling size, AICc values of each model were also considered. However, it was not possible to calculate AICc values for the model *fitSexT*, due to larger number of coefficients. *fit0* showed the smallest AICc value, with 417.996. This model, as already mentioned, considered no covariates in the analysis.

Model ID	g_0	σ	AIC	AICc	Density estimation (Indd. / 100 km²)
fit0	Constant	Constant	405.996	417.996	0.456 ±0.21
fitSex1	Constant	Sex-dependent	394.024	434.024	0.674 ±0.32
fitSex2	Sex-dependent	Constant	402.661	442.661	0.543 ±0.25
fitSexT	Sex-dependent	Sex-dependent	395.918	NA	0.678 ±0.32

Table 5: Accuracy test for each model tested in the secr package in RStudio.

Model *fit0* estimated a density of 0.456 leopards per 100 km², with a standard error of ±0.21. g_0 value was 0.0513 (±0.15 SE) and σ 3252.33 (±468.1 SE).

Detection probability curve confirmed our choice for the buffer size of 12 km. We can clearly see that over this value the detection probability of leopards stabilises approaching the horizontal asymptote which equals to zero (**Figure 12**). In fact, this buffer value was also the suggestion which was provided by R Studio with the `suggest.buffer` function (11,885 m). By increasing the buffer size, density estimation did not change relevantly.
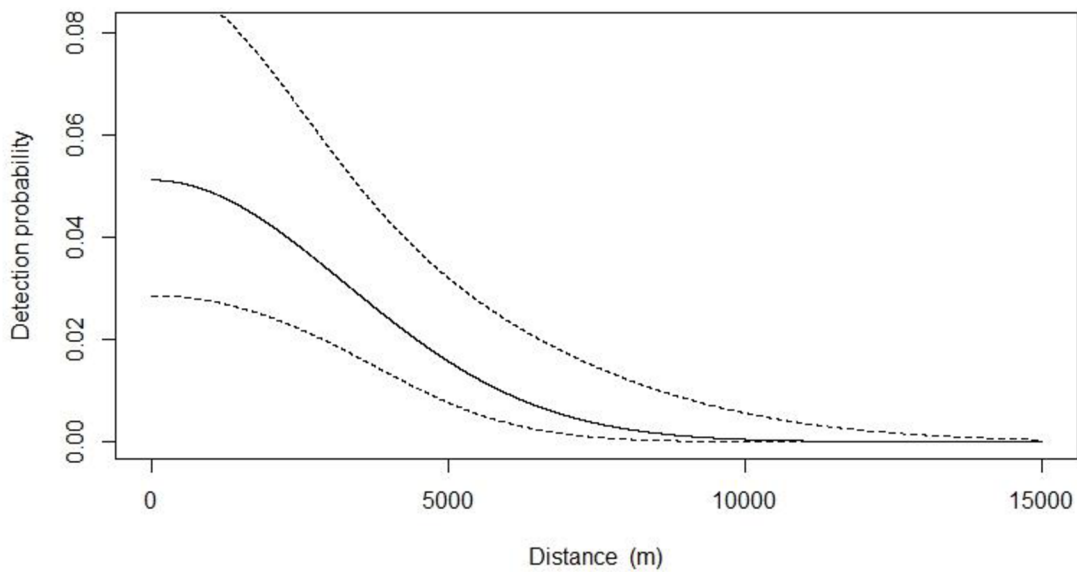
Figure 12: Leopard's detection probability in the study area, with a 12 km buffer size.

Model *fitSex1* estimated a higher density of 0.674 leopards per 100 km², with a standard error of ±0.32. g_0 value was constant: 0.0591 (±0.017 SE); while σ differed substantially between males and females. Males had a σ of 3522.87 (±615.07 SE); females had a smaller value, 866.09 (±299.68 SE), meaning that their detection function curve skewed towards zero more rapidly when increasing the distance.

Detection function curves of males and females can be seen in **Figure 13**.
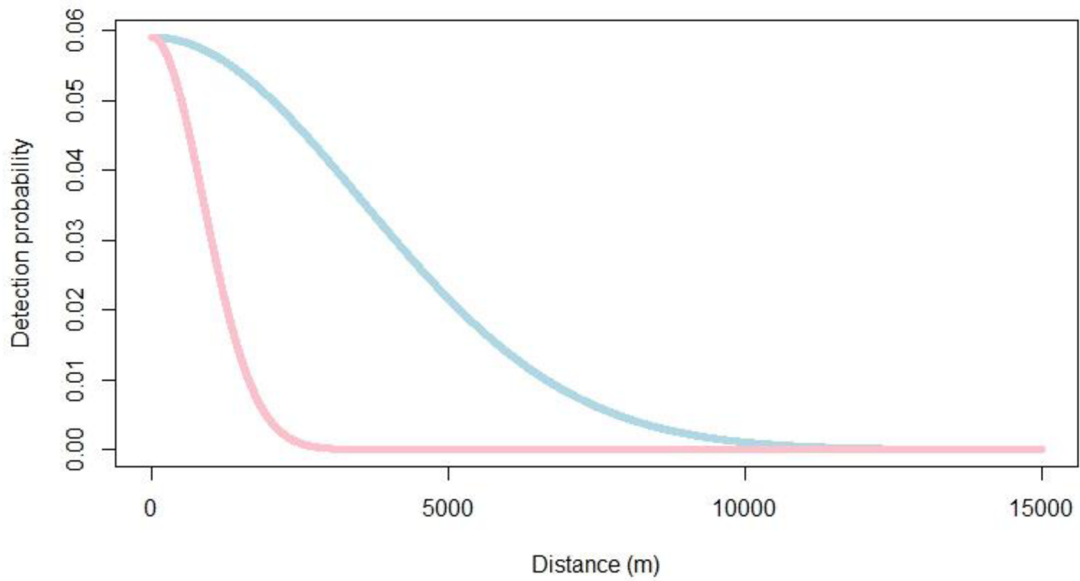
Figure 13: Detection probability curves of male (light blue) and female (pink) individuals according to the model *fitSex1*.

Detection probability parameter reaches the asymptotic zero at approximately 12,000 m for males and 3,500 for females, indicating that a leopard belonging to that gender whose activity centres was located at this distance from a given camera trap station had a theoretical capture probability of zero.

5. Discussion

5.1.1. Sampling Effort and Environmental Features

Our results highlighted the difficulty in monitoring efforts on large areas with little or no tree coverage. In such areas, camera trap placement can be really challenging because of the lack of narrow passages that are preferentially chosen by roaming wildlife in forested habitats. Initially, water points seemed to constitute obliged waypoints for leopards, especially in such an arid region. In this sense, the preliminary study showed to be crucial to maximise our sampling effort and to concentrate the camera trap placement on dry riverbanks, since no leopard appeared at water points. This can be explained by different hypothesis. The first reason would be the proximity of the sampling area to the Orange river, which may constitute the primary water source for wildlife in general, including leopards. Since ungulates are probably gathering in the vicinity of the riverbanks when drinking, that area could be an effective hunting ground for predators as well. We know that the very definition of territory is a defined space which is actively defended because of the resources it hosts, which can be water, food sources, shelter, etc (Russel et al 2009). It is therefore reasonable to think that a sort of spatial gradient could exist in the size and distribution of leopard's territories across the study area, when approaching to the Orange river, once confirmed that this area would host an higher amount of resources. This critical element of the landscape would also re-shape their home ranges across the study area and affect their density. Another hypothesis that could explain the low capture rate on water points is the fact that leopards are able to acquire moisture from their preys and by consuming succulent plants at times, especially in arid areas (see **Chapter 1.1.4**), thus making them less dependent by water sources (Bothma 2005). In fact, they can resist for up to three days without drinking.

If we look at **Figure 14**, we can see that all the camera trap stations which were closer to the Orange river obtained multiple leopard sightings, whereas many camera trap stations in the central portion of the KumKum farm did not catch any leopard.

However, this portion of the study area was the one in which most of leopard's signs of presence was observed.
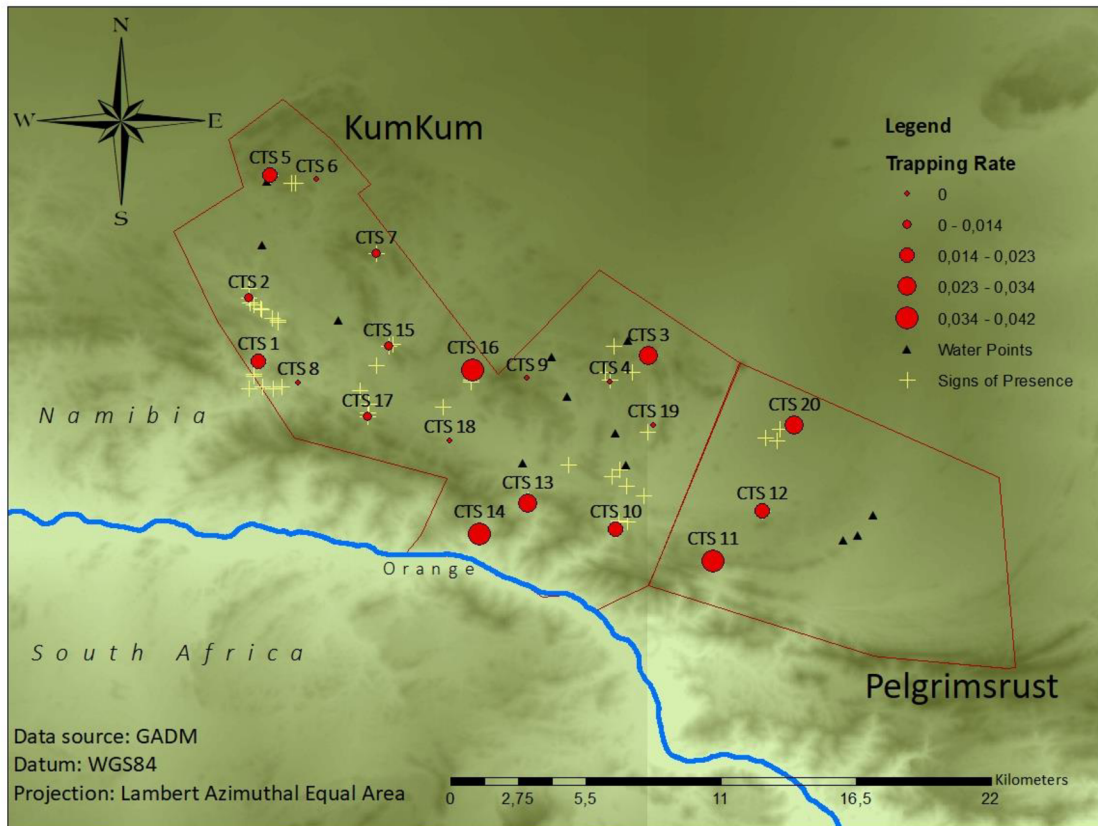
Figure 14: Value of leopard's trapping rate in each camera trap station. Water points and signs of presence are also visible across the study area.

From the resulting map it is hard to state whether the Orange River may have a certain influence on the distribution of leopard territories. It is important to highlight that in **Figure 14** all the leopard records were considered for the computation of the trapping rate, regardless of their individual recognition.

A much clearer result is observed by the map which is computed by RStudio when plotting the leopard population density gradient across the study area by the SECR package (**Figure 15**). In this case the coordinate system is not projected and cartesian points describe the camera trap stations locations. In addition to that, only individually recognized leopards were considered for plotting the map, so it was clearly impossible to take into account also tracks or scats. With such few data, the estimate of the number of individuals per 100 km² is not accurate when considering individual contour lines across the gradient. On the contrary, it is more meaningful to consider the overall mean

density value across the study area, as reported in the previous chapter. Nevertheless, contour lines provide visual feedback on how much the density estimation varies across the sampled farms. We can observe that the density estimation remains constant across most of the area, but changes quite abruptly between contour lines over a relatively short distance in the south-east (here referring to the projected coordinate system). In this case, the peak of the density estimation falls close to CTS 11, in the southern part of the sampling area between the two farms, thus very proximate to the Orange river.

We recommend the use of game paths as preferential locations to place camera traps in similar studies in the same environment, with a focus on the proximity of river banks.

Figure 15: Variation of the number of individual per hectare in the study area, as computed by the secr package in RStudio.

If we look at **Figure 16** we can observe the number of leopard captures in comparison to the total wildlife capture in each camera trap station. We can highlight the fact that both CTS9 and CTS3 registered a relatively high number of events (439 and 285 respectively), but no leopards. It is meaningful to consider also the total number of events if we want to exclude the possibility that camera trap stations with no leopard records were placed in zones with little or no passage of wildlife in general.
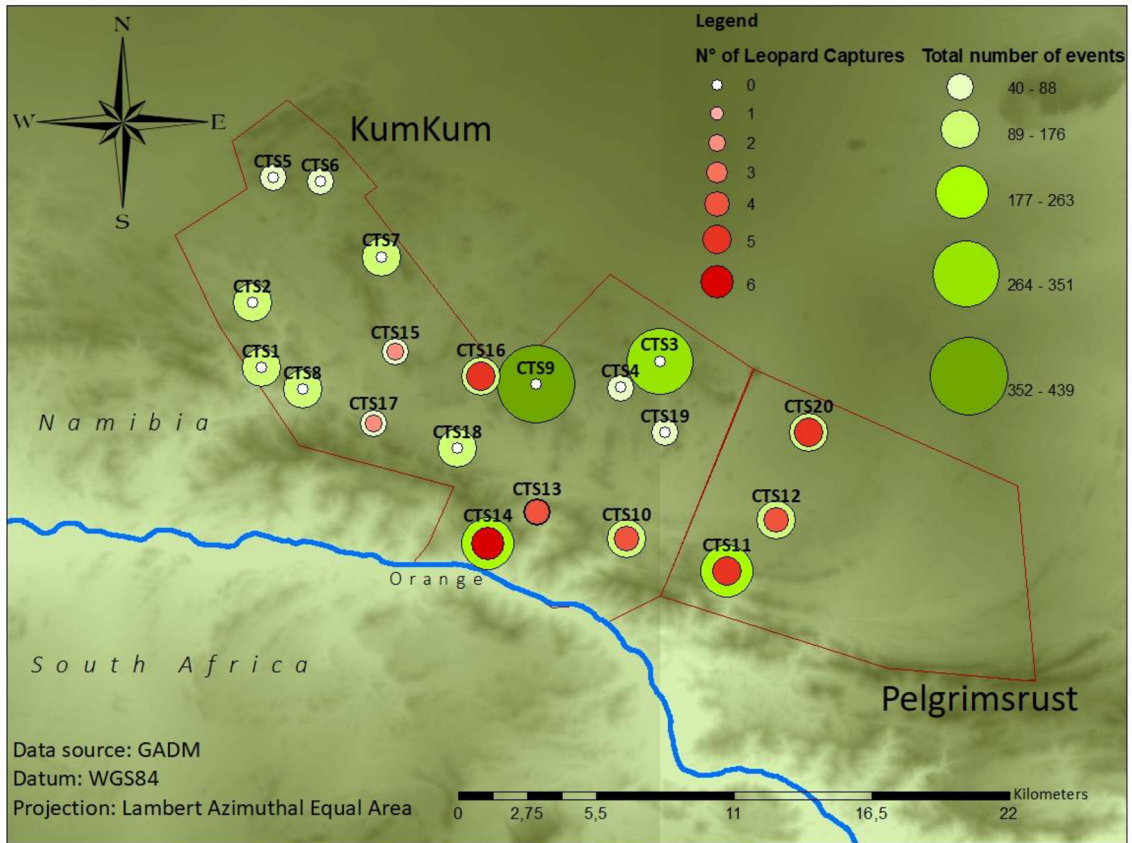
Figure 16: Number of leopard's captures and total wildlife captures in each camera trap station.

Even after detecting the preferential passageways for detecting wildlife, the 62-days sampling length registered a relatively small sample size for leopards, with only 41 records in total. This value may seem quite low when it comes to building solid statistical models, but we must bear in mind that the population closure assumption requires a relatively short timeframe for the sampling effort. Reviewing leopard capture results in published literature, some authors suggest that for wide-ranging large carnivorans, longer sampling surveys provide more accurate density estimates (Jędrzejewski et al. 2017; Devens et al. 2019; Dupont et al. 2019; Harmsen et al. 2020). For instance, a study carried out in Mpumalanga, South Africa, ran a six-months sampling effort by rotating the location of camera stations, with the aim to capture every adult leopard in the study area (Morris et al. 2021). Other authors suggested that shorter survey length (30-90 days) ensure the population will not experience birth, deaths, immigration or emigration (Tobler and Powell 2013). We can then affirm that our sampling length was a reasonable trade-off between satisfying the population closure assumption and collecting enough

data for a robust abundance estimation, since capture probabilities are relatively low for large carnivorans (Harmsen et al. 2010), especially in a region where we already strongly suspected a low animal density.

5.1.2. Sex Ratio and Home Ranges

Counting four males and two females in the monitoring area can be surprising in a certain way. In fact, we expected a reverse sex ratio, which is confirmed also in similar studies (Morris et al. 2021; Devens et al. 2018; Grey et al. 2013) due to the fact that males have much larger home ranges when compared to females. As already mentioned, male's home ranges usually overlap with several female's home ranges and may entirely embrace them. It is unclear why the sex ratio resulted to be that skewed towards males. A possible explanation would be the uncertainty of the sex determination of some individuals, which were therefore not considered in the SECR analysis. We strongly believe that the majority of animals which were not individually recognized were females, possibly adding more individuals to the total detected in the study area. Moreover, male leopards generally show more territorial behaviours than females, actively patrolling their established home ranges more frequently than females (Mizutani & Jewell 1998), and this could explain why males tended to appear more at the stations.

On the other hand, setting a thicker sampling scheme in order to leave less distance between camera traps would be theoretically better to maximise the capture of all the individuals roaming in the study area. However, in such arid area the home range size estimation is relatively large, therefore setting a layout which would imply a less than 2 km spacing between camera trap stations is not supported by significant benefits, especially with limited resources and the need to sample a large area. If we look at **Figure 14**, we can notice that many signs of presence were recorded in the immediate surroundings of camera trap stations which had low trapping rate, thus suggesting that more individuals were probably moving around the stations without being recorded there.

With larger home ranges, males usually tend to cover more distances than females. This was confirmed in our study, as the two females were seen in one station only (CTS 12 and CTS 16 respectively), while every male in at least two stations (Paw), with a maximum of five stations (Set). If we consider the biggest area covered by the movement of a single re-captured individual, we can calculate the area covered by the male Set by the minimum convex polygon (**Figure 17**).

In this case Set's individual home range measures roughly 50 km², with the two further camera trap stations (CTS 15 and CTS 12) which are separated by almost 17 km. It is very likely that by expanding the sampling area, the same males would be captured also at longer distances, given the fact that home range sizes of male leopards in similar environment were reported to measure up to 885 km² in Central Namibia (Snider et al 2021) and 2000 km² in Kalagadi Transfrontier Park (Bothma et al 1997). Moreover, the ideal methodology to calculate home range sizes for large felids would be by use of radiocollars, especially with such large areas to cover.
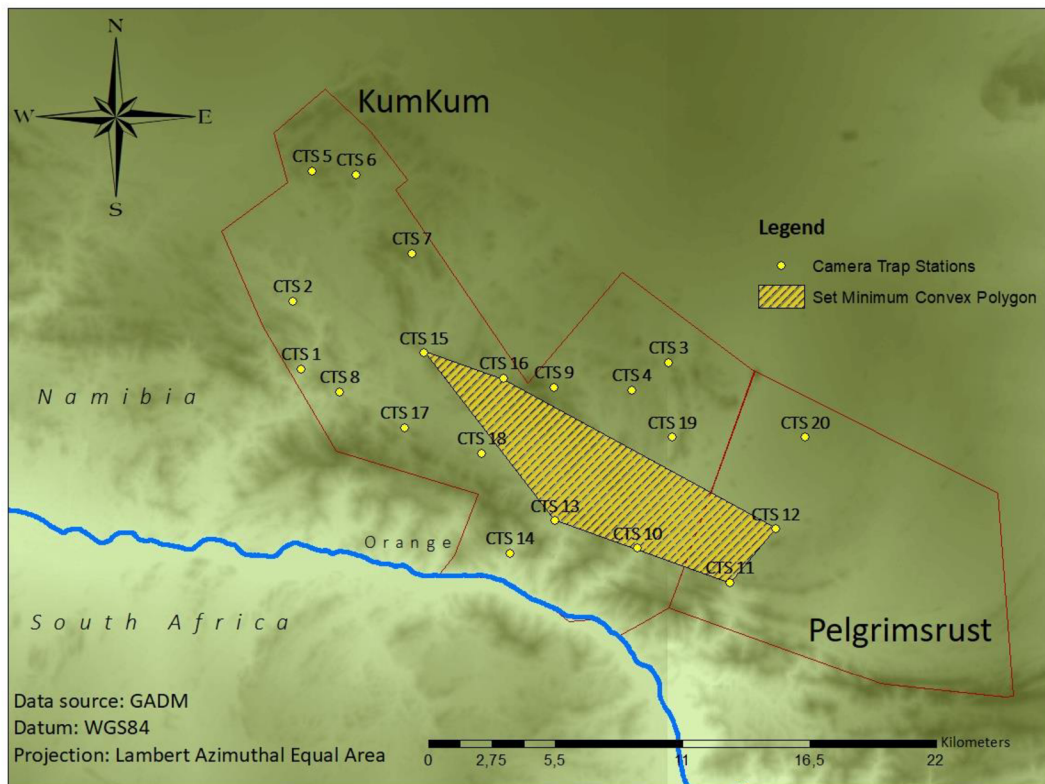

Figure 17: Set's home range extension in the study area, as computed by the minimum convex polygon.

5.1.3.   Population Density

After testing different models in the secr package in RStudio, model *fitSex1* showed the smallest AIC value (394.024). This model assumed that g_0 was constant (and resulted to be 0.0591 ±0.017); and σ was influenced by the sex of individuals. We recall that g_0 can be defined as the capture probability of an individual at the exact centre of its home range. Since σ is a spatial parameter which is function of movement, it is directly correlated with the home range size of the individual. The population density estimation according to this model was 0.674 leopards per 100 km², with a standard error of ±0.32. Since males had a σ of 3522.87 (±615.07 SE) and females had a σ of 866.09 (±299.68 SE), female's home ranges were estimated to be smaller than males. In fact, σ value determines how rapidly the detection function curve is skewed towards the asymptotic zero as the distance from the centre of the home range increases. However, σ is expressed in the denominator in [2], therefore we can state that the smaller this value is, the smaller is the extension of the home range area of the considered individual(s).

In addition to the AIC value, when the sampling size is low, like in our case, it is recommended to consider the AICc value as it provides a better estimate of the goodness of the model fitting (Delsole, 2021). This is the reason why we took into account also model *fit0*, which had an AIC value of 405.996, but the smallest AICc value (417.996) than *fitSex1* (434.024). *fit0* estimated a density of 0.456 ±0.21 leopards per 100 km². In this case the g_0 value was very similar to the one obtained in the previous model, being 0.0513 ±0.15 and σ resulted to be 3252.33 (±468.1 SE), which is somehow similar to the σ value of males in model *fitSex1*.

We also tested two models in which g_0 was assumed to be sex dependent. Those models were respectively *fitSexT*, which assumed that σ was sex dependent too, and *fitSex2*, which assumed that σ was constant. Theoretically, expecting that g_0 could also differ between males and females was reasonable, because of the differences in the capture rates which were explained in the previous chapter. Unlike females, not only we

recaptured males in multiple camera trap stations (thus suggesting bigger home ranges, and higher σ values), but also females appeared much less on cameras in general, even in the stations which registered their presence. Overall, we obtained 5 captures only (17%) of females, and 30 captures of males (83%), hence prompting to the consideration of different g_0 values. As a matter of facts, *fitSexT* had even a lower AIC value than *fitSex1*, so this model can not be easily discarded as not representative. However, AICc values cannot be calculated for it since the number of coefficients is too low. The population density estimation which was given by *fitSexT* is 0.678 ±0.32, which is almost identical to the result shown by *fitSex1*. Since the only difference between the two models is the sex influence on the g_0 value, we can conclude that we did not observe any influence in the capture probability between males and females at the centre of their home ranges. *fitSex2* computed an intermediate result between the model with no covariates and the ones with σ influenced by sex. In this case, the density estimation was 0.543 ±0.25 individuals per 100 km². Given the fact that the AIC (402.661) and AICc (442.661) values were higher than in the other models, combined with the fact that σ showed to vary relevantly between males and females, we could state that this model is probably the least representative in our study.

Overall, it is not easy to determine which model better describes the situation for the sampling between KumKum and Pelgrimrust. AICc value provides a statistical proof of the goodness of the model fitting and can be used to compare different models, however, fitting sex as a covariate in SECR analysis normally improve density estimates (Sollmann et al. 2011; Tobler and Powell 2013). Our visual data and the detection curve function strongly suggests that σ is influenced by sex. If we consider the spectrum of the density estimates by all models, the difference between the lower and the upper limit is only 0.21 individuals per 100 km². In general, we can conclude that our final result about the leopard population density estimation varies between 0.46-0.67 leopards per 100 km².

Even with a small dataset, this result is coherent with other estimates by other authors in similar biomes by use of the SECR methodology. In Western and Estern Cape, South Africa, the population density estimation in the thicket, fynbos and succulent karoo ranged between 0.2 and 0.9 leopards per 100 km² (Devens et al 2019; Devens et

al 2018). As we expected, we are very far from the density estimations in the woodland savannah or grasslands of Southern Africa. Moving to northern Namibia, for instance, a leopard density of 14.5 individuals per 100 km² was recorded in the Okonjima Nature Reserve (Noack et al. 2019); in the Kruger National Park (South Africa), the density estimation was also much higher (12.7 individuals per 100 km²). Another study which was carried out in Southern Namibia by use of the non-spatial capture recapture density estimation, computed 0.59-0.90 leopards per 100 km² (Edwards, 2015).

The last national leopard census was carried out in 2019, and according to that study, the Karasburg constituency fell into a density interval of 0.5-1 individuals per 100 km² (Figure 18). Our result could confirm this estimate, even if the uncertainty of the models put our numbers at the borderline between the two lowest intervals (0-0.5 and 0.5-1 individuals per 100 km² respectively).
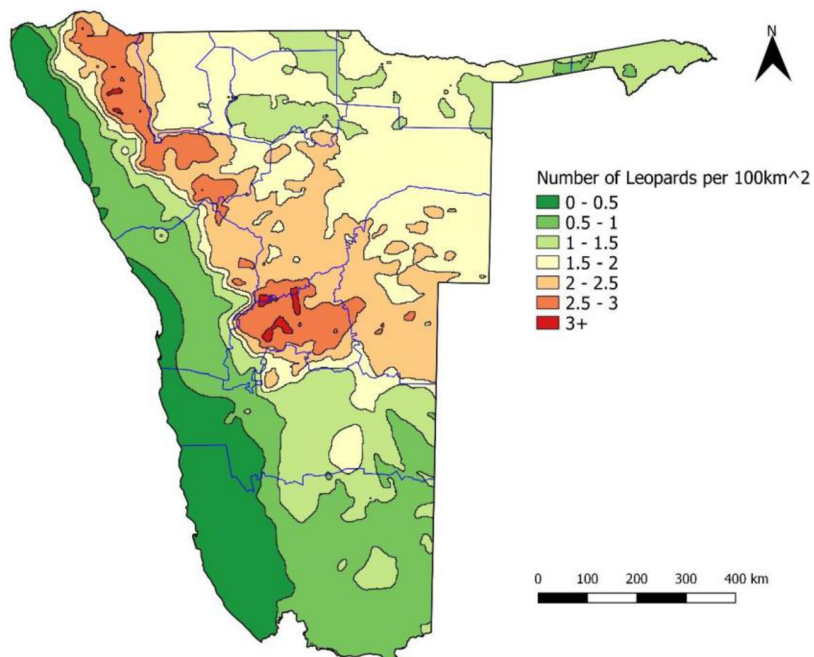

Figure 18: The variation in leopard density using seven density intervals derived into discrete contours across Namibia (from: Richmong-Coggan 2019)

5.1.4.   Interspecific Interactions

Other than leopards, the most counted species in the study area was the rock hyrax (476 total events), followed by the baboon (425), the slender mongoose (367) and the klipspringer (324). When classified by the occupancy, the most represented species was the slender mongoose (with a modelled estimate of 0.95 ±0.05), followed by the klipspringer (0.86 ±0.08), the rock hyrax (0.8 ±0.09) and the baboon (0.37 ±0.11).

Data from the Cape Province in a mountainous habitat suggested that leopards tend to prey on smaller ungulates in the absence of larger competitors, such as lions. (Norton et al. 1986; Ott 2004). Similarly, competition may expand the body mass range of prey taken by leopards (Johnson et al. 1993). In the study area, the brown hyena was the only other big carnivoran reported, with 3 records only in the camera traps. Another recent study also reported very few caracal (*Felis caracal*) sightings in the study area (Koch Jiménez 2021), even if they never appeared in our camera trap stations. With such low densities, we can state that leopards have virtually no carnivore competitors in the area. We can therefore expect leopards to prefer smaller preys if compared with their diet in other contexts in Southern Africa.

According to leopard's diet studies, the slender mongoose does not represent a preferred leopard's prey species. Rock hyraxes and klipspringers were reported as one the preferred prey species in the Cedarberg mountains in South Africa, in a similar environment (Martins et al. 2011). Their diurnal habit probably limits their chances of encounter with leopards, which are mainly nocturnal-crepuscular. The 96% of the rock hyrax capture events occurred by day, and the percentage for klipspringer was 84%. Baboons were also reported as frequent prey species, even though are usually avoided if other preys are available (Hayward et al. 2006). The 77% of baboon kills in Kruger were attributed to leopards (Pienaar 1969), that manage to hunt them actively during the night (Cowlishaw 1994). However, this does not necessarily imply that they constitute a high percentage in the leopard's diet. In fact, their group vigilance and arboreal habit decreases the probability of success of leopard's attack upon them during the day. In our case, baboons were recorded by day for the 90% of the total events for this species. In addition to that, adult males may constitute risky targets as they are very agile and

equipped with large canines (Zuberbuhler & Jenny 2002). Porcupines have shown to be another frequent leopard prey species, covering on average the 4.3% of its diet (Hayward et al. 2006), according to published studies. In the study area, porcupines were the species that overlapped the most with leopards, given their nocturnal habits. They were never recorded by day during our sampling effort. Their modelled occupancy was 0.78 ±0.2.

Red rock rabbits can be considered as potential prey species, even if its body mass is normally too low to constitute a preferential prey species when other ungulates are available (Hayward et al. 2006). Their nocturnal activity makes this species one of those that overlapped the most with leopards, with only the 6% of its total captures that occurred by day. Their modelled occupancy was 0.71 ±0.1.

Greater kudus, oryxes and zebras, with their relevant body mass (up to 270 kg, 240 kg and 370 kg respectively) (Wilson & Reeder 1993; Walther 1990; Kingdon 1997), clearly outweigh the range of ideal prey species, which reveals an optimum around 23 kg - see **Chapter 1.1.4** (Hayward et al. 2006). In the study area they were much less abundant than the above-mentioned small mammals; moreover, in absence of other predators, we have no particular reason to consider those species as significative leopard prey species.

In **Figure 19** are reported the distribution of all the potential prey species in the study area, according to the number of events per camera trap. Baboons appeared to be the species which more overlapped with the area of maximum leopard population density, which fell in the south-east of the study area according to the scheme computed by the SECR analysis.
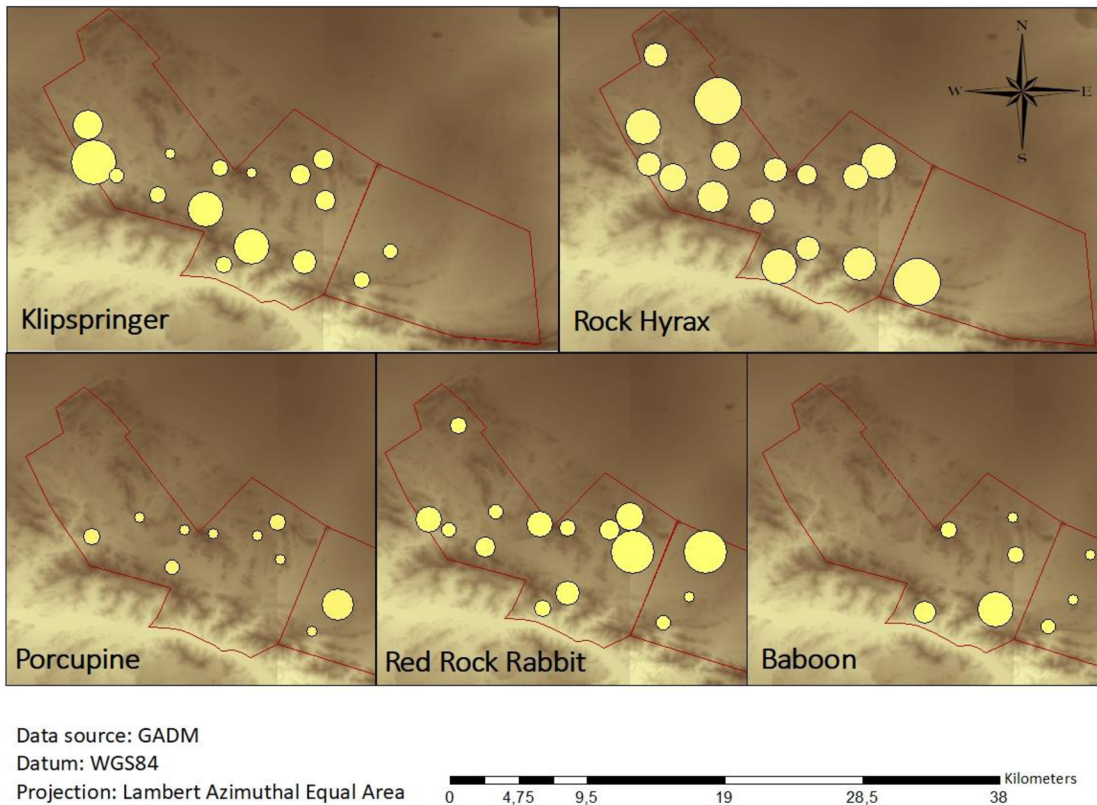
Figure 19: Distribution of potential prey species across the study area. Number of captures (ranging from 1 to 21) are represented by the yellow circles.

Leopard killings on smaller competitor are more frequent than expected (Hayward et al. 2006). Usually, individual preferences drive the reason for interspecific killing among predators (Henschel & Ray 2003). Among the carnivores which are hunted more often by the leopard, we can mention the black-backed jackal, which appeared in our camera trapping campaign. Its numbers in the study area were very low, with only three captures in total. Caracals are also listed as relatively frequent victims of leopard killings for resource competition (Pienaar 1969; Bothma 1997). Small-spotted genets (5 total events in our sampling effort) and striped polecat (4 events) are also reported as smaller competitors and potential leopard's victims (Hayward et al. 2006), along with the Cape Fox, which were not recorded by our stations but resulted to be present in another camera trap survey in the area (Koch Jiménez 2021). Overall, we observed a very little abundance of mesocarnivorans in our study area.

The honey badger seemed to be the most abundant mesocarnivoran in the area, and this is an interesting fact since this species is the one which is normally not suffering significant predation pressure by leopards (Hayward et al. 2006), even if their activity patterns overlapped substantially in our case, with the 61% of its capture being nocturnal.

Similar studies which were carried out in the Northern Cape also highlighted a low density of black-backed jackals, which was explained by limited resources available in the area, or either by threats which impact some predator species and not others (Curveira-Santos et al. 2020). Other studies observed a higher abundance of mesocarnivores in areas where human density was higher (Davis et al. 2021); given the very low human population density in the study area, this could explain our result. Local persecution of those carnivorans, as explained in **Chapter 1.1.6**, may have led to a local pattern of extirpation of this species. Interviews to local farmers in the study area, which were carried out in 2021 by Koch Jiménez, reported that black-backed jackal and caracal were the most conflictual species, followed by wild cats and the Cape fox, according to respondents. Since the 100% of farmers admitted that they tried to remove carnivores by shooting or by use of gin traps, this could explain why caracals and jackals occurred at such low densities (Koch Jiménez 2021).

There are probably multiple reasons explaining the low number of such carnivorans. One could definitely be found in human persecution, but it is reasonable to think that also the competition with the leopard itself could have an impact on the abundance of those species. Interspecific killings between carnivorans are probably underestimated, and different studies demonstrated that the loss of competing guild members, such as lions, are expected to increase the levels of competition between remaining carnivorans (Davis et al. 2021). Consequently, intraguild relationships can be altered, potentially increasing the risk of further population decline (Davis et al. 2021).

Leopard's influence on the community structure of other carnivores, as well as the mammalian community in general, has been little studied. The presence of African big felids seems to trigger a higher abundance of mesocarnivorans species, but also to decrease their population sizes in the area of co-occurrence, without implying a

suppressive effect that could lead to their local extinction (Curveira-Santos et al. 2020). In other context out of the African continent, the presence of large felids demonstrated to be beneficial for smaller mammal thanks to the control effect they exert on smaller carnivores. For instance, the Iberian lynx (*Lynx pardinus*) reintroduction in Spain provoked a reduction in the abundance of mesocarnivorans (such as *Vulpes vulpes* and *Herpestes ichneumon*) by 80%. This implied the recovery of small game such as the European rabbit (*Oryctolagus cuniculus*) and the red-legged partridge (*Alectoris rufa*). This mesocarnivoran reduction resulted in an estimated 55.6% less rabbit consumption by the entire carnivoran guild (Jiménez et al. 2019). It would be interesting to investigate more about the effect that leopard may exert on other species in the study area due to predation. The low abundance of mesocarnivorans, in our case, may result in unusually higher densities of mongooses, rodents, lagomorphs and even reptiles.

Mesocarnivorans decline, due to several factors which may include the sole leopard's presence in absence of other large carnivorans, may affect the delivery of fundamental ecosystem functions which are provided by those species (Curveira-Santos et al. 2020). Therefore, we recommend focussing the research effort in the study area also in this direction, in order to evaluate the overall ecosystem status and future community structure projections.

6.   Conclusions

This study provided insights on the leopard population density in the Karasburg Constituency, in South-Eastern Namibia. The last leopard national census suggested to further investigate its status across this understudied region with very low human population density (Richmond-Coggan 2019).

The study area covered a territory shared between two farms, characterized by very low mean annual rainfall and predominant aridity across the whole zone, which is mitigated in the vegetation composition only by the presence of the Orange river at the southern border with South Africa. Livestock and game farming is the main activity which is carried out in the region, and these practices sometimes result into competition between carnivores and local farmers. Hence the need to deepen our knowledge about the local leopard population status, in order to take management decision that could minimize the level of conflicts with locals without affecting the already threatened conservation status of leopards.

We adopted the SECR methodology to estimate the leopard population density across the study area by use of camera traps, expecting to detect a low number of individuals per 100 km², as observed in similar environment and reported for the region in the leopard national census of 2019.

We highlighted the difficulty to detect preferential pathways for wildlife in such an open environment, which consequently produced a small sampling size in the camera trap stations. In total, we detected 5 males and 2 females in our stations. Males showed a higher mobility across the study area, always being recaptured in multiple camera trap stations. The few females, on the other hand, were recorded in singular stations and had very low recapture values. Our population density estimate was 0.46-0.67 leopards per 100 km², with a certain degree of uncertainty due to different models tested for the analysis. Our data suggest that males have significantly bigger home ranges, if compared to females. To gain insight about the actual home range size of females' or males' leopards in such an arid area, the use of telemetry technology would be recommended, as the extent of the plot and the habitat type to investigate would be too dispersive for

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camera traps. However, with such low density we can already conclude that home range sizes are probably among the largest recorded in the African continent. This imply that a successful conservation strategy of this species should take into consideration several contiguous natural areas and its management cannot be fragmented according to human-set administration boundaries between different constituencies.

The Orange River probably plays an important role in the density variation across the study area, creating a microhabitat which is richer in resources such as water, vegetation cover and prey availability.

In this area, given the absence of other large carnivorans such as lions, leopards play the role of apex predator in the ecosystem. The most abundant preys observed in the study area were rock hyraxes and klipspringers.

Human persecution, along with the leopard presence in the study area, may have significantly affected the presence of mesocarnivorans, which were reported in very few numbers in the study area. We stress the importance to investigate more about the relationship between the leopard and mesocarnivorans in similar contexts, and the consequences of their scarcity on the species at a lower level of the trophic pyramid.

Figure 20: One of the leopards detected by camera traps during the study.

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