Spatial distribution and intensity of snare poaching in the Boland region of South Africa: implications for optimising anti-poaching efforts

By
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Abstract

The human population of sub-Saharan Africa is growing exponentially, increasing anthropogenic impacts on natural resources, including wildlife, both inside and outside of protected areas. The rising demand for cheap sources of protein is fuelling the harvesting of bushmeat. In South Africa, illegal wire-snares are the most popular method of bushmeat harvesting. However, snare poaching is indiscriminate and inhumane, causing the death of many non-target species and suffering by all animals captured. The impacts of snaring on an ecosystem can be devastating, yet few studies have explored wire-snare poaching trends in southern Africa or on private agricultural lands. This study used data obtained during 210 snare patrols to investigate the intensity of use and spatial distribution of wire-snares across 111 private agricultural properties in the Boland region in the Western Cape province, South Africa. I considered the influence of social and ecological attributes on property-level snare use, including punitive measure enforcement, the employment of seasonal workers, farmer residency, the use of legal lethal control measures, the number of families on the property, property size, the proportion of natural land, and primary agricultural output. I also considered the influence of anthropogenic structures and abiotic variables on snare placement across the landscape, including elevation, fine-scale land-use types, slope, ruggedness, and distance to the nearest street, river, servitude area, farm boundary, and protected area. Wire-snares were largely placed close to the ground, along game trails and fence lines, and anchored to trees and fence posts. My findings reveal that snare use was higher on properties where the farmer lived permanently on the property ($P = 0.005$) or the primary agricultural output was orchards ($P = 0.043$). Snares were more likely to be present further from a public street but within roughly 1 km, close to rivers, at an elevation of 300 to 500 m, and in patches of forest plantations, wetlands, bare ground, and natural woody vegetation. There was also a strong interaction (interaction size = 116.56) between distance to street and proximity to a protected area. The predicted snare hotspots are centred around protected areas at mid-elevation (300-500 m) but are not remote in terms of distance to a public street. It is important to use these findings to inform anti-snaring efforts as wire-snare poaching is likely to be a growing threat to local biodiversity. Future studies should use questionnaires or structured interviews in conjunction with field studies to collect data on snare use. This will help to prevent the misleading interpretation of respondent claims, avoid respondent biases and improve targeted snare removal and law enforcement actions. It will also provide insight into the local context, crucial for identifying potential local drivers of snaring, such as food security, and informing the focus of awareness campaigns.

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1. Introduction

1.1. Anthropogenic pressures

The increasing human population is impacting biodiversity negatively, particularly outside protected areas where anthropogenic pressures are intensifying (Kiringe et al. 2007). Pressure from human populations living outside protected areas has been linked to increases in the extinction rates of carnivore, primate, and ungulate species within neighbouring reserves (Brashares et al. 2011). Sub-Saharan Africa is projected to experience the highest population growth in the coming decades and will become one of the most populous regions in the world (UN-DESA, 2019). Growing populations consume more resources, including protein, which is likely to increase bushmeat hunting for consumption and/or to generate an income (Noss 1998; Fa et al. 2002; Knapp 2012). Hunting, poaching, and the illegal wildlife trade are among the principal anthropogenic drivers of defaunation (Peres 2000). Hunting has been called an 'invisible threat' as it is cryptic in nature, with the extent of population declines or even species loss often going unnoticed or underestimated (Phillips 1997). Land-use changes often further intensify these pressures with agriculture having arguably the biggest impacts through reducing the land available for wildlife, fragmenting the landscape, and isolating populations (Saunders et al. 1991; Dixo et al. 2009; Harrison et al. 2013; Beck et al. 2013; Jorge et al. 2013; Poulsen et al. 2013).

Currently, most wildlife populations live in or around protected areas, which are increasingly threatened by the pressure from a growing human population (Wittemyer et al. 2008). Many people from the rural communities located on the edges of protected areas depend on natural resources for their livelihoods and basic needs (Wittemyer et al. 2008). Anthropogenic activities on the peripheries of protected areas can exacerbate edge effects, both constraining the wildlife populations within the protected areas (Woodroffe & Ginsberg 1998) or creating sinks, areas where local mortality exceeds reproduction (Pulliam 1988), outside of the protected areas (Romero-Muñoz et al. 2019). As animals move out of natural areas and encounter people, mortality rates rise dramatically (Schwartz et al. 2006; Loveridge et al. 2007). For example, carnivores may be killed by humans intentionally, such as through hunting and poaching activity, or accidentally, such as through vehicle collisions and non-selective trapping (Revilla et al. 2001). Traps, such as snares, have been used to capture animals for many thousands of years (Hoffecker & Hoffecker 2017).

1.2. Trends in trap use

Traps are used across the globe, with millions of wild animals being caught annually for fur, meat, pest control, research, and wildlife management, including resolving human-wildlife conflicts (Iossa et al. 2007). In Australia, various types of leg-hold traps are used to legally capture pest animals, such as wild dogs (including dingoes, *Canis familiaris dingo*, and feral dogs, *C. f. familiaris*), European red foxes (*Vulpes vulpes*), and feral cats (*Felis catus*), as they kill livestock, domestic pets, and threatened native species (Fleming et al. 1998; Short et al. 2002). In the United Kingdom, snares are set by gamekeepers and farmers to control red fox and rabbit (*Oryctolagus cuniculus*) numbers (Defra 2012). Several rodent species are frequently trapped in Europe for the same purpose, while in Russia, parts of the United States of America (USA), and Canada other mammals, such as wolverines (*Gulo gulo*), American beavers (*Castor canadensis*), and muskrats (*Ondatra zibethicus*), are trapped for fur (Iossa et al. 2007). Neck snares on traplines or at carrion baits are used to harvest carnivores such as wolves (*Canis lupus*) and coyotes (*Canis latrans*, Knopff et al. 2010; Proulx et al. 2015), while Aldrich foot snares are often used by researchers and wildlife managers to catch bears (Lemieux & Czetwertynski 2006; Flaa et al. 2009).

There is a lot of controversy and public pressure surrounding the animal welfare aspect of trap use (Fleming et al. 1998; Iossa et al. 2007; Gardner 2010). This is likely to influence the demand for furs or other derived products, which affects the participation levels of avocational trappers in furbearer harvest (Armstrong & Rossi 2000; White et al. 2021). The trapping of wildlife for consumptive use may also be becoming less valued as a cultural tradition (Vantassel et al. 2010). Anti-trapping sentiment and lower pelt values have resulted in declining recruitment rates for new trappers and less avocational (recreational) trapping (Armstrong & Rossi 2000; White et al. 2021). The growing public opposition to trapping animals has also resulted in the banning of certain trap types, although the legislation differs across country and state lines (Iossa et al. 2007). A lot of effort has been devoted to developing sophisticated trap designs which increase capture efficiency, animal welfare, and selectivity for target species (Lemieux & Czetwertynski 2006; Flaa et al. 2009; White et al. 2021).

The Asian and South American contexts appear to be more similar to what is being seen in Africa (Alves et al. 2009; Lindsey et al. 2013; Figel et al. 2021). Indiscriminate and illicit snare trapping, a form of poaching, is widespread and intensifying, especially in Southeast Asia, causing population declines for large mammal species in particular (Figel et al. 2021). In northern Sumatra, rural communities poach at a subsistence level for food and pest control, while other poachers target high-value species, such as elephants (*Elephas maximus sumatrensis*) and tigers (*Panthera tigris sumatrae*), for the illegal trade in wildlife parts (Figel et al. 2021). Poachers generally use wire or cable foot snares when hunting wildlife for subsistence or commercial purposes, mostly placing these along game trails in the forest (O'Kelly et al. 2018; Figel et al. 2021). The rise in wire-snare poaching is due to many factors related to increased accessibility and demand (Harrison et al. 2016; Gray et al. 2018). There is improved road access to remote areas, more markets, better hunting technology, and rising demand for bushmeat, exotic wildlife for pets (international trade), and medicinal products derived from wild animals (Nijman 2010; Harrison et al. 2016). Increased demand is linked to economic growth, which has boosted the purchasing power of a growing middle class (Nijman 2010). The global demand for tiger products has created such a strong economic incentive for snaring that law enforcement is unlikely to be a strong enough deterrent (Johnson et al. 2016), and when snare materials are provided by traders and buyers, the confiscation of these is no longer a significant financial loss for the poachers (Risdianto et al. 2016). Local cultures have been affected by the influence of outside traders, for example, in northern Laos, snares were not commonly used until traders from Vietnam and China started supplying local hunters with snares to hunt tigers (Johnson et al. 2016). Interestingly, strict enforcement of gun laws which limits both their availability and use, as is done in Indonesia and Vietnam, has been shown to increase the use of snares (Harrison et al. 2016).

In South America, bushmeat networks linking hunters to urban consumers have been uncovered across Brazil, Colombia, and Peru (Van Vliet et al. 2014, 2015). This is not driven by a preference for bushmeat as a source of protein but rather its important role in social relations customs, such as food sharing (Morsello et al. 2015). A greater belief in taboos and increased wealth tended to result in lower bushmeat consumption (Morsello et al. 2015). In Brazil, a wide variety of mechanical traps are used by hunters, including dead-fall traps, nooses, and cages (Alves et al. 2009). These are constructed from iron, fishing line, wood, rope, twine, wire, or a combination of these materials (Alves et al. 2009). Hunting in the Caatinga region is done for leisure and entertainment, with many people hunting from childhood, as well as for subsistence (food), to control the numbers of predators and/or damage-causing animals, for medicinal and ornamental purposes, and to obtain pets (Alves et al. 2009). In Brazil, the hunting of feral pigs (*Sus scrofa*) is allowed, and hunters use both legal and prohibited traps to catch them (Carvalho et al. 2019). In such scenarios, there may be contradictory and conflicting motivations for trapping. The sportsman hunts the feral pigs for entertainment and to obtain meat, while the conservationist hunts to control the population and ultimately eradicate a non-native species (Carvalho et al. 2019).

In Africa, snares, gin traps, small mammal and bird traps, and pitfall traps are utilised for bushmeat harvesting (Fa & Brown 2009; Lindsey et al. 2013). Trapping is largely done at a subsistence level, to obtain a source of protein, but occasionally at a commercial level, as a source of revenue (Wilkie & Carpenter 1999; Fa & Brown 2009; Lindsey et al. 2013; Rogan et al. 2018). In tropical forests, the bushmeat extraction rates are very high because livestock productivity in tropical forest conditions is low (Fa et al. 2002; Fa & Brown 2009). Livestock husbandry, therefore, has high risks and investment costs associated with it, but forest dwellers often have low purchasing power (Fa & Brown 2009). The demand for protein is also growing due to accelerating population growth (Wilkie & Carpenter 1999; Fa & Brown 2009). Bushmeat harvesting using snares is also occurring in African savanna regions (Lindsey et al. 2013; Van Velden et al. 2018), but our understanding of the dynamics in these systems is limited (Rogan et al. 2018). In South Africa, wire-snares are the most common method of bushmeat hunting (Lindsey et al. 2013). Snares are most often made from steel wire or cable that is often sourced from fences and hence readily available (Lindsey et al. 2011). The wire is typically tied into a noose and attached to an anchor point, such as vegetation or fences (Noss 1998). Wire-snares are popular because they are simple to set up, catch a wide array of species, are relatively affordable, and the materials needed are normally more accessible to locals than firearms (Noss 1998; Hofer et al. 2000; Lindsey et al. 2011). Additionally, detecting snares is difficult and enforcement of laws banning their use is rare (Noss 1998; Lindsey et al. 2013), reducing the costs of engaging in this illegal activity.

Wire-snares raise serious welfare concerns, largely due to the injuries sustained by animals who break free from the snares and because, in many cases, death is not instantaneous (Cawthorn & Hoffman 2015). The low cost of wire-snares means poachers are not incentivised to check them regularly or retrieve them with the consequence that many captured animals die slowly in the trap and then rot or are scavenged before they can be retrieved (Noss 1998; Lindsey et al. 2011). The non-selective nature of snares means that non-target, threatened and charismatic species are frequently injured or killed (Becker et al. 2013). Predators are often caught as by-catch (Lindsey et al. 2013), and in the Western Cape province of South Africa, both leopard (*Panthera pardus*) and caracal (*Caracal caracal*) have been found with wire-snares (Nieman et al. 2019b; Cape Leopard Trust, pers. comm.). Target species also tend to be severely impacted, causing substantial declines or even local extirpations (Lindsey et al. 2011, 2013; Becker et al. 2013).

1.3. Bushmeat harvesting

People living near protected areas often depend on the hunting of wildlife for improved food security and an alternative source of income (Lindsey et al. 2011; Rentsch & Damon 2013). However, such activities are rarely sustainable (Fa et al. 2002; Mainka & Trivedi 2002; Robinson & Bennett 2002) and have threatened biodiversity in the Amazonian forests (Peres 2000) and savannah biomes (Lindsey et al. 2013). In Kenya, the extinction of greater kudu (*Tragelaphus strepciceros*) and roan antelope (*Hippotragus equinus*) in the Maasai Mara National Reserve in the 1970s can be largely attributed to illegal hunting (Ogutu et al. 2009), while poaching with snares was responsible for a substantial decline in endemic roan antelope in Ruma National Park (Kimanzi et al. 2015). Other risks associated with bushmeat hunting include the threat of zoonotic disease transmission, modified plant-animal interactions, and cascading effects on the functioning of the ecosystem and trophic relationships (Wolfe et al. 2005; Poulsen et al. 2009; Effiom et al. 2014; Ripple et al. 2016). Bushmeat poaching can also undermine the function of wildlife habitat corridors, resulting in further fragmentation of landscapes or/and the isolation of protected areas (Loveridge et al. 2020).

Understanding the motivations behind bushmeat extraction is complicated and the drivers probably vary greatly between regions (Luiselli et al. 2019; Loveridge et al. 2020). Expanding human settlement, population growth, immigration of settlers, increasing encroachment into wildlife habitat, and intensifying livestock production have all been linked to increased wire-snare poaching (Kiringe et al. 2007; Loveridge et al. 2020). In the Northern Congo, an influx of immigrant workers for logging operations resulted in increased use of wire-snares and was found to be the method used for 72% of all the bushmeat harvested (Poulsen et al. 2009). Other drivers include poverty and food insecurity, livestock ownership, a lack of frameworks for local communities to legally benefit from wildlife, ambiguous rights over wildlife or property, and insufficient wildlife laws and enforcement (Loibooki et al. 2002; Lindsey et al. 2011, 2013; Brashares et al. 2011). However, in some places, an increase in wealth results in more bushmeat consumption, not less (Brashares et al. 2011; Rentsch & Damon 2013). In the Tanzanian Serengeti, correlations have been found between the hunting or the consumption of bushmeat and the perceived effectiveness of law enforcement, as well as how close individuals lived to a protected area (Fischer et al. 2014). In the Okavango Delta, Botswana, households which participate in illegal hunting tend to live near to wildlife, are more likely to farm crops, and have at least one household member earning a regular income through formal employment (Rogan et al. 2018). This means that bushmeat hunting may not be essential for subsistence in many cases, but is rather an additional source of income through sales (Rogan et al. 2018). Other factors that are specific to different environments or stochastic events influence the level of poaching pressure, such as drought conditions, increases in resource value, and human-wildlife conflict (Kaltenborn et al. 2005). Even political instability and cultural demands can play a role (Kaltenborn et al. 2005; Bouché et al. 2012; Lindsey et al. 2013). In lower Omo, Ethiopia, it was found that hunting was highly valued for building long-term social bonds

(Tadie & Fischer 2013). The urges of particular individuals, such as thrill-seeking, rebellion, or skills development, can also motivate wire-snare poaching (Forsyth & Marckese 1993; Grey-Ross et al. 2010).

Bushmeat hunting does not occur randomly in the landscape. Trends show that bushmeat harvesting tends to increase near to the borders of protected areas (Knapp et al. 2010; Lindsey et al. 2011), near to residential areas, including highways (Hofer et al. 2000; Wato et al. 2006), and near to areas where the wildlife numbers are higher, such as water bodies, game trails, and fruiting or flowering trees (Becker et al. 2013). In Ruma National Park, Kenya, it was found that snares were being placed in clumped patterns (Kimanzi et al. 2015). These hotspots were located near water bodies, salt licks, and the park boundary – all areas frequented by wildlife (Kimanzi et al. 2015). Areas devoid of steep slopes, far from roads, and with burned vegetation were also preferentially chosen (Kimanzi et al. 2015)

1.4. Study motivation

Previous studies on wire-snare poaching have largely focussed on protected areas in forest and savanna biomes of Central and West Africa, as well as some parts of East Africa (Fa et al. 2002; Barnes 2002; Bowen-Jones et al. 2003; Brashares et al. 2011). Few studies have explored wire-snare poaching on communal or privately owned land (Van Velden et al. 2018; Martins & Shackleton 2019). However, recent studies show that 30 to 60% of rural households in the communal tenure regions of South Africa consume bushmeat (Grey-Ross et al. 2010; Martins & Shackleton 2019). In the Mount Frere region of the Eastern Cape province, South Africa, the bushmeat off-take weight per km^2 for some species is comparable to what is seen in tropical forest areas (Kaschula & Shackleton 2009). Data on snaring in the Fynbos Biome, which supports low animal biomass, are very sparse but suggest the practice is common on private agricultural land (Nieman et al. 2019b).

Nieman et al. (2019b) interviewed farm managers or owners and permanent labourers on private agricultural properties close to protected areas in the Boland region of the Western Cape province to investigate wire-snare poaching. A number of the labourers admitted to frequent wire-snare poaching (Nieman et al. 2019b) with preferred target species being: grey duiker (*Sylvicapra grimmia*), Cape porcupine (*Hystrix africaeaustralis*), Cape grysbok (*Raphicerus melanotis*), land fowl (e.g., helmeted guineafowl – *Numida meleagris*), feral pigs, grey rhebok (*Pelea capreolus*), and klipspringer (O*reotragus oreotragus)* (Nieman et al. 2019b). These species are common prey items of leopards in the Boland region (Mann et al. 2019). Healers from the local rural communities also most frequently utilise leopard, chacma baboon (*Papio ursinus*), Cape porcupine, monitor lizard species (*Varanus* spp.), puff adder (*Bitis arietans*), genet species (*Genetta* spp.), and black-backed jackal (*Canis mesomelas*) for traditional medicinal purposes (Nieman et al. 2019a), which could be driving additional wire-snare poaching. Some farmers divulged that they had abandoned anti-snaring actions, hoping that the activity would reduce the presence of damage-causing species, such as the invasive feral pigs (*S. scrofa*, Nieman 2018).

Nieman et al. (2019b) also explored the socioecological and biophysical factors which influence wire-snare poaching and the spatial distribution of wire-snares in the region. Nieman et al. (2019b) found that the number of snares on a property was most influenced by the number of families living on the property, whether seasonal workers are employed, and whether there are enforced punitive measures. Nieman et al. (2019b) also found that the reported density of wire-snares increased on properties at higher elevations, closer to protected areas, and further away from major residential areas and major roadways. A limitation of this study was the use of indirect methods (i.e., questionnaires) to study bushmeat hunting. Biases are especially prevalent when bushmeat consumers or hunters are required to self-assess their participation in potentially illegal activity (Loveridge et al. 2020). Combining questionnaire data with snare patrol data could provide a more objective assessment of the intensity of wire-snare use and distribution, and is thus preferable (Bowen-Jones et al. 2003). Identifying differences between perceptions and objective observations would also provide valuable insight into the views held by the local communities.

1.5. Study aims and objectives

This study aimed to use data from wire-snare patrols to investigate the intensity of use and spatial distribution of wire-snares on private agricultural properties in the Boland region in the Western Cape province, South Africa. The primary objectives of the study were thus: 1) to determine which socio-ecological attributes of properties correlate with the intensity of wire-snare poaching pressure, 2) to identify the biophysical and anthropogenic factors that correlate with the spatial distribution and intensity of wire-snares, and 3) to use these data to create a predictive landscape of snaring probability which might direct future snare patrol efforts in the region.

2. Methods

2.1. Study area

The study area (Fig. 1) is 4,000 km^2 in size and includes sections of the Cape Winelands and Overberg municipal districts within the central and southern parts of the Boland Mountain Complex region. The study area includes the Cape Floristic Region (CFR) biodiversity hotspot and falls within the Fynbos Biome (Rebelo et al. 2006; Rutherford et al. 2006). The Cape Fold Mountains run through the centre of the study area on a north-south axis, comprising mostly fenced and unfenced public and private nature reserves, including the Hottentots-Holland, Limietberg, Jonkershoek, Kogelberg Biosphere, Cape Winelands Biosphere, Steenbras, and Helderberg reserves. Low lying land adjacent to the mountains is largely transformed for agriculture (e.g., wheat and vineyards), and the mountains are thus biodiversity 'islands' (Hess & Fischer 2001) or refugia and corridors for the remaining wildlife. The study area largely overlaps with that of Nieman et al. (2019b, 2020). This research was largely conducted on private properties adjacent to the mountainous protected areas. These properties are utilised for a variety of agricultural ventures as well as ecotourism. They also provide income and housing for a substantial proportion of the region's population (Nieman 2018).

2.1.1. Climate, topography and geology

The Boland region has winter rainfall and sunny, dry summers (Botai et al. 2017). The study area largely falls within the Southwest Fynbos Bioregion and is bordered by the East and West Coast Renosterveld Bioregions (Rutherford et al. 2006; Mucina et al. 2014). The Southwest Fynbos Bioregion has a median minimum monthly temperature of about 6˚ and a median maximum monthly temperature of about 27˚ (Bradshaw & Cowling 2014). More than 60% of the rainfall in the Southwest Fynbos bioregion is received in winter, which is classified as a mediterranean rainfall regime (Bradshaw & Cowling 2014). The highest annual rainfall in the Greater Cape Floristic Region (GCFR), up to 3000 mm, is recorded on the mountaintops of the Southwest Fynbos (Bradshaw & Cowling 2014). Besides rainfall, moisture is also obtained from fog, infrequent snow on the peaks of the Cape Fold Mountains, and frost at higher elevations (Rebelo et al. 2006).

The topography of the landscape is diverse, including high mountain peaks which are part of important water catchments, rugged slopes and deep valleys, surrounded by low lying flat or undulating land (Fig. 1, Nieman 2018; Mann et al. 2019). The elevation of the area ranges from sea level to 1996 m (Mann et al. 2019). The Boland region has nutrient-poor, sandy soils (Rebelo et al. 2006) formed from hard quartzite and sandstone rocks (Rebelo et al. 2006; Bradshaw & Cowling 2014). These rocks belong to the Cape Supergroup (Bradshaw & Cowling 2014). The sands are deficient in important nutrients for plant growth, such as phosphorus (P) and nitrogen (N, Rebelo et al. 2006; Bradshaw & Cowling 2014).

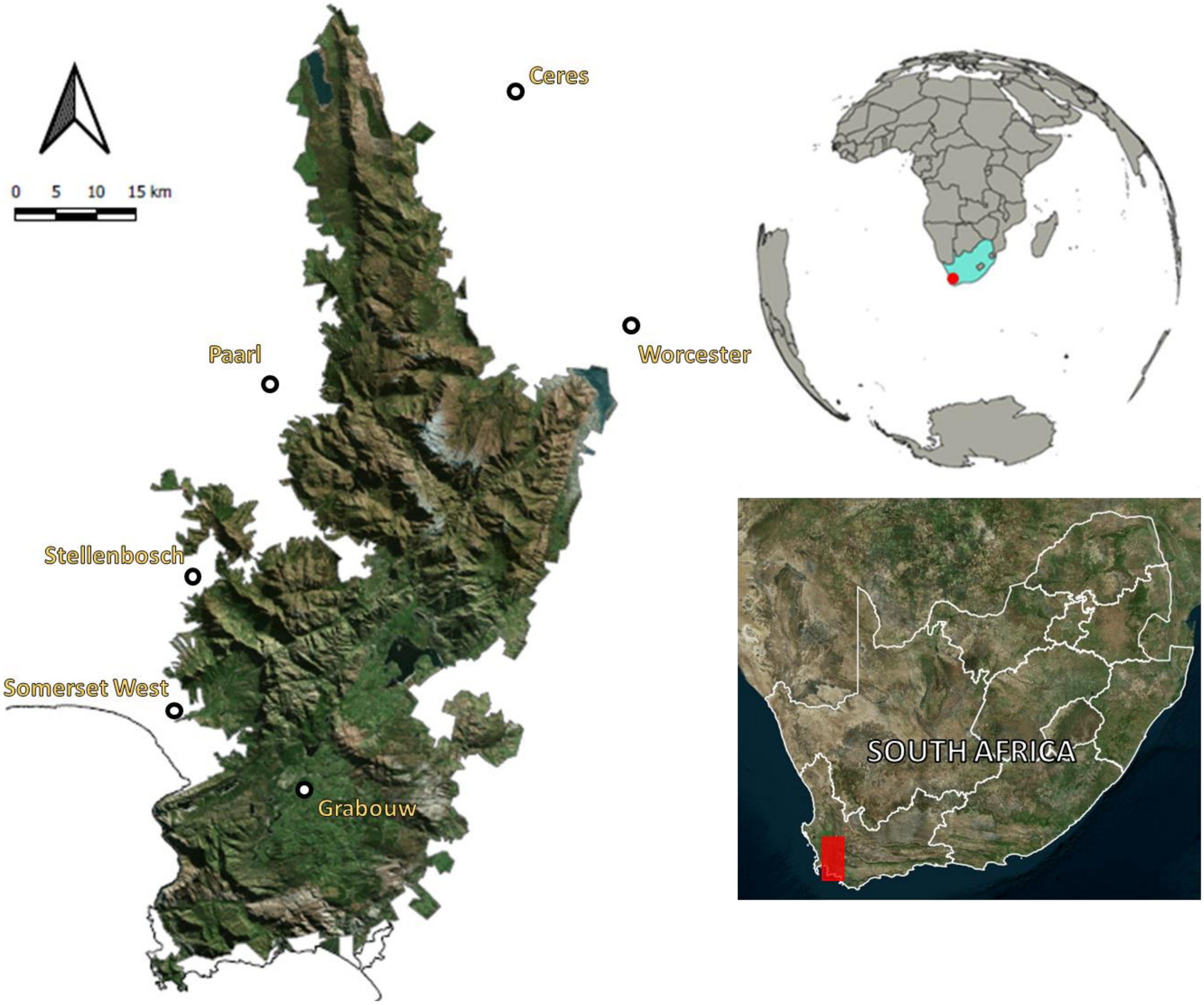


Figure 1. A topographical map showing the position of the study area in the Boland region of South Africa. Circles in the map on the left indicate the position of the major towns in the study area and the grey line at the bottom of the map represents the southern coastline of South Africa.

2.1.2. Flora and fauna

Within the study area, the vegetation types present are sandstone fynbos, granite fynbos, alluvium fynbos, shale fynbos, sand fynbos, shale band vegetation, and shale renosterveld (Mucina et al. 2014). Most of the study area consists of fynbos (Fig. 2). Fynbos has many unique floristic characteristics and contains unmatched species diversity, endemism, and turnover (Born et al. 2006; Bergh et al. 2014). Structurally it is a low, largely treeless 'heathland' which is dominated by ericoid shrubs of Ericaceae coupled with a graminoid component of Restionaceae and Cyperaceae and a taller shrub component of Proteaceae (Born et al. 2006; Bergh et al. 2014). Over time, sections of fynbos have been replaced by dense patches of invasive trees and shrubs, most notably *Acacia*, *Hakea*, and *Pinus* species (Rouget et al. 2003; Van Wilgen et al. 2016).

The Fynbos Biome also hosts a high level of faunal diversity and endemism (Kerley et al. 2003). The reptile, amphibian, and invertebrate (especially insect) diversity are high, while the bird diversity is relatively low (Colville et al. 2014). Historically, a large number of large herbivore species were found in the Cape, including black rhino (*Diceros bicornis bicornis*), eland (*Taurotragus oryx*), quagga (*Equus burchelli quagga*), hippo (*Hippopotamus amphibus*), ostrich (*Struthio camelus*), red hartebeest (*Alcephalus buselaphus*), mountain zebra (*Equus zebra zebra*), and African elephant (*Loxodonta africana*, Boshoff & Kerley 2001; Rebelo et al. 2006). These species mainly occurred in low-lying areas and it is hypothesised that they mostly fed on renosterveld, which grows on more nutrient-rich soil and is more palatable than fynbos vegetation (Rebelo 1992; Rebelo et al. 2006; Radloff et al. 2010). The complete large carnivore guild of southern Africa was also present, including cheetah (*Acinonyx jubatus*), leopard, Cape lion (*Panthera leo*), wild dog (*Lycaon pictus*), brown hyaena (*Hyaena brunnea*), and spotted hyaena (*Crocuta Crocuta*, Boshoff & Kerley 2001; Rebelo et al. 2006). More vultures and other birds of prey were also present historically in the region (Rebelo et al. 2006). Many of the large mammal and bird species historically found in the CFR were driven to near extinction by 1800 due to hunting for sport, meat, or the eradication of 'problem' animals (Rebelo 1992).

The species currently found in the Boland region are either mountain specialists or generalist species able to survive in mountainous habitats (Mann et al. 2019). A camera trap survey that covered 21 nature reserve properties and 22 private agricultural properties captured 26 species between 22 October 2020 and 31 January 2021 (Cape Leopard Trust data, unpublished). The highest number of photos obtained were of chacma baboons, followed by klipspringer, grey rhebuck, rock hyrax (*Procavia capensis*), and grysbok (Cape Leopard Trust data, unpublished). The least number of photos were obtained of aardvark (*Orycteropus afer*), water mongoose (*Atilax paludinosus*), aardwolf (*Proteles cristata*), bat-eared fox (*Otocyon megalotis*), gemsbok (*Oryx gazella*), and small-spotted genet (*Genetta genetta*, Cape Leopard Trust data, unpublished). It is important to note that these numbers are likely skewed as the potential non-independence of captures and the number of individuals in an image have not been controlled for. Currently, human-wildlife conflict is still present in the study area, both with carnivores and species which damage crops and infrastructure (Nieman et al. 2020). Chacma baboons, feral dogs (*Canis lupus familiaris*), and feral pigs are the most heavily persecuted by farmers in the region (Nieman et al. 2020).

2.1.3. Land-use

The CFR is most threatened and transformed by agriculture, alien invasive plants, and urbanization (Rebelo 1992; Rouget et al. 2003). Only ~33% of the low-lying land is untransformed in the Boland region (Mann et al. 2019). The mountainous areas are bordered by large swathes of cultivated land (Fig. 2), much of which are monoculture orchards, vineyards, and wheat fields (Mann et al. 2019). Livestock and game farming are rarer forms of land-use (Mann et al. 2019). The agricultural sector of the Western Cape province is very important to the economy as it contributes the most to total national income from commercial agriculture and is the largest provincial employer in the commercial agriculture industry

(Statistics South Africa 2017). In the province, farming often occurs close to protected areas and the greatest proportion of agricultural activity is horticultural (Nieman 2018).

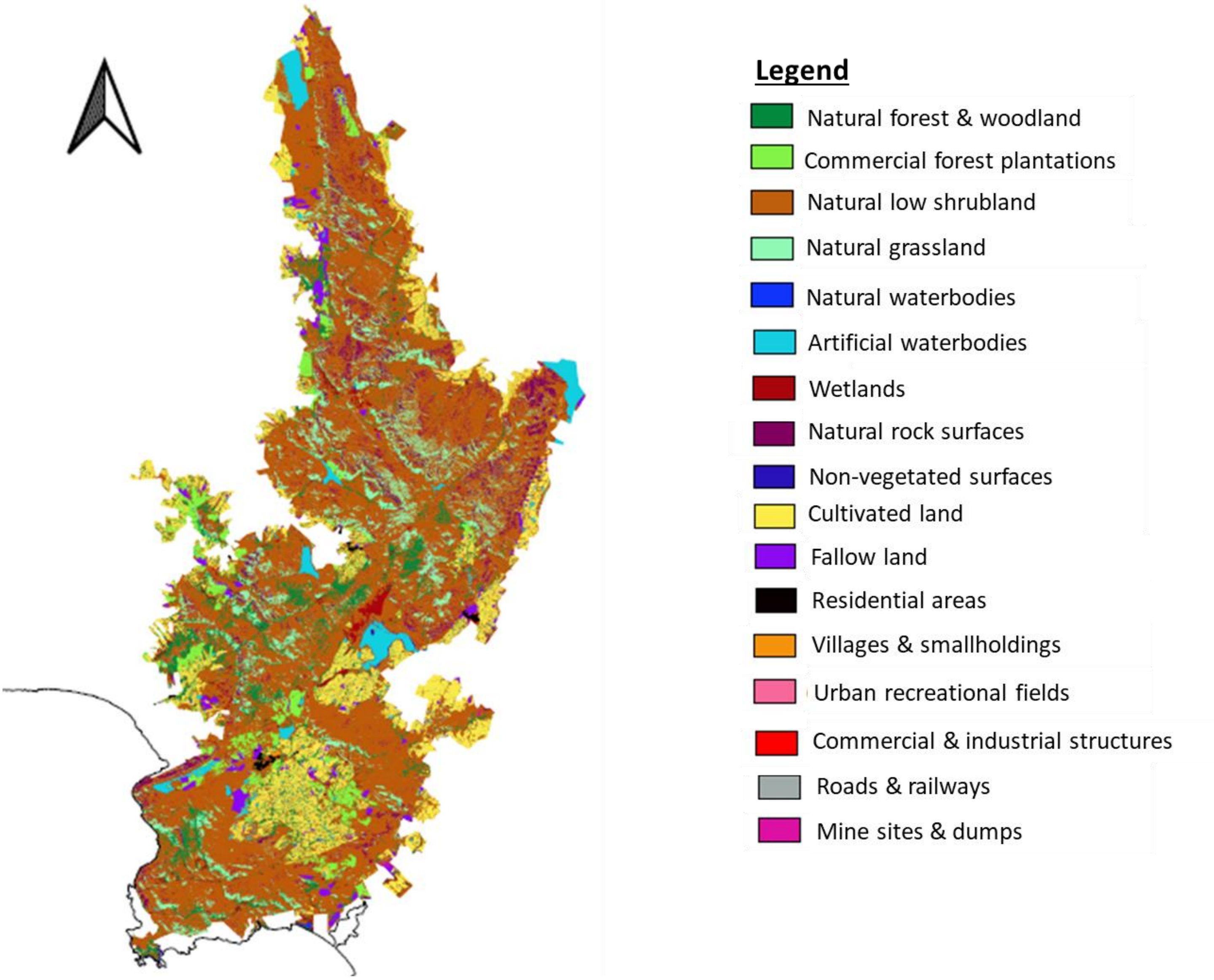


Figure 2. The land-use and land-cover types occurring in the study area. Adapted from the 2018 South African National Land-Cover dataset (Thompson 2019).

2.2. Data collection

The Cape Leopard Trust's snare patrol officer (MJ Grobler) carried out patrols from the 11th of June 2019 to the 18th of June 2020. He conducted 210 patrols on 111 properties during this time, 15 of which were novel properties not included in the study by Nieman et al. (2019b). The data from the novel properties were not analysed at the property-level. Each patrol was limited to a single property, with generally two properties being patrolled in a day. The patrols were conducted in an adaptive manner in order to try and locate as many snares as possible in ~4-6 hours, depending on the size of the property. The patrols varied in length from 0.6 km to 24.7 km, with an average of 6.6 km. A total of 1410.2 km was patrolled. Most properties were patrolled twice, with a roughly 6-month window between patrols. Some could not be patrolled a second time due to the restrictions placed on fieldwork due to the COVID-19 pandemic. The snare patrol officer recorded the Global Positioning System (GPS) locations of each snare he found and recorded whether they were set up and anchored in place or prepared snares found lying on the ground (Fig.3). For the anchored snares, he also recorded whether they were active or inactive due to being broken or the loop pulled closed, to what it was anchored, the material it was constructed from, the height the snare loop was positioned at, and the trap location, such as on a game trail or near a clear animal dwelling, e.g. a burrow (Fig.3). He also GPS-tracked the patrol routes he followed.

Figure 3. Images depicting the data collection process and examples of snares found during the patrols. A) a wire-snare attached to a fence line adjacent to a farm road, B) a wire-snare anchored to a rock along a game path, C) the snare patrol officer recording data for a wire-

snare anchored to a tree along a footpath, D) a nylon snare (foreground) and a steel cable snare (background) attached to the same tree. Photo credits: Cape Leopard Trust.

I included data from the research conducted by Nieman for his Masters dissertation (Nieman 2018) to derive socio-ecological attributes for the corresponding private properties included in this study. These data were obtained from face-to-face interviews with permanently employed labourers on agricultural properties bordering protected areas and the landowners or managers of these properties (Fig. 4). These interviews were conducted by Nieman between July 2017 and May 2018 and were based on closed-format questionnaires. A total of 103 landowners or managers and 307 labourers were interviewed. The Human Research (Humanities) Council at Stellenbosch University gave ethical clearance for this research (Reference: SU-HSD-004696, Nieman 2018). The information extracted from the interviews included the presence or absence of enforced punitive measures, whether seasonal workers are employed, the number of families on the property, property size, the proportion of the property consisting of natural, untransformed land, whether the farmer lives on the property, whether lethal control measures for pest species are used on the property, and primary agricultural output.

Figure 4. W. A. Nieman conducting the interviews (Nieman 2018). Photo credits: B. C. Schultz.

2.3. Spatial analyses

All spatial analyses were done in QGIS (QGIS Development Team 2020). I used map layers depicting the human structures and biophysical features of the landscape in which these patrols were conducted (Table A1). Layers showing farm portions, servitude areas, servitude lines, and street network were obtained from the Western Cape surveyor general (http://csg.dla.gov.za/). A street is defined as "A parcel of land restricted for use by the Public, the control of which is vested in the local authority" (Office of the Chief Surveyor-General 2016). A servitude area or line is a "right of use or access a legal entity over the property of another legal entity", for example, an access road (Office of the Chief Surveyor-General 2016). The servitude area and servitude line layers were merged to form a single servitude layer. The river network layer was obtained from the Institute of Water Quality Studies & the Chief Directorate of Surveys and Mapping (http://www.dwa.gov.za/iwqs/gis_data/river/rivs500k.aspx). The protected area layer was obtained from the South African Department of Environment, Forestry, and Fisheries (https://egis.environment.gov.za/). The elevation layer was created from the Shuttle Radar Topography Mission (SRTM) and obtained from the Regional Centre for Mapping of Resources for Development (RCMRD) geoportal (http://geoportal.rcmrd.org/layers/servir%3Asouth_africa_srmt30meters). The elevation layer was used to calculate the slope and ruggedness (Terrain Ruggedness Index) layers using the terrain function from the 'raster' package (Hijmans 2020). The land-use types layer came from the 2018 South African National Land-Cover layer obtained from the South African Department of Environment, Forestry, and Fisheries (https://egis.environment.gov.za/). I simplified the land-cover classification by grouping some of the land-use types present in the study area (Table A2).

Wire-snares were found at a rate of one snare for every 2.18 km patrolled. To extrapolate snare absence points, I used the *QChainage* plugin and derived GPS locations every 2 km along the patrol routes. All vector layers were then rasterized, and proximity (raster distance) layers were generated for input into the boosted regression tree spatial prediction. I then extracted the elevation, land-use type, slope and ruggedness values for each snare present or no snare present data point. In addition, I calculated the distance to the nearest street, river, servitude, protected area boundary, and farm portion boundary at each of the points using the Point Sampling Tool plugin.

2.4. Data analyses

All data analyses were done in RStudio (R Core Team 2019). The significance level was set at 0.05. Snare characteristics were interpreted descriptively.

2.4.1. Property-level analyses

I had both questionnaire and patrol data for 92 properties, which included 307 labourer responses and 180 patrols. I applied Nieman et al. (2019b)'s socioecological model on this subset of the data using a zero-inflated generalised linear mixed model (GLMM) with a Type I negative binomial distribution utilising the 'glmmTMB' package (Brooks et al. 2017). This package was chosen for its flexibility and familiar interface (Brooks et al. 2017). I applied a single zero-inflation parameter to all observations (zi =~1). The socio-ecological predictor variables I included were the perceived presence or absence of enforced punitive measures, whether seasonal workers are employed, the number of families on the property, property size, the proportion of the property consisting of natural land, whether the farmer lives on the property, whether lethal control measures for pest species are used on the property, and the property's primary agricultural output (animal production, vineyards, or orchards; Table A3).

The response variable was the number of wire-snares each labourer reportedly saw on the property in the month preceding the interview. On most properties, multiple labourers were interviewed, so I controlled for individual property characteristics by including them as a random intercept effect. Nieman et al. (2019b) used a generalised linear model with a Poisson family distribution and a "log"-link function and did not control for the effect of individual property characteristics. He used the mean number of wire-snares found by labourers on each property as the response variable. The only predictor variable he did not include in his model was whether lethal control measures for pest species are used on the property. The 'DHARMa' package (Hartig 2020) was used to check the model's distribution, dispersion, outliers, residuals, and goodness-of-fit. I then used the R package 'MuMIn' (Barton 2020) to perform model selection comparing all possible models by ranking them according to the corrected Akaike Information Criterion (AIC_C) values of the different combinations. The effects of predictor variables that were found in the top models ($\Delta AIC_C \leq 2$) were explored (Burnham & Anderson 2002). The 'broom' (Robinson et al. 2021) and 'broom.mixed' (Bolker & Robinson 2020) packages were used to extract the coefficients for these predictors.

I then ground-truthed the first socio-ecological model based on questionnaire data by replacing the worker's estimates of the number of snares seen on the properties in a month with the number of snares found during a patrol of the corresponding properties. I used another zero-inflated generalised linear mixed model with a Type I negative binomial distribution and a single zero-inflation parameter to all observations (zi =~1). The predictor variables included were the same as for the first model. If a single labourer from a property perceived enforced punitive measures to be present, enforced punitive measures were taken to be perceived as present when the patrols were carried out on that property. As multiple patrols were conducted on some of the same properties, I again controlled for individual property characteristics by including them as a random intercept effect. I performed model checking, model selection, and coefficient extraction in the same manner as with the first model.

2.4.2. Landscape-level analyses

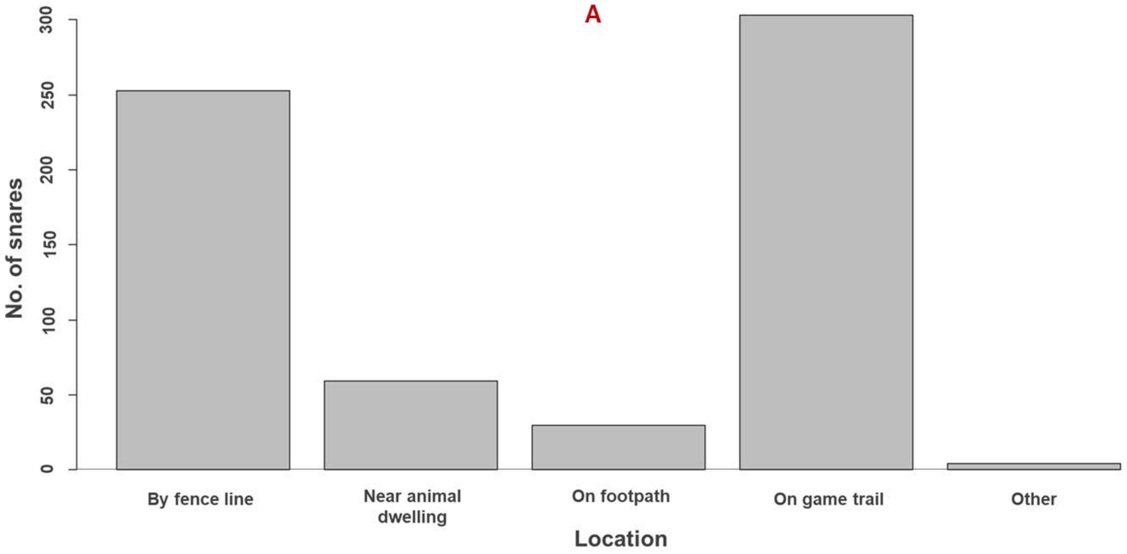
I used a boosted regression tree (BRT) model for the landscape-level analyses because it can fit complex nonlinear relationships, automatically handle interactions, and does not require data transformation (Elith et al. 2008). All 111 properties were included in these analyses. The response variable was the presence or absence of anchored wire-snares at points in the landscape covered during the patrols on all 111 properties. I included elevation, land-use type, slope, ruggedness, and distance to the nearest street (private roads not included), river, servitude area, farm boundary, and protected area as biophysical variables (Table A4).

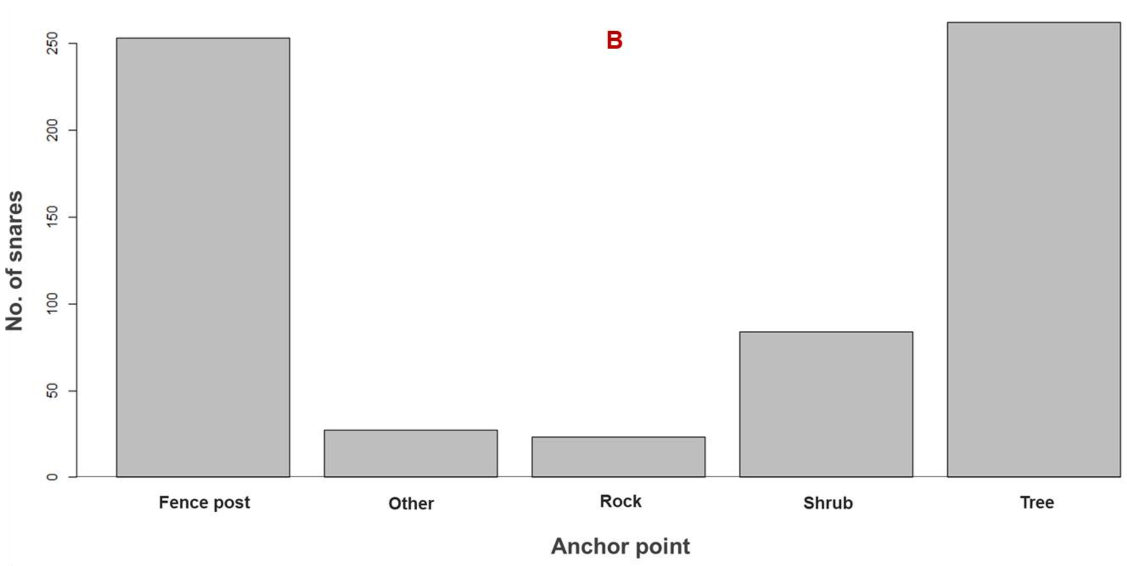
The BRT model was constructed using the 'dismo' package (Hijmans et al. 2020) and 'gbm' package (Greenwell et al. 2020). The model was set up to optimise model performance and ensure convergence following Elith et al. (2008)'s rule-of-thumb guidelines. The final model parameters were a tree complexity of 7, a learning rate of 0.005, 10-fold cross-validation, and a bag fraction of 0.75. A Bernoulli distribution was specified. The predictor variables were ranked according to relative influence and the optimal simplification process resulted in the elimination of ruggedness as it was a non-informative predictor. For each of the models, the pseudo-*R2* and percentage of the mean total deviance explained were calculated for comparison. The final, simplified model was then fitted, and I inspected the fitted function of each predictor and the pairwise interactions. The final model was also used to generate a spatial prediction of the probability of wire-snares being present across the wider study area.

3. Results

3.1. Snare characteristics

The snare patrol officer found 671 snares during his 210 patrols on 111 private properties, 649 of which were anchored snares, while the other 22 were prepared snares left lying on the ground. Of the anchored snares, 537 were active and 132 were inactive and no longer functional. No snares were found on 114 of the 210 patrols. The average number of snares found on a patrol was 3.21. The average number of snares found on a patrol where at least one snare was located was 7.06. A small number of carcasses were discovered in snares, including porcupine, duiker, bushpig (*Potamochoerus larvatus*), grysbok, guineafowl, and genet. Most snares were placed on a game trail (46.68%), followed by a fence line (38.98%), near an animal dwelling (9.09%), on a footpath (4.62%) and elsewhere (0.61%, Fig. 5A). Most were anchored to a tree (40.37%) or fence post (38.98%), and the rest were anchored to a shrub (12.94%), a rock (3.54%), or something else (4.16%, Fig. 5B). The largest proportion of snares were constructed from wire (69.95%), followed by nylon (18.8%) and steel cable (10.32%), while 0.92% were made from another material (Fig. 5C). Most snares were placed close to the ground, with 69.18% being suspending between 0 and 20 cm, 16.95% being suspended between 21 to 40 cm, 10.94% being suspended between 41 and 60 cm, 2.77% being suspended between 61 and 80, and 0.15% being suspended between 81 and 100 cm (Fig. 5D).





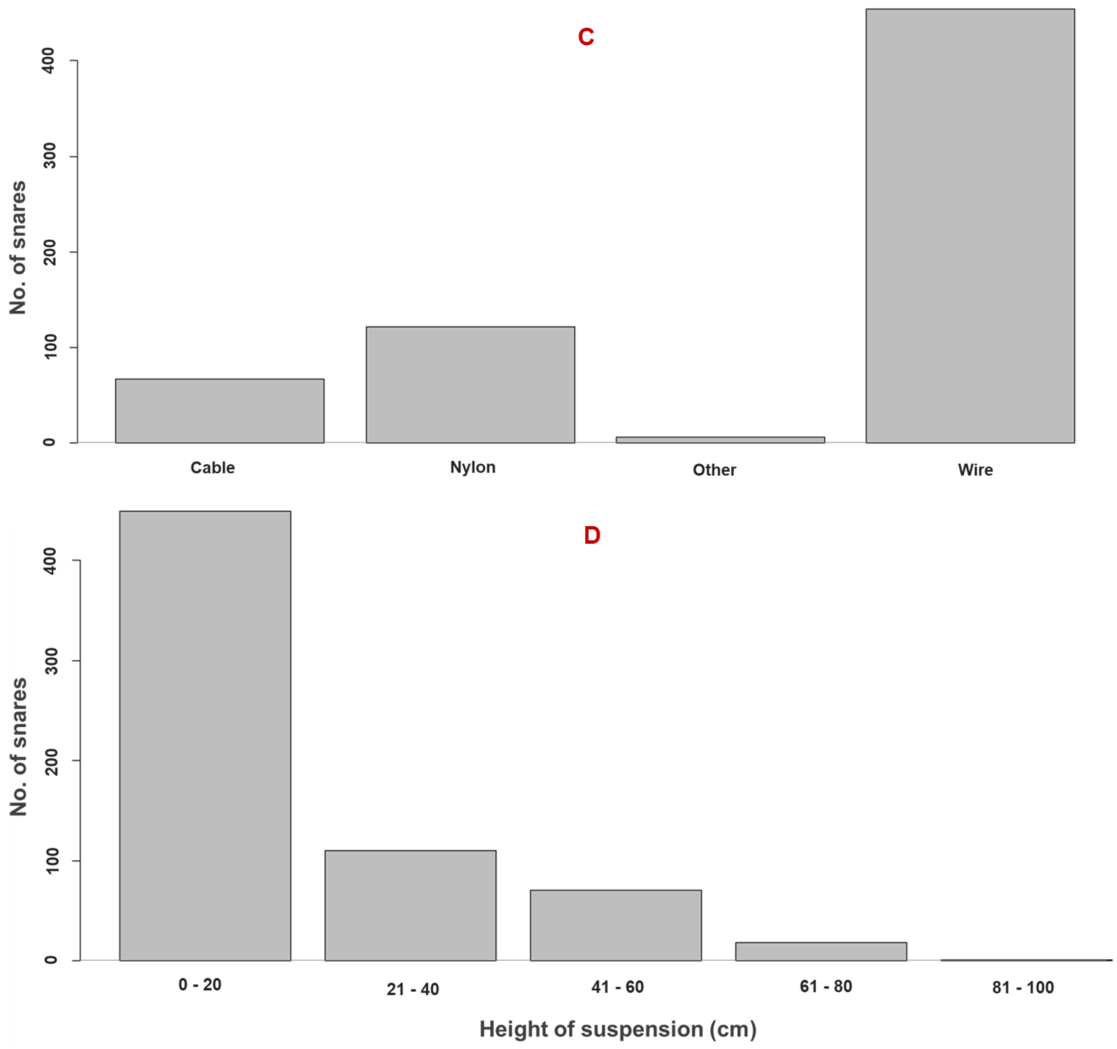


Figure 5. The characteristics of the total number of anchored snares (n=649) that were found during 210 snare patrols on 111 private properties. A) The precise location, B) the anchor point used, C) the material it was constructed from, and D) the height at which it was suspended.

3.2. Property-level analyses

3.2.1. Questionnaire data

The full zero-inflated generalised linear mixed model (GLMM) was run with the response variable 'the number of wire-snares each labourer reportedly saw on the property in the month preceding the interview'. The qq-plot plot and plot of residuals against the predicted value revealed there were no significant problems with distribution, dispersion, or outliers (Fig. B1). A nonparametric dispersion test on the scaled residuals revealed the model was not over- or under-dispersed (P = 0.944). A zero-inflation test showed the expected number of zeros were present in the model (P = 0.744). The predictor effects plots showed fewer snares to be present where enforced punitive measures are perceived to be present, where seasonal workers are employed, where the farmer resides on the property, and where orchards are the primary agricultural output (Fig. B2). They also showed more snares to be present where more families live on the property, where animal production is the primary agricultural output, and where lethal control measures are used for pest management on the property (Fig. B2). Property size and the proportion of natural vegetation appear to have little effect (Fig. B2).

Dredging the full model revealed nine top models (Δ AICc ≤ 2) consisting of subsets of the predictor variables (Table 1). The number of families living on the property, the farmer's use of lethal control measures to deal with problem species, and the perceived presence or absence of punitive measures were present in all the top models (Table 1). The top model based on the AICc score had four predictor variables: number of families living on the property, the farmer's use of lethal control measures, perceived presence or absence of punitive measures, and primary agricultural output (Table 1).

Table 1. The top GLMM models (Δ AICc ≤ 2) for predicting the number of snares seen by a labourer in the month before the interview.

	df	**AICc**	**Δ AICc**	**W**
FmP[a] + OwC[b] + PaO[c] + PnM [d]	9	1102.35	0.00	0.100
FmP + OwC + OwR [e] + PaO + PnM	10	1102.44	0.09	0.095
FmP + OwC + PaO + PnM + SsW [f]	10	1103.90	1.55	0.046
FmP + OwC + OwR + PaO + PnM + SsW	11	1104.03	1.68	0.043
FmP + OwC + PnM + SsW	8	1104.08	1.73	0.042
FmP + OwC + OwR + PnM + SsW	9	1104.11	1.76	0.041
FmP + OwC + PnM	7	1104.13	1.78	0.041
FmP + OwC + OwR + PnM	8	1104.28	1.94	0.038
FmP + NtV[g] + OwC + PaO + PnM	10	1104.34	2.00	0.037

([a] FmP = Number of families living on the property, [b] OwC = Farmer's use of lethal control measures, [c] PaO = The property's primary agricultural output, [d] PnM = Punitive measures present or absent, [e] OwR = Farmer resident on the property or not, [f] SsW = Seasonal workers employed or not, [g] NtV = The proportion of natural vegetation on the property).

Property size was the only predictor variable that was not present in any of the top models and was thus dropped and a simplified model was run (Table B1). The number of resident families was a significant predictor (β = 0.009, 95% CI [0.006, 0.013], P = <0.001) and more snares were reported where more families are living on the property (Table B1, Fig. 6). The use of lethal control measures was a significant predictor (β = 0.581, 95% CI [0.192, 0.971], P = 0.003), with more snares being reported where farm management uses lethal control measures (Table B1, Fig. 6). The perceived presence of punitive measures (β = -1.015, 95% CI [-1.766, -0.264], P = 0.008) was a significant predictor, with fewer snares reported where punitive measures were in place (Table B1, Fig. 6).

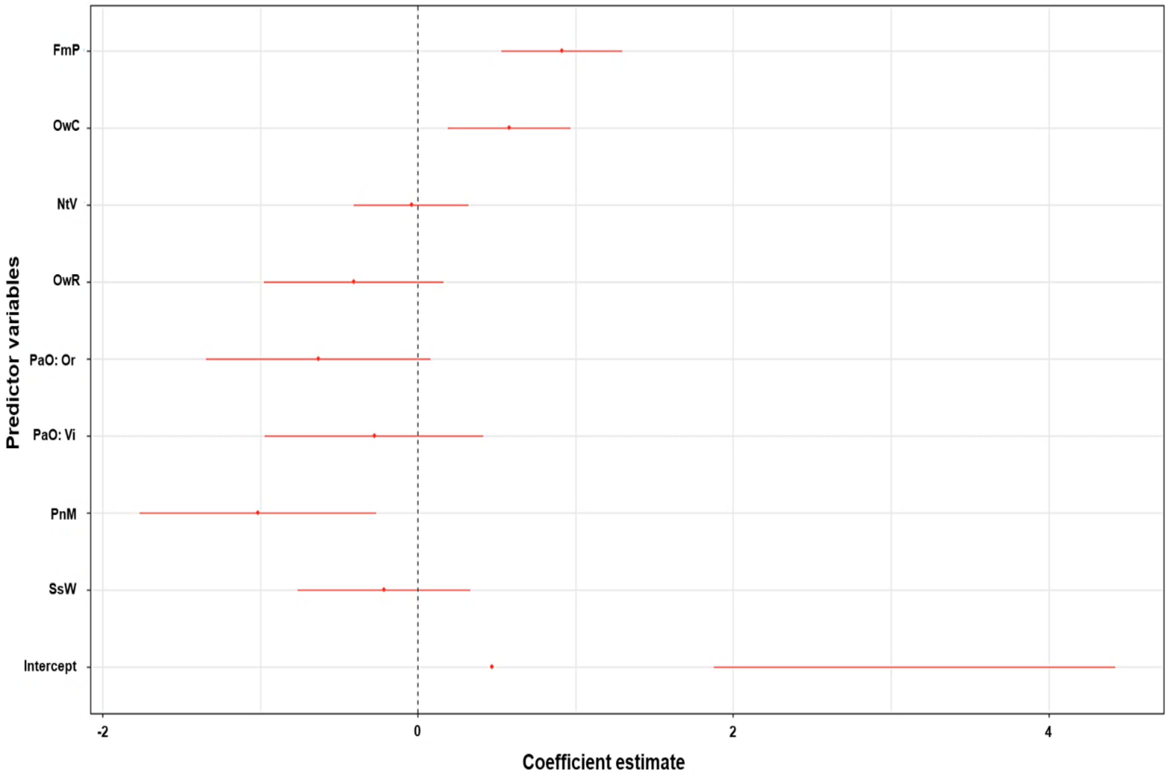


Figure 6. Coefficient plot showing the correlation between each predictor variable in the simplified GLMM and the number of snares seen on a property in a month. The red dot indicates the coefficient estimate and the line shows the 95% confidence interval.
(FmP = Number of families living on the property, OwC = Farmer uses lethal control measures, NtV = The proportion of natural vegetation on the property, OwR = Farmer resident on the property, PaO: Or = Primary agricultural output: Orchards, PaO: Or = Primary agricultural output: Vineyards, PnM = Punitive measures present, SsW = Seasonal workers employed, Intercept = Property effect).

3.2.2. Patrol data

The full zero-inflated generalised linear mixed model (GLMM) was run on the response variable 'the number of snares found on the property during a single patrol'. The qq-plot plot and plot of residuals against the predicted value revealed there were no problems with distribution, dispersion, or outliers (Fig. B3). A nonparametric dispersion test on the scaled residuals revealed the model was not over- or under-dispersed ($P = 0.776$). A zero-inflation test showed the expected number of zeros were present in the model ($P = 1$). The predictor effects plots show fewer snares to be present where the proportion of natural vegetation is low, and where animal production is the primary agricultural output (Fig. B4). They also showed more snares were present where seasonal workers are employed, where more families are living on the property, where the property is larger, where the farmer resides on the property, where the primary agricultural output is either orchards or vineyards and where lethal control measures for pest species are used (Fig. B4). Whether punitive measures are perceived to be present or not does not have much of an effect (Fig. B4).

Dredging the full model revealed 14 top models (Δ AICc ≤ 2) consisting of subsets of the predictor variables (Table 2). The only predictor variable present in all the top models was whether or not the farmer resides on the property (Table 2). The top model based on the AICc score had four predictor variables: number of families living on the property, the farmer's residency, property size, and the employment of seasonal workers (Table 2). The only predictor variable in common with the top model using the labourers' estimates from the questionnaire data, was the number of families living on the property (Table 1, Table 2).

Table 2. The top GLMM models (Δ AICc ≤ 2) for predicting the number of snares found on the property during a single patrol.

	df	**AICc**	**Δ AICc**	**W**
FmP [a] + OwR [b] + PrS [c] + SsW [d]	8	645.30	0.00	0.054
FmP + OwR + SsW	7	645.31	0.01	0.053
FmP + OwR + PaO [e] + SsW	9	645.66	0.36	0.045
FmP + OwR + PaO + PrS + SsW	10	645.85	0.55	0.041
FmP + OwR + PaO	8	646.08	0.78	0.036
OwR + PaO + PrS + SsW	9	646.39	1.09	0.031
FmP + OwC [f] + OwR + SsW	8	646.58	1.28	0.028
FmP + OwC + OwR + PaO + SsW	10	646.70	1.40	0.027
FmP + NtV [g] + OwR + PrS + SsW	9	646.83	1.53	0.025
OwR + PrS + SsW	7	646.88	1.58	0.024
FmP + OwC + OwR + PaO	9	646.89	1.59	0.024
FmP + OwR + PaO + PrS	9	647.03	1.73	0.023
FmP + NtV + OwR + PaO + PrS + SsW	11	647.23	1.92	0.020
FmP + OwC + OwR + PrS + SsW	9	647.30	2.00	0.020

([a] FmP = Number of families living on the property, [b] OwR = Farmer resident on the property or not, [c] PrS = Property size, [d] SsW = Seasonal workers employed or not, [e] PaO = The property's primary agricultural output, [f] OwC = Farmer's use of lethal control measures, [g] NtV = The proportion of natural vegetation on the property).

The perceived presence or absence of punitive measures was the only predictor variable that was not present in any of the top models, it was therefore dropped, and a simplified model run (Table B2). The residency of the farmer was a significant predictor (β = 3.049, 95% CI [0.904, 5.193], P = 0.005), with more snares being found on properties where the farmer is resident (Table B2, Fig. 7). A primary agricultural output of orchards was a significant predictor (β = 1.261, 95% CI [0.037, 2.484], P = 0.043), with more snares being found on properties that produce orchards than those that focus on vineyards or animal production (Table B2, Fig. 7).

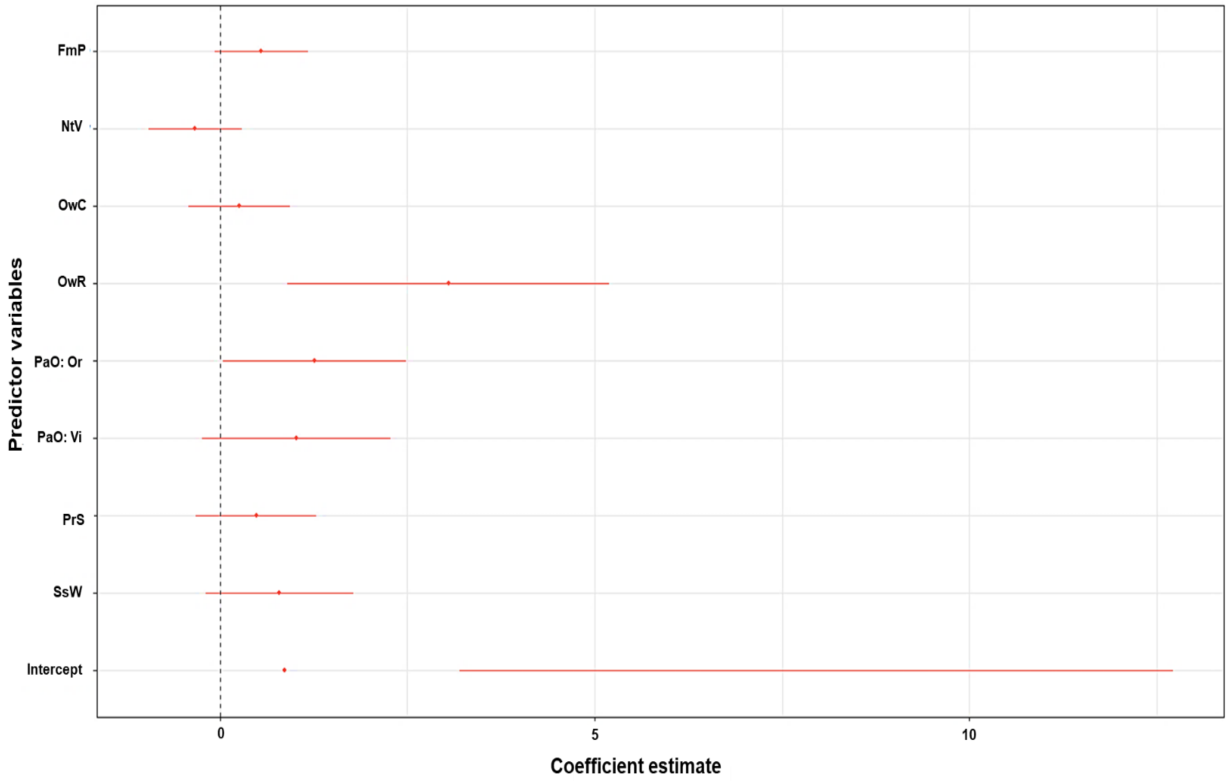


Figure 7. Coefficient plot showing the correlation between each predictor variable in the simplified GLMM and the number of snares found on a property during a patrol. The red dot indicates the coefficient estimate and the line shows the 95% confidence interval.
(FmP = Number of families living on the property, NtV = The proportion of natural vegetation on the property, OwC = Farmer uses lethal control measures, OwR = Farmer resident on the property, PaO: Or = Primary agricultural output: Orchards, PaO: Or = Primary agricultural output: Vineyards, PrS = Property size, SsW = Seasonal workers employed, Intercept = Property effect)

3.3. Landscape-level analyses

A base boosted regression tree (BRT) model was fitted with the optimal 6,450 trees to predict the presence or absence of wire-snares in parts of the landscape covered by the patrols (Fig. C1). The percentage of the total deviance explained by this model was 83.48% and the cross-validated AUC calculated during model building was 0.915 (SE = 0.009). The three most influential variables in the base model were distance to the nearest street (21.48%), distance to the nearest river (12.95%), and land-use type (12.04%, Table B1). The three least influential variables were distance to the nearest servitude area (9.07%), slope (5.96%), and ruggedness (4.00%, Table C1).

The simplification process showed that the removal of one predictor variable would not negatively impact model predictive performance. A simplified BRT model, with ruggedness dropped as a predictor, was fitted with the optimal 6050 trees (Fig. C1). The simplified model had a higher pseudo-R^2 value (0.46 vs 0.48), so it was utilised as the final model. The percentage of the total deviance explained by this model was 82.01% and the cross-validated AUC calculated during model building was 0.918 (SE = 0.007). When ranked according to relative contribution to the model, the variables were: distance to the nearest street (22.43%), distance to the nearest river (13.13%), land-use type (12.38%), elevation (12.16%), distance to the nearest protected area (11.87%), distance to the nearest farm boundary (11.01%), distance to the nearest servitude area (9.18%), and slope (7.83%, Table C1, Fig. 8).

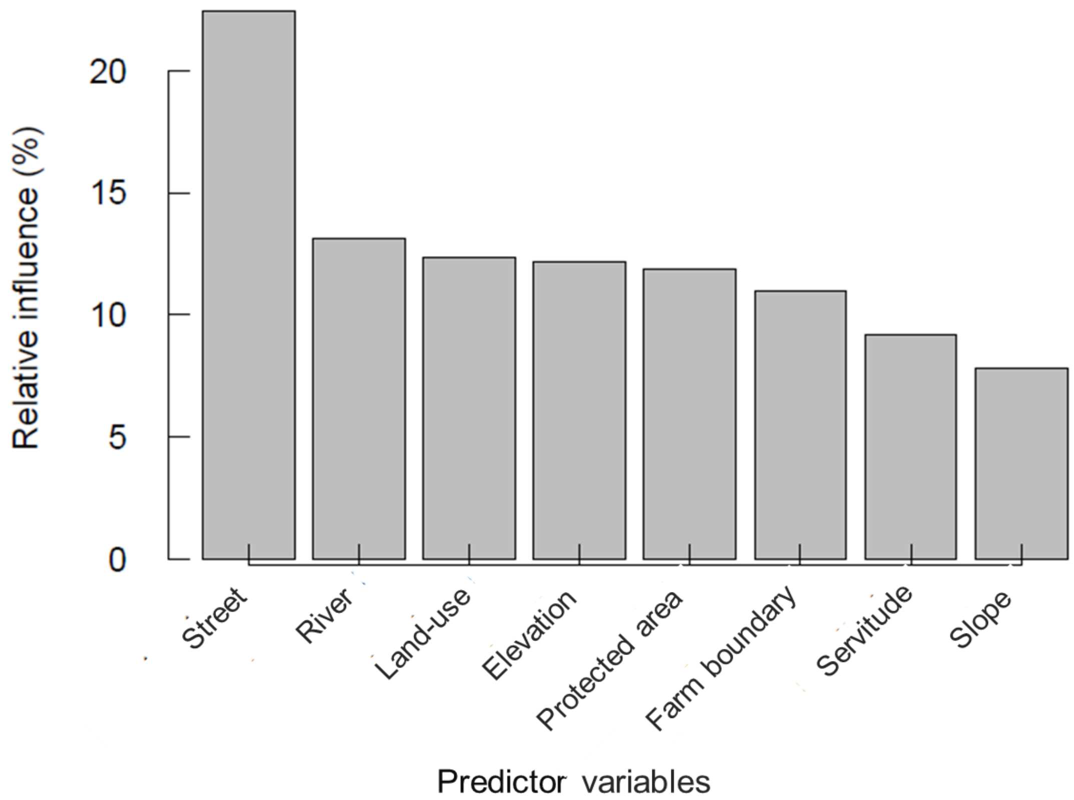


Figure 8: The relative influence of each of the predictor variables in the simplified BRT model on the presence or absence of snares at points in the landscape covered during the patrols. Protected area, street, river, farm boundary, and servitude refer to the nearest distance of the snare to each of these features.

The partial dependence plots (Fig. 9) showed that there was a higher chance of finding snares between roughly 250 to 1100 m from the nearest public street with the biggest spike between 450 to 650 m, 10 to 80 m from the nearest river, 20 to 70 m from the nearest protected area, on a farm boundary as well as 12 to 18 m from the nearest farm boundary, and 38 to 60 m from the nearest servitude area. In terms of land-use types, snares are most likely to be found in forest plantations, wetlands, bare ground/rocks, and natural forest/thicket (Fig. 9). Snares are very unlikely to be found in villages/smallholdings (Fig. 9). In terms of elevation, snares are more likely to be found between roughly 300 and 500 m asl and 650 to 700 m asl (Fig. 9). The three most important pairwise interactions were between distance to the nearest street and distance to the nearest protected area, elevation and distance to the nearest street, and land-use type and elevation, with interaction sizes of 116.56, 71.02, and 42.81 respectively (Table C2). Parts of the landscape that fall between 200 and 1000 m from a public street and within 70 m from a protected area are at an especially high risk of snaring (Fig. C2). Areas located between 150 and 650 m in elevation and 200 to 1200 m from a street are also at high risk (Fig. C3). The spatial prediction of wire-snaring risk shows these interactions (Fig. 10). Although centred around the protected areas, the areas of highest risk are not right up against the borders of the protected areas but rather at mid-level elevation (300-500 m, Fig. 10). The most prominent hotspots appear to be in the north and south-east sections of the study area (Fig. 10).

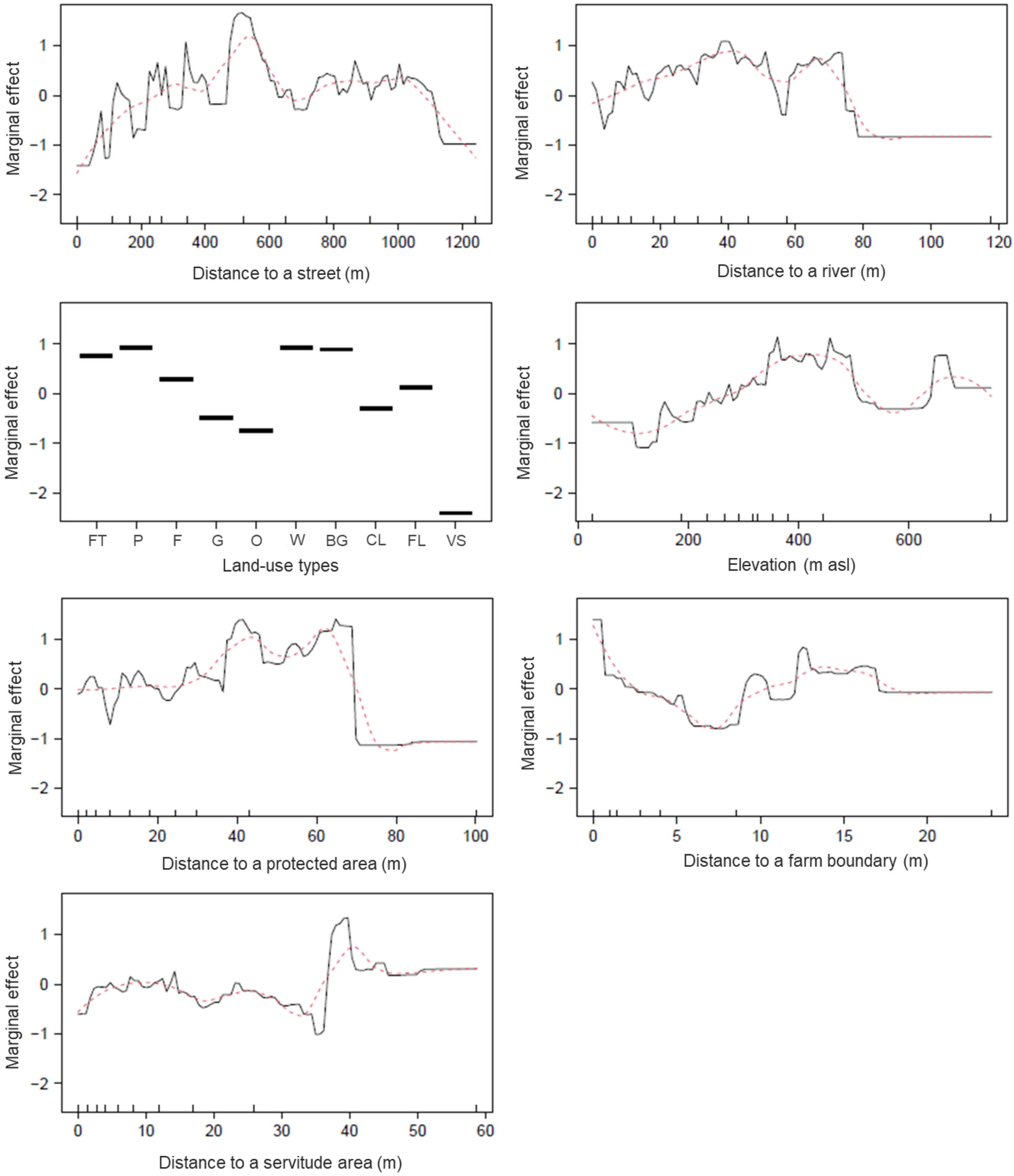


Figure 9. The partial dependence plots of each predictor variable in the final, simplified BRT model ordered by their relative importance in predicting the presence or absence of wire-snares. The y-axis shows the marginal effect of the variable compared to the mean response value. (FT = forest/thicket, P = plantation, F = fynbos, G = grassland, O = other, W = wetland, BG = bare ground, CL = cultivated land, FL = fallow land, VS = village/smallholding (Table A2))

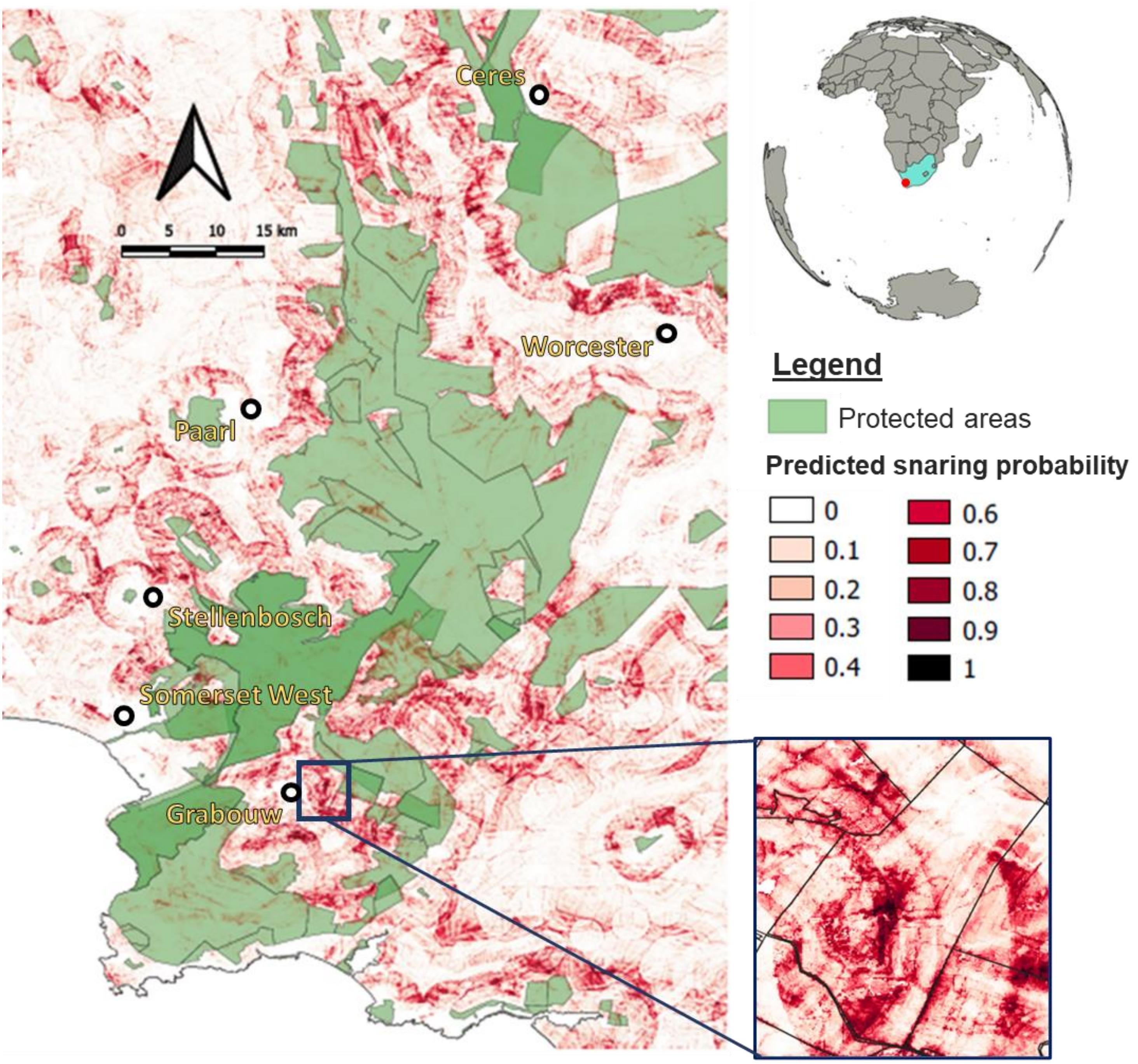


Figure 10. A spatial prediction of wire-snaring risk across the study area generated from the simplified BRT model. Protected areas are indicated in green. The inset shows the risk of snaring on one property. Straight lines within the protected areas are cadastral boundaries. The grey line along the bottom edge of the map is the coastline with the Atlantic Ocean. Circles indicate the position of the major towns in the study area.

4. Discussion

The growing human population and the accompanying demand for protein are exerting increasing pressure on wildlife, both within and outside of protected areas (Fa et al. 2002; Knapp 2012). The use of illegal wire-snares is the most common method of bushmeat poaching in South Africa (Lindsey et al. 2013). This practice is largely unsustainable due to its non-selective nature, as well as being a cruel and wasteful method (Noss 1998; Cawthorn & Hoffman 2015), resulting in severe negative effects on the overall ecosystem (Lindsey et al. 2011, 2013; Becker et al. 2013). Despite the many negative impacts, research on the topic in southern Africa is lacking. The Western Cape province of South Africa is seeing an influx of people into the province and other associated anthropogenic pressures are likely to follow (Poulsen et al. 2009; Nieman et al. 2019b). Anecdotal and observational accounts suggest that the Western Cape province may be experiencing an increase in illegal bushmeat harvesting, often using wire-snares, despite this being a criminal offence (Nieman 2018; CapeNature data, unpublished). Research on the use of wire-snares for bushmeat hunting on private agricultural land in the Fynbos Biome is especially limited. Reliable data on the drivers, intensity, and spatial distribution of snares on both private properties and protected areas are needed to develop effective mitigation strategies. Using a combination of snare patrols, snare detections by respondents to questionnaires, property attributes, and landscape characteristics, I investigated snaring pressure on privately-owned agricultural properties in the Boland region. Wire-snares were most likely to be present, and in greater numbers, where anti-snaring regulations are likely not enforced, where people have easy access to the land and materials for constructing snares, where there is a high demand for protein from seasonal workers or nearby residential areas, and where preferred target species are present in high densities.

4.1. Potential predictors of snare use on private property

4.1.1. Law enforcement

Unravelling the decision-making process of people who are setting snares is a challenging process. I originally hypothesised that having the farm owner or manager, an authoritative figure, present on the farm outside of work hours would discourage the setting of snares, but the opposite trend was seen. It seems likely that anti-snaring regulations and punitive measures are not being enforced by property owners/managers. Nieman (2018) found that labourers in the region frequently believed they were permitted to use wire-snares while most farm owners claimed that this was not the case. A small number of farmers even admitted to allowing labourers to use snares specifically to capture invasive feral pigs (Nieman 2018). In Israel, it was found that farmworkers were poaching many wildlife species, mostly using traps, and that the farm owners were largely indifferent to this activity despite having the capacity to lessen it substantially (Yom-tov 2003). The workers on some properties were even encouraged by the farmer to poach to reduce the number of wild animals causing damage to crops and as a form of entertainment or hobby (Yom-tov 2003). However, I did not find a significant relationship between the use of lethal methods for controlling damage-causing animals on a farm and the number of snares found on that farm. By not formally implementing lethal control measures, farm management may be hoping to appear more eco-friendly and avoid negative publicity in an increasingly environmentally conscious society.

The perceived presence or absence of punitive measures also had little effect on the number of snares found. There was considerable confusion regarding this variable, with labourers working on the same property providing contradictory statements on whether punitive measures were enforced on the farm. Clearly, farm owners and managers are not effectively communicating their stance on wire-snaring and the penalties for being caught. If this was rectified, this trend may change. Alternatively, as I have speculated, farm management may be being deliberately unclear about anti-snaring policies as the poaching of animals that cause infrastructure and crop damage could be viewed as beneficial. I have reason to believe this because the perceived effectiveness of law enforcement is an important driver of bushmeat poaching in numerous contexts (Lindsey et al. 2011, 2013; Fischer et al. 2014). In many places, the cost associated with being arrested is low, such as warnings, community service, or small fines, and the chances of being caught and convicted are slim (Barnett 1997; Loibooki et al. 2002; Lindsey et al. 2013). Illegal hunting, mainly using wire-snares, caused substantial declines in resident and migratory herbivore populations in the Serengeti National Park, Tanzania (Hofer et al., 2000). For many locals, the benefits of bushmeat hunting far outweigh the costs associated with law enforcement (Hofer et al., 2000). In South Africa, the historical injustices of apartheid, including lack of access to land and property rights for most farm labourers may have exacerbated poaching behaviour (Hall 2004; Kepe & Hall 2018). It has been shown that marginalisation and historical grievances over land can drive bushmeat poaching as a form of protest (Holmes 2007; Lindsey et al. 2013). Farmworkers and local people from the nearby informal settlements may feel that they have a right to hunt, to benefit from wildlife, on the land regardless of what the law says. Many of the labourers who admitted to snaring expressed the opinion that if the farm owner can hunt, then so can they. If bushmeat hunting is left relatively unregulated, declines in local wildlife populations are likely. In Coutada 9, central Mozambique, bushmeat harvesting, largely with gin traps, resulted in greatly depleted wildlife populations and the extirpation of some species (Lindsey & Bento 2012). Due to a lack of government support (fines not enforced and therefore not acting as a deterrent) and the large area to cover, anti-poaching efforts are challenging (Lindsey & Bento 2012).

4.1.2. Land-use, target species density, and human demand

The presence of mammals in the mosaic of protected areas, agriculture, and urban areas is linked to the species ability to adapt to the resources available and the disturbance levels (Ramesh et al. 2017; Ehlers Smith et al. 2018). The primary agricultural output of a property in the Boland region appears to play an important role in the level of snaring pressure present, with crop-producing farms being more likely than livestock farms to have higher numbers of snares present. Orchards had significantly higher snaring pressure, possibly because they attract certain preferred targeted species, such as porcupines who ringbark trees (Nieman et al. 2020), duiker who eat young shoots (Nieman et al. 2020), and feral pigs who are known to eat fallen fruit (Ballari & Barrios-García 2014). In an urban-agriculture mosaic landscape in southern KwaZulu-Natal, South Africa, it was found that porcupine occupancy is positively correlated to human population size and grey duiker occupancy is higher outside of protected areas than within (Ehlers Smith et al. 2018). Many studies show that snaring efforts are concentrated where wildlife aggregates (Lindsey & Bento 2012; Becker et al. 2013; Lindsey et al. 2013). Snares are known to be placed preferentially by trees as the flowering of certain species attracts browsers (Becker et al. 2013). Trees were also identified as a preferred anchor point for snares.

The anchoring of snares to sturdy tree trunks makes it harder for a snared animal to break free (Lindsey & Bento 2012; Becker et al. 2013). The non-native trees planted to form wind- and firebreaks between the orchard blocks were largely used for this purpose. Labourers working in the orchards would have easy access to these and would not raise suspicions walking in the vicinity, so snares placed there could be checked regularly without much extra effort. Wire was by far the most common material used for snares in the study area and may be easily obtained from orchard trellises. It is known that, in places with an abundance of readily available wire, it is difficult to control bushmeat hunting (Lindsey et al. 2013). Properties with a primary agricultural output of vineyards also had higher levels of snaring, and many of the reasons evoked for orchards would apply to this land-use too.

Snares were more likely to be found closer to rivers, which are known to attract wildlife. Similar results were found in Zambia's Luangwa valley where nearly 80% of the snares were placed within 20 m of water (Becker et al. 2013), while Watson et al. (2013) found that wire-snares set in the land around national parks were preferentially placed near crops and permanent water. Many mammals have been known to use the dense vegetation next to rivers as a corridor because it provides the cover and food that animals need to move through a fragmented agricultural landscape (Rondinini et al. 2006; Lees & Peres 2008; Zimbres et al. 2017; Paolino et al. 2018). Placing high numbers of snares in the riparian vegetation is therefore likely to have a negative impact on dispersal and gene flow for local wildlife populations. In the Boland region, snares were also more prevalent closer to the boundary of protected areas which are potentially viewed as a source of preferred target species by poachers. By contrast, few snares were placed in proximity to villages or smallholdings where wildlife is likely to be scarce. In an area of Cameroon where villagers hunt bushmeat, it was found that encounter rates and densities for most game species tended to decline as the distance to human activity decreased (Muchaal & Ngandjui 1999).

As hypothesised, more snares were likely to be found on properties with a larger number of families and those that employed seasonal workers. More families mean more people have access to the farm and the opportunity to set and check snares. When large numbers of people have access to a natural area when carrying out their job, a large increase in bushmeat harvesting can be expected (Poulsen et al. 2009). Most labourers that admitted to regular wire-snare poaching said they were motivated by food insecurity (Nieman et al. 2019b). This is a common driver of bushmeat poaching globally (Mainka & Trivedi 2002; Lindsey et al. 2013; Rentsch & Damon 2013; Cawthorn & Hoffman 2015). This is likely the reason that properties that hire seasonal workers also tend to experience higher levels of snaring. These labourers face more food insecurity because they lack permanent employment, resulting in a higher demand for a cheap source of protein. They also have less to lose if caught by a property owner or manager who is implementing punitive measures, as the threat of losing a permanent job is not present. A shortage of food and lack of jobs can be important motivators for bushmeat hunting (Gandiwa et al. 2013). The COVID-19 pandemic has put a significant strain on South Africa's economy, leading to job losses and financial hardship (Arndt et al. 2020), which could lead to more snaring in the future. The Western Cape province is the country's main wine region, an industry that was hit particularly hard with many businesses closing and more than 14,000 people losing their jobs (Capon 2020).

At a landscape-scale, distance to a public street was the most important factor for where snares were found. Snares were generally not found within 250 m of a public street as, due to the higher human traffic, there is an increased risk of being reported or apprehended (Haines et al. 2011). This links with Nieman et al. (2019b)'s finding that snare density increased further from residential areas and roadways. However, the relationship between snare presence and distance from public streets was not monotonic but rather increased sharply between 450 and 600m and then decreased again after that. In Zambia, snares placed on land bordering national parks were found to be preferentially set in proximity to roads, with wire-snaring only taking place within roughly 6 km of roads (Watson et al. 2013). A similar trend is seen in the Boland region, with the chances of finding a snare more than 1100 m from a public street being very low. Travel time and distance are limiting factors for poachers, increasing the effort and costs required to both find preferred target species and transport them once captured (Hofer et al. 2000; Hayward 2009). Snaring also tended to be more prevalent at mid-level elevation (300-500 m), which is likely to also be linked to convenience and accessibility, as most farms do not extend to high elevations. Variables linked to the difficulty of the terrain, specifically ruggedness and slope, were the least informative. This may be due to these variables being too uniform over the study area. Alternatively, rugged terrain may not have been a deterrent if people need to set snares to meet their basic survival need for protein. Snares are frequently placed over sizeable areas with variable terrain (Mudumba et al. 2020). This is worrying as even subsistence hunting has been shown to have a potentially devastating effect on vertebrate community structure (Peres 2000).

Predicted snaring hotspots across the region were present at mid-level elevation (300-500 m) and mostly centred around protected areas in the vicinity of public streets. There appeared to be more snaring in the vicinity of some towns, e.g., Grabouw, than others, e.g., Somerset West. Rural communities in the same area sometimes differ quite substantially in their use of natural resources (Shackleton et al. 2007, Nyaki et al. 2014). Hayward (2009) suggested that in southern Africa, 'halos of defaunation' could form around poorly resourced protected areas due to the demand for bushmeat. This is likely to further isolate these protected areas and in a fragmented landscape, edge effects can have a substantial influence on populations in protected areas (Saunders et al. 1991; Murcia 1995). Population sinks are likely to form around these protected areas, and if there is not enough reproduction and immigration into these areas to counteract the mortality rate, this will have serious consequences for resident wildlife populations and increase their chance of extinction due to stochastic events, such as an extensive fire (Woodroffe & Ginsberg 1998). For example, the leopards that reside in the Boland region already have a very limited prey base (Mann et al. 2019). This means the leopard population is especially vulnerable to a significant decline in the abundance of key prey species (Mann et al. 2019). In certain contexts, some species within the leopard's prey range appear to benefit from transformed land (Ehlers Smith et al. 2018; Zungu et al. 2019), however, we cannot be sure that this applies to the Boland region. Reduced prey bases would force leopards to travel further and to explore transformed lands where the risk of being snared unintentionally as bycatch increases dramatically (Becker et al. 2013; Loveridge et al. 2020). The removal of apex predators from already fragile ecosystems would have severe knock-on effects, such as decreased species diversity, changes to the biomass present at each trophic level, an imbalance in predator-prey interactions, and ultimately an unstable, overly simplified ecosystem with less resilience to large scale perturbations, such as climate change (Estes et al. 2011; Galetti & Dirzo 2013).

4.2. Limitations

Questionnaires can be a useful tool for ecological management and conservation strategies when needing to get a sense of public or stakeholder perceptions, consultation and education effectiveness, and human behaviour (White et al. 2005). However, the impact of the farmer residing on the property, the primary agricultural output of the properties, and the employment of seasonal workers all showed opposite trends when predicting the number of snares reported to have been seen in a month by labourers compared with the number of snares found during a patrol of the property. There could be several different reasons for this. Labourers may have under-reported the number of snares to the interviewer to hide the fact that they and/or their family are engaged in an illegal activity on the property where they are employed. It is unlikely they would want the property identified as a snaring hotspot, inviting further scrutiny from law enforcement and the potential for stricter punitive measures. Alternatively, their estimates may have been inaccurate because they did not notice all the snares due to their discrete nature (Lindsey et al. 2011) and the fact that they were not actively searching for them as was done during patrols. Although the use of questionnaires and interviews was crucial for determining the attitudes, motivations, and perceptions surrounding the use of wire-snares in my study area, they appear to be an ineffective tool for determining the distribution and intensity of wire-snare poaching.

The perceived presence of punitive measures was a significant predictor of fewer snares being reported to the interviewer, while the use of lethal control measures for damage-causing animals by the farmer was a significant predictor of more snares being reported to the interviewer. This suggests that labourers' responses may have been influenced by the perceived acceptance of the practice by farm management. Using both direct and indirect interview strategies to assess levels of bushmeat poaching has been shown to frequently be inaccurate (Knapp et al. 2010; Nyaki et al. 2014). The memory of respondents is unlikely to be accurate, people may substantially under-report their involvement in illegal activities due to fear of associated punishments (Knapp et al. 2010), and some respondents may even overestimate their involvement (Loibooki et al. 2002). Comparing what is reported by people from the local communities and what can be quantified through routine snare patrols can provide valuable insight into the value of questionnaires as a more convenient proxy of the extent and intensity of snares on individual properties.

It is important to note that snare patrols themselves may suffer from bias. While variation in detection between patrollers was controlled for by having only a single patrol officer for all properties, the ability of that patroller to detect snares equally across the landscape is uncertain. Dense vegetation far from existing game trails and roads and rugged terrain with no game trails, paths, or roads is likely to have been under-sampled, although efforts were made to search the dense vegetation adjacent to rivers. Hence the reported distribution and intensity of snares across properties were almost certainly biased to areas with higher access and visibility. Importantly, these same variables are likely to influence snare placement by poachers who themselves would be impeded by dense vegetation and difficult terrain. However, the possibility exists that some poachers overcome these challenges and may be responsible for considerable success in remote areas that are under-sampled in routine patrols. Addressing this bias would only be possible through random assignment of patrol transects and this remains a challenge for future research.

This study is an important step in building on the work of Nieman et al. (2019b), but the one-year interval between the completion of the questionnaires and the commencement of snare patrols means that certain socio-ecological characteristics of properties may have changed. There is the possibility that some farmers and farm labourers changed their attitude towards snaring in response to Nieman's study, for example, a farmer may have started enforcing stricter punitive measures. Some properties could not be patrolled a second time due to restrictions on fieldwork put in place because of the global COVID-19 pandemic. The contextualisation of my findings was challenging due to the limited literature currently available on wire-snare poaching within the Fynbos Biome or a South African agricultural context. I, therefore, strongly recommend that more studies of this nature are carried out in southern Africa, as bushmeat hunting is likely to increase as the population grows (UN-DESA, 2019). Snare patrols should be carried out within the protected areas too, as this would provide a better overall understanding of the overall bushmeat poaching dynamics in the region. If resources allow, snare patrols should also be carried out in perpetuity to get a better sense of the influence of the seasonal, year, and the ever-changing sociopolitical and ecological environment.

4.3. Recommendations for anti-snaring efforts

4.3.1. Snare patrols and law enforcement

Anti-poaching efforts can only be effective if the punishment is a strong enough deterrent and there is a high enough risk of being caught (Lindsey et al. 2013). To this end, I recommend the enforcement of anti-snaring regulations is increased in the region. Hunters have been found to ignore laws that are introduced without effective enforcement systems in place (Rowcliffe et al. 2004). A collaboration between landowners, police, and conservation officers to establish a robust, consistent security presence along with stricter laws and punishments for wildlife crime could help discourage illegal hunting (Grey-Ross et al. 2010). Nyaki et al. (2014) recommend including the local communities in this process, which I strongly agree with. Many villagers living adjacent to the Serengeti National Park, Tanzania, were found to believe that stricter law enforcement was needed to combat poaching and they were open to working with authorities to achieve this (Kaltenborn et al. 2005). They also expressed a wish for education about wildlife management and the legal use of wildlife as a resource for the local communities (Kaltenborn et al. 2005). When applying policy, it is important to have an open dialogue between local communities and conservationists, so that differences in community attitudes and understanding can be considered (Nyaki et al. 2014). A more collaborative law enforcement strategy should be put in place, so that information about new laws, legal procedures, and legal wildlife use are communicated clearly to locals (Nyaki et al. 2014).

I recommend that active snare patrols to search for and remove snares continue in the Boland region. It should be noted that routine and publicised snare patrols on properties is in itself likely to reduce the use of snares, for it is a constant reminder of the continued use of illegal activities with the potential for criminal prosecution. However, the latter demands improved patrolling to detect those deploying snares (e.g., through camera trapping or CCTV cameras) and the enforcement of relevant laws. Local conservation agencies may not have the time or resources to do this. I suggest that 'Enviroclubs' at local schools, a club for farm children, or scout groups could be organised to conduct snare patrols in a similar manner to which litter clean-ups are carried out. Effective patrolling has the potential to reduce both illegal activities and management costs (Plumptre et al. 2014) but is rarely achieved. Analysis of patrol data from the Greater Virunga Landscape showed that only 60% of the area was visited by rangers, with just 22% of the landscape being effectively patrolled (Plumptre et al. 2014). The proposed snare patrols should therefore focus on those agricultural properties with a resident farmer and a primary agricultural output of orchards to be as effective as possible. Special attention should be paid to areas between 450 to 650 m from a public street, close to a river, or close to a protected area boundary during snare patrols. Patches of commercial forest plantations, wetlands, bare ground and rocks, and natural forest and thicket should be checked thoroughly. With roughly 86% of snares being place on game trails and along fence lines, snare patrols should focus their efforts along and within these features. Extra attention should be paid to the bottom of trees and fence posts, as these were used as anchor points for most of the snares found. Eyelines should be kept low as most snares were positioned less than 40 cm off the ground. To ensure the right areas are patrolled with the limited time and manpower available, the Cape Leopard Trust online snare reporting platform (app.capeleopard.org.za) could be utilised to monitor for any changes in snaring activity and hotspots. This platform allows the public to report snare findings. Any signs of commercialisation, the formation of a bushmeat market, should be investigated. In Kerinci Seblat National Park, Sumatra, a greater frequency of forest ranger patrols reduced the number of snares set in the park and helped maintain the prey and predator populations (Linkie et al. 2015). They were more successful at locating snares when ‘tipped-off’ by reports from local people (Linkie et al. 2015).

4.3.2. Awareness campaigns and food security

Although very important, intensifying law enforcement is not a viable long-term solution to dealing with illegal bushmeat harvesting because the drivers of this activity are so strong (Challender & MacMillan 2014). More focus should be placed on incentivising local communities to conserve wildlife, building their capacity to do so, and fostering their intrinsic motivations to get involved, such as feelings of competency and group pride (Challender & MacMillan 2014; Cetas & Yasué 2017). Awareness and education campaigns targeting farmers, farmworkers, and the local public are likely to be especially important and should be done regularly. Milner-Gulland et al. (2003) stated that addressing the ‘wildmeat crisis’ will require increasing the awareness of the public and policymakers. Nieman (2018) found that many owners and managers were unaware of the regular snaring activity occurring on their property. The cryptic nature of wire-snares and where they are typically placed should, therefore, be emphasised during any awareness campaigns. Grey-Ross et al. (2010) found a similar phenomenon in the KwaZulu-Natal farmlands, with landowners reporting little or no illegal hunting on their properties, even though 64% of respondents admitted to regularly hunting. Education and awareness campaigns should call attention to the cruelty and wastefulness of wire-snare poaching. To account for the possibility of farmers purposefully turning a blind eye to this illegal activity, the indiscriminate nature of snares should be highlighted, including their propensity to maim and kill predators that may otherwise suppress damage-causing animals (Becker et al. 2013). If farmers are a driving force behind snaring, educating them about ethical, legal control measures for dealing with damage-causing species is vital.

Around 70% of snares were made of wire, so reducing the availability of discarded or freely available wire on farms could discourage those poachers who are motivated by the relative convenience of this hunting method more than food security. Most farmers have little options in terms of needing fences on and around their property or foliage wires for their vineyard and orchard trellises, but encouraging them to clear piles of old, discarded wire from the property could help in this regard. Limiting the supply of wire can reduce the density of snares placed in an area (Lindsey & Bento 2012). When poachers must invest more in the materials for their traps, it lowers the relative rewards of bushmeat poaching and having them confiscated frequently is a loss that could discourage them from continuing (Lindsey & Bento 2012). Along with education, a strategy simultaneously implementing better law enforcement and the provision of an alternate cheap protein supply or employment has been suggested as the most effective way to decreasing poaching (Grey-Ross et al. 2010).

To decrease levels of illegal hunting, it is essential to first tackle the social drivers behind it (Grey-Ross et al. 2010). Nieman et al. (2019b) found that the majority of farm labourers in the region who admitted to regular wire-snare poaching said they were motivated by food insecurity. As the demand for cheap forms of protein is high in the region, there may be potential for an economically feasible meat provision programme. People who have an affordable substitute source of protein are less likely to participate in illegal hunting (Loibooki et al. 2002, Wilkie et al. 2005). Pest species, such as the invasive feral pigs, and common species of low conservation priority, such as grey duiker and Cape porcupine (both of which are preferred target species for snaring), could be hunted legally with the correct permits in place. As locals may not have access to firearms, this could be done by conservation agencies or farmers. The meat would then be provided to local communities while the farmers would also perceive a benefit from the removal of potential crop and infrastructure damaging animals. A comprehensive assessment of prey numbers would first need to be completed to ensure the feasibility and sustainability of such a programme. This approach would also allow for the management of the offtake numbers to avoid over-depleting the prey base for the apex carnivores in the region. It would also help reduce the number of slow, painful deaths and serious injuries caused by this activity. A meat provision project could include a punitive aspect, where workers caught participating in illegal wire-snare poaching will not be given meat from the programme. For this idea to work, the protected areas must function as effective source areas with no illegal hunting activity within them. No-take areas are needed to conserve the hunted species at a landscape scale and facilitate sustainable harvest outside of the protected area (Milner-Gulland et al. 2003). It appears that high bushmeat off-takes from low conservation priority species can be maintained where animals with low fecundity are largely absent, even in densely populated and heavily harvested communal lands (Kaschula & Shackleton 2009). Workshops should be carried out to explain the legislation for legal hunting to farm labourers, such as prohibited hunting methods, daily bag limits, hunting seasons, the need for a hunting licence or permit, and the need for written permission from the landowner. It is important that frameworks be put in place that allow local communities to obtain wildlife benefits in a sustainable manner (Lindsey et al. 2013).

5. Conclusions

My study is important for growing the modest literature on bushmeat poaching activity in southern Africa, and the even more limited knowledge of snaring dynamics on private farmland in the Fynbos Biome. Bushmeat poaching is likely to be a major, growing threat to local biodiversity and ecosystem functioning in natural habitats, and should thus be approached as a priority challenge for the relevant conservation authorities. If the drivers and spatial patterns of wire-snare poaching can be identified, this can be used to improve the effectiveness of snare removal and law enforcement and thereby slow the activity (Critchlow et al. 2015). In the Boland region, the socio-ecological attributes of a private agricultural property which most strongly correlate with intensity of snaring pressure are having the farmer is residing on the property and having orchards as the primary agricultural output. The biophysical and anthropogenic factors that most correlate with where snares are more likely to be found are distance to the nearest public street, distance to the nearest river, and the land-use type. This is may be because this is where anti-snaring regulations are not being enforced, people have easy access to suitable land and materials for constructing snares, and the preferred target species are attracted to the vegetation present. Decisions about whether to set snares, how many to set, and where to set them, are probably made at numerous scales and based on a complex interaction of factors.

Where bushmeat is the principal source of protein for people, essential for meeting their basic needs, addressing the human side of this issue is critical (Cawthorn & Hoffman 2015). I recommend that in the Boland region, targeted snare patrols and awareness campaigns, in combination with increased food security and law enforcement, should be implemented. The situation should be re-evaluated regularly as local snare dynamics are likely to change as the population grows, and there is a risk of transition from subsistence use to commercialised use. Commercialised bushmeat trade would be predicted to rapidly increase snaring pressure (Fa & Brown 2009; Rogan et al. 2018). Keeping an open dialogue with local communities and building trust is especially important. Further research on the use of wire-snares on farmland in southern Africa is crucial to growing our knowledge of the dynamics present. A combined approach of questionnaires or structured interviews and snare patrols should be used to ensure a more complete and accurate understanding of the local context and drivers of snaring is obtained. Anti-snaring efforts should be tailored to take these drivers into account, and collaborations between government agencies, policymakers, conservation agencies, researchers, farm managers, farmworkers, and the public must be facilitated. Time, manpower, and funds are almost always limited for conservation initiatives, so they should be utilised as effectively and efficiently as possible.

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Appendices

Appendix A: Predictor variable specifications

Table A1. The sources of the GIS map layers used for the spatial and landscape-level statistical analyses.

Map layers	Source
Farm portions	Western Cape surveyor general (http://csg.dla.gov.za/)
Servitude areas	Western Cape surveyor general (http://csg.dla.gov.za/)
Servitude lines	Western Cape surveyor general (http://csg.dla.gov.za/)
Street network	Western Cape surveyor general (http://csg.dla.gov.za/)
River network	Institute of Water Quality Studies & Chief Directorate of Surveys and Mapping (http://www.dwa.gov.za/iwqs/gis_data/river/rivs500k.aspx)
Protected areas	South African Department of Environment, Forestry, and Fisheries (https://egis.environment.gov.za/)
Elevation	Regional Centre for Mapping of Resources for Development (http://geoportal.rcmrd.org/layers/servir%3Asouth_africa_srmt30meters)
Slope	Calculated from elevation
Ruggedness	Calculated from elevation
Land-cover	South African Department of Environment, Forestry, and Fisheries (https://egis.environment.gov.za/)

Table A2. The land-cover classes that were combined to form the land-use type variable for landscape-level analyses. Adapted from the 2018 South African National Land-Cover dataset Thompson (2019).

Class number	Original class name	New class name
2	Contiguous Low Forest & Thicket	Forest & thicket
3	Dense Forest & Woodland	
4	Open Woodland	
5	Contiguous & Dense Planted Forest	Forest plantations
6	Open & Sparse Planted Forest	
22	Herbaceous Wetlands (currently mapped)	Wetlands
23	Herbaceous Wetlands (previous mapped extent)	
25	Natural Rock Surfaces	Bare ground & rocks
30	Bare Riverbed Material	
31	Other Bare	
32	Cultivated Commercial Permanent Orchards	Cultivated land
33	Cultivated Commercial Permanent Vines	
39	Cultivated Commercial Annuals Non-Pivot Irrigated	
40	Cultivated Commercial Annuals Non-Pivot / Non-Irrigated	
42	Fallow Land & Old Fields (Trees)	Fallow land
44	Fallow Land & Old Fields (Grass)	
45	Fallow Land & Old Fields (Bare)	
73	Fallow Land & Old Fields (wetlands)	
55	Village Scattered	Villages & smallholdings
56	Village Dense	
59	Smallholdings (low veg/grass)	
19	Artificial Dams	Other
61	Urban Recreational Fields (Tree)	
63	Urban Recreational Fields (Grass)	
66	Industrial	
67	Roads & Rail (Major Linear)	

Table A3. The predictor variables included in the property-level models. Data type and the reason for inclusion are specified.

Variable	Data type	Reason	Reference(s)
Enforced punitive measures	Categorical (Perceived present/absent)	Clear laws and strong enforcement have been shown to be important for curbing illegal bushmeat hunting.	Loibooki et al. 2002; Lindsey et al. 2013; Ripple et al. 2016
Employment of seasonal workers	Categorical (Yes/no)	Bushmeat plays an important role in food security for many people. Seasonal workers may have less food security as they lack permanent employment.	Cawthorn & Hoffman 2015
Farm owner/ manager residency	Categorical (On/off property)	The continuous presence of an authoritative figure could discourage the setting of wire-snares outside of work hours if seen as law enforcement.	Loibooki et al. 2002; Lindsey et al. 2013; Ripple et al. 2016
Use of lethal control measures for damage-causing wildlife on the property	Categorical (Yes/no)	The potential removal of damage-causing animals can lead to farm owners/managers encouraging the use of snares.	Nieman 2018
The number of families on the property	Continuous (Count)	The more people living on a property, the greater the demand for bushmeat and the more people who will have access to the land and opportunities to set wire-snares.	Wato et al. 2006; Poulsen et al. 2009
Property size	Continuous (Area in ha)	Larger farms could allow for more wire-snares to be set without detection.	
The proportion of the property consisting of natural, untransformed land	Continuous (Percentage)	This habitat type could be seen as a source of target species. Natural vegetation patches are important for sustaining native wildlife in a fragmented landscape.	Ehlers Smith et al. 2018
Primary agricultural output	Categorical	More wire-snaring on properties with vineyards because the young vines attract high densities of duiker and	Nieman et al. 2020

	(Vineyards/ orchards/animal production)	orchards as these attract porcupines that often ringbark fruit trees

Table A4. The predictor variables included in the landscape-level model. Data type and the reason for inclusion are specified.

Variable	Data type	Reason	Reference(s)
Elevation	Continuous (Distance above sea level in m asl)	As most farms are located on the slopes of the mountains and protected areas are at high elevations, this is likely to play a role. Snare density found to be highest at high elevations.	Nieman et al. 2019b
Slope	Continuous (Steepness in degrees)	Difficult terrain could discourage people from setting wire-snares due to the extra effort required to transverse the area and check on the snares	
Ruggedness	Continuous (Elevation difference)	Difficult terrain could discourage people from setting wire-snares due to the extra effort required to transverse the area and check on the snares	
Distance to the nearest protected area	Continuous (Length in m)	The mountainous areas covered by the protected areas may be a major source of wild animals in the region.	Mann et al. 2019
Distance to the nearest river	Continuous (Length in m)	The water source and concealment provided by riparian habitat may attract a higher density of preferred target species.	Haines et al. 2011
Land-use types	Categorical (Forest & thicket/ plantation/fynbos/ grassland/other/ wetland/bare ground/cultivated land/fallow land/ village & smallholding)	Certain land-use types provide more cover and food, attracting more wild animals, while certain types are more accessible to farm labourers.	Nieman et al. 2020
Distance to the nearest farm boundary	Continuous (Length in m)	Farm boundaries frequently have fences with fire breaks on either side which provides easy access on foot, wire for snares, and many potential anchor points.	Keeping 2014; Naude et al. 2019; Fonteyn et al. 2020

		Wildlife may also use fire breaks when moving through the landscape to conserve energy.	
Distance to the nearest servitude area	Continuous (Length in m)	These allow the farmer, his family, visitors, and labourers to cross a neighbouring property providing more people with the opportunity to set wire-snares nearby. Wildlife are also likely to use servitude areas when moving through the landscape to conserve energy.	Keeping 2014; Naude et al. 2019; Fonteyn et al. 2020
Distance to the nearest street	Continuous (Length in m)	The accessibility of an area, such as being near to a public street, can play an important role in the bushmeat hunting pressure experienced.	Hofer et al. 2000; Hayward 2009; Watson et al. 2013

Appendix B: Property-level analyses

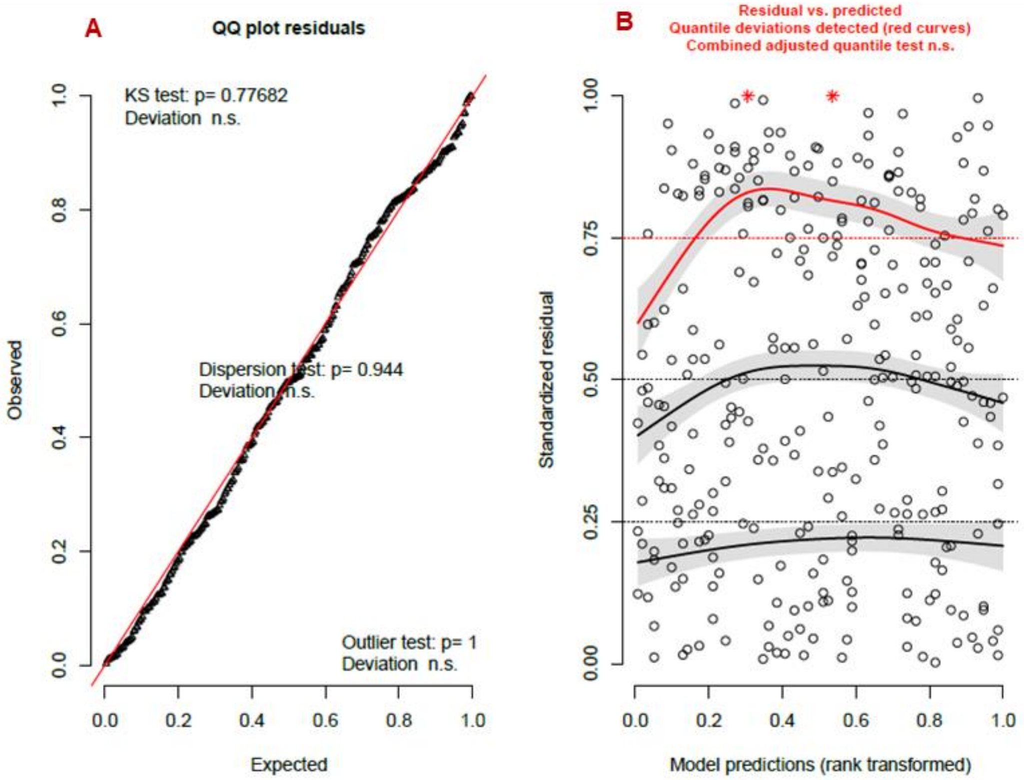

Figure B1. Model-checking for the GLMM fitted with the questionnaire estimate of the number of snares reportedly seen by a labourer on the property in the month prior to the interview. A) QQ-plot depicting correct distribution (KS), dispersion, and outlier tests. B) A plot of residuals against the predicted value with simulation outliers highlighted as red stars.

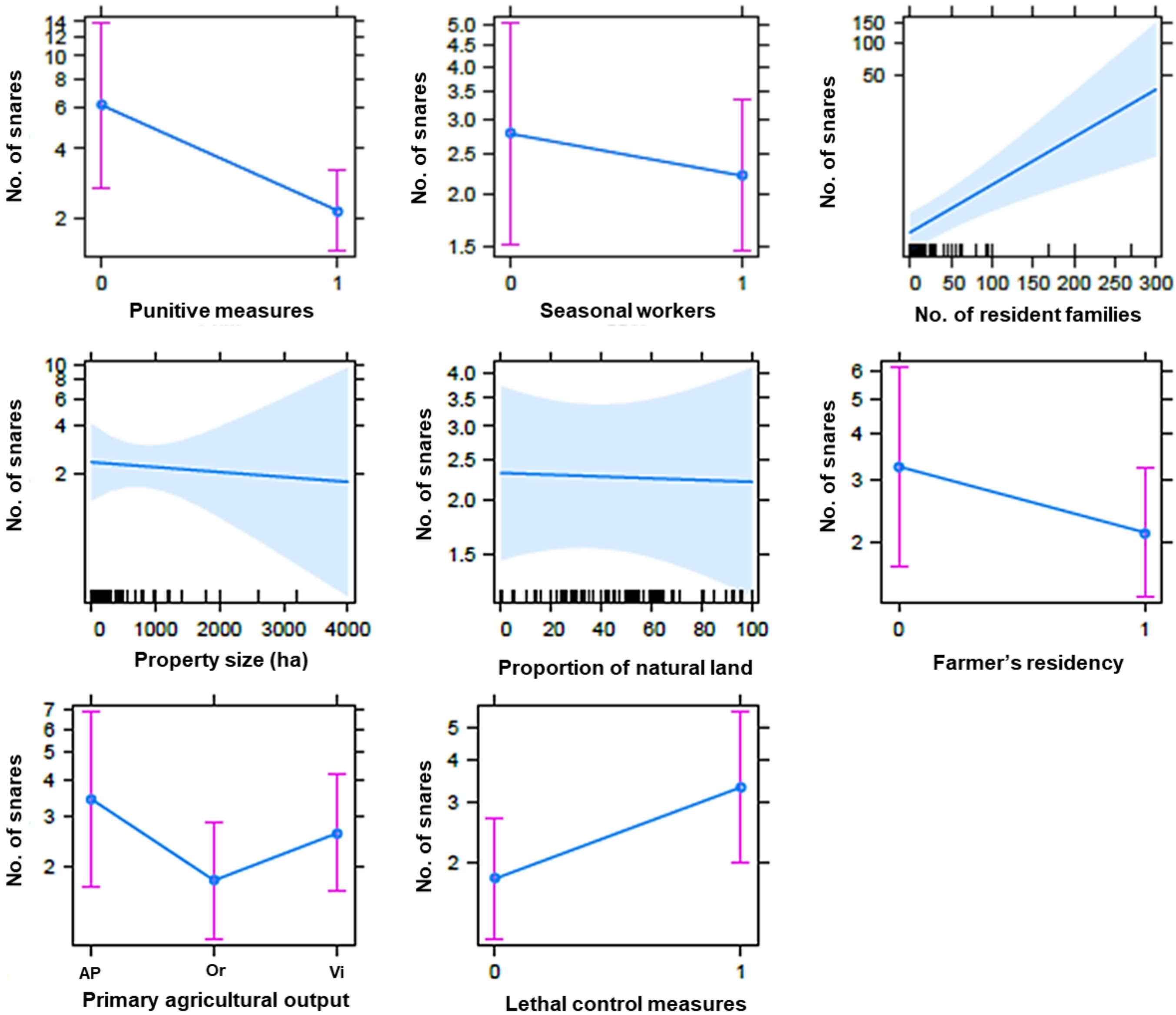

Figure B2. Effect plots for each of the predictor variables for the GLMM fitted with the questionnaire estimate of the number of snares reportedly seen by a labourer on the property in the month prior to the interview. The blue line indicates the partial slope and the blue shaded area for continuous variables indicates the pointwise confidence band.
(0 = Absent, 1 = Present; AP = Animal production, Or = Orchard, Vi = Vineyard)

Table B1. The simplified GLMM model for predicting the snaring pressure experienced by a property based on the number of snares reportedly seen by a labourer in the month prior to the interview. (* = significance)

	Estimate	***SE***	***Z* value**	***Pr* (>|*Z*|)**
(Intercept)	2.295	0.485	4.726	<0.001*
No. of resident families	0.009	0.002	4.665	<0.001*
Lethal control measures used	0.581	0.199	2.924	0.003*
Proportion of natural land	-0.001	0.004	-0.215	0.830
Farmer resident	-0.404	0.291	-1.389	0.165
Primary agricultural output - Orchards	-0.631	0.363	-1.738	0.082
Primary agricultural output - Vineyards	-0.276	0.354	-0.781	0.435
Punitive measures present	-1.015	0.383	-2.648	0.008*
Seasonal workers employed	-0.214	0.279	-0.768	0.442

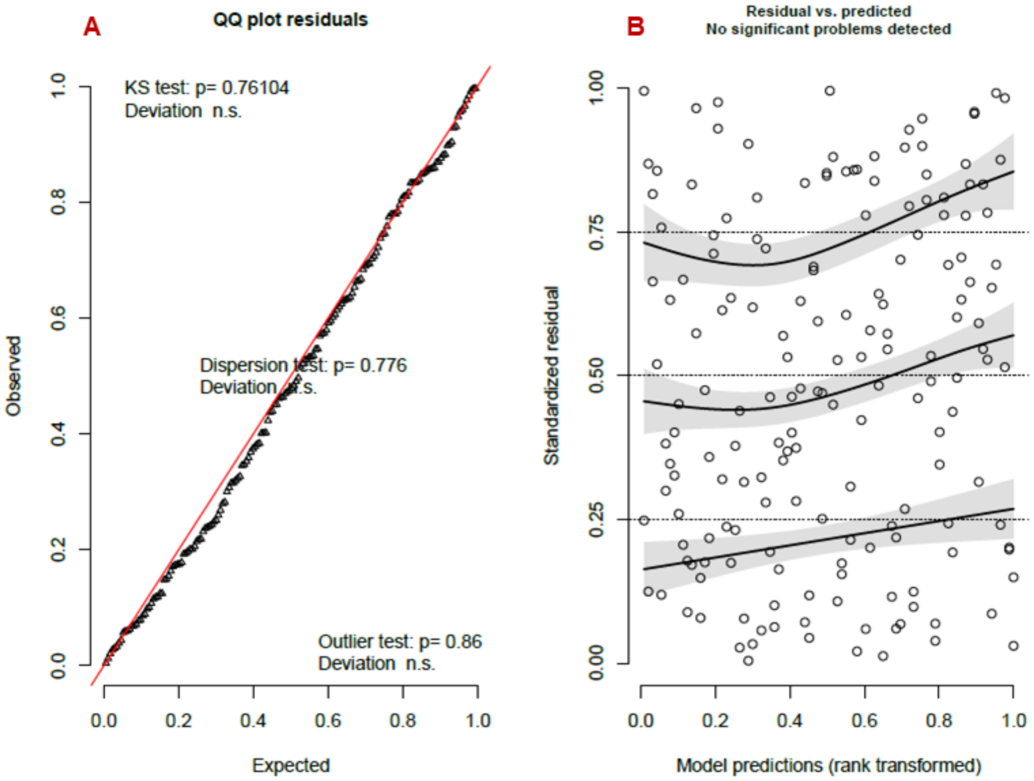

Figure B3. Model-checking for the GLMM fitted with the number of snares detected on a property during a patrol. A) QQ-plot depicting correct distribution (KS), dispersion, and outlier tests. B) A plot of residuals against the predicted value.

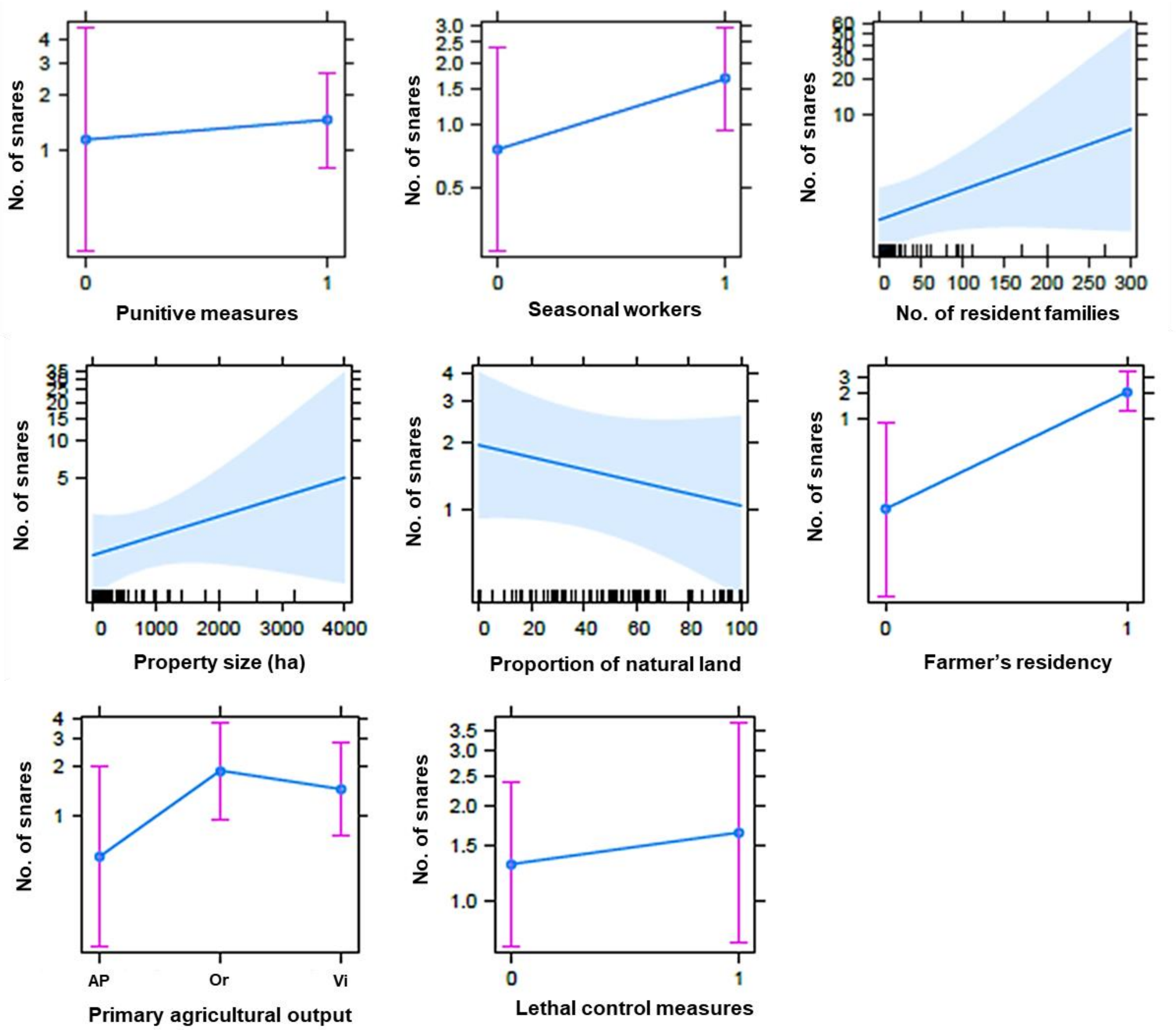

Figure B4. Effect plots for each of the predictor variables for the GLMM fitted with the number of snares detected on a property during a patrol. The blue line indicates the partial slope and the blue shaded area for continuous variables indicates the pointwise confidence band.
(0 = Absent, 1 = Present; AP = Animal production, Or = Orchard, Vi = Vineyard)

Table B2. The simplified GLMM models for predicting the snaring pressure experienced by a property based on the number of snares detected during a patrol. (* = significance)

	Estimate	***SE***	***Z* value**	***Pr* (>|*Z*|)**
(Intercept)	-4.095	1.369	-2.991	0.003*
No. of resident families	0.006	0.004	1.738	0.0822
Proportion of natural land	-0.006	0.006	-1.025	0.305
Lethal control measures used	0.259	0.344	0.754	0.451
Farmer resident	3.049	1.094	2.786	0.005*
Primary agricultural output - Orchards	1.261	0.624	2.019	0.043*
Primary agricultural output - Vineyards	1.023	0.641	1.595	0.111
Property size	<0.001	<0.001	1.186	0.236
Seasonal workers employed	0.793	0.503	1.575	0.115

Appendix C: Landscape-level analyses

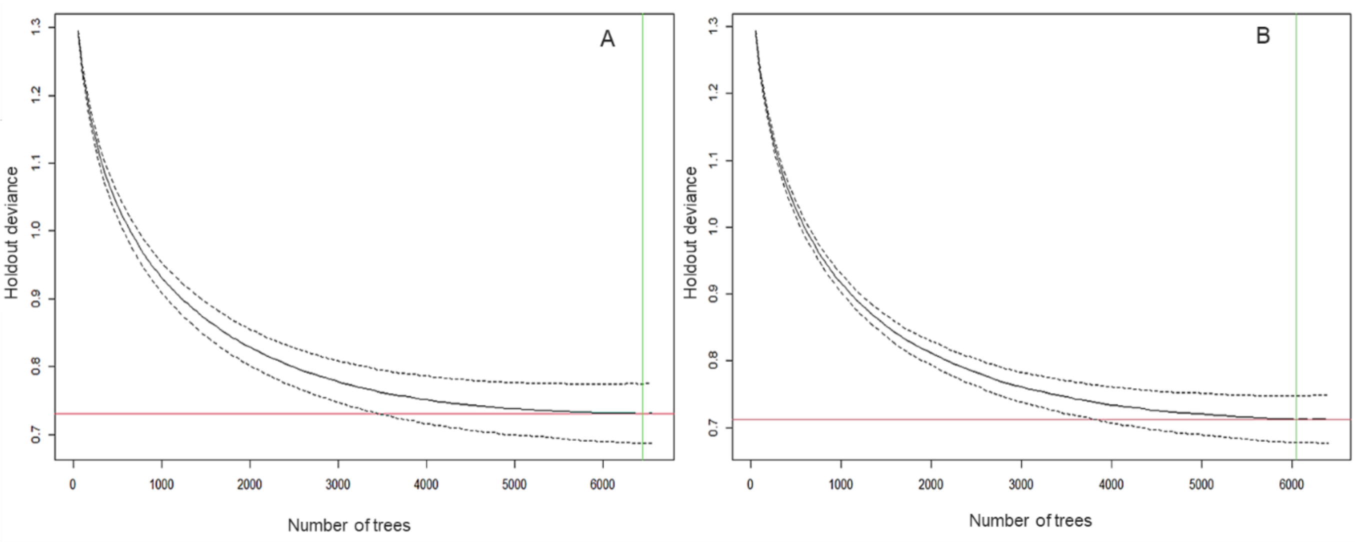

Figure C1. The optimization plots for the BRT base model (A) and the simplified model (B). The black curve shows the mean change in predictive deviance, with the red line indicating the minimum. The dotted lines curves show ± the standard error. The green line indicates the optimal number of trees.

Table C1. The relative contributions (%) of the predictor variables when predicting the presence or absence of snares at points in the landscape covered during the snare patrols for the BRT models. The base model was fitted with 9 predictors, and ruggedness was removed with optimal simplification.

Predictor	**Base model**	**Simplified model**
Dist. to street	21.48	22.43
Dist. to river	12.95	13.13
Land-use	12.04	12.38
Dist. to protected area	11.93	12.16
Elevation	11.90	11.87
Dist. to farm boundary	10.67	11.01
Dist. to servitude	9.07	9.18
Slope	5.96	7.83
Ruggedness	4.00	-

Table C2. The 10 most important pairwise interactions between predictor variables in the simplified BRT model when predicting the probability of wire-snare occurrence in the landscape. They are ranked according to interaction size.

Variable 1	**Variable 2**	**Interaction size**
Dist. to street	Dist. to protected area	116.56
Elevation	Dist. to street	71.02
Land-use	Elevation	42.81
Dist. to servitude	Dist. to street	41.81
Dist. to protected area	farm	40.27
Land-use	Dist. to river	39.03
Land-use	Elevation	38.64
Dist. to street	Dist. to farm boundary	37.53
Dist. to servitude	Dist. to river	37.20
Land-use	Dist. to protected area	25.84

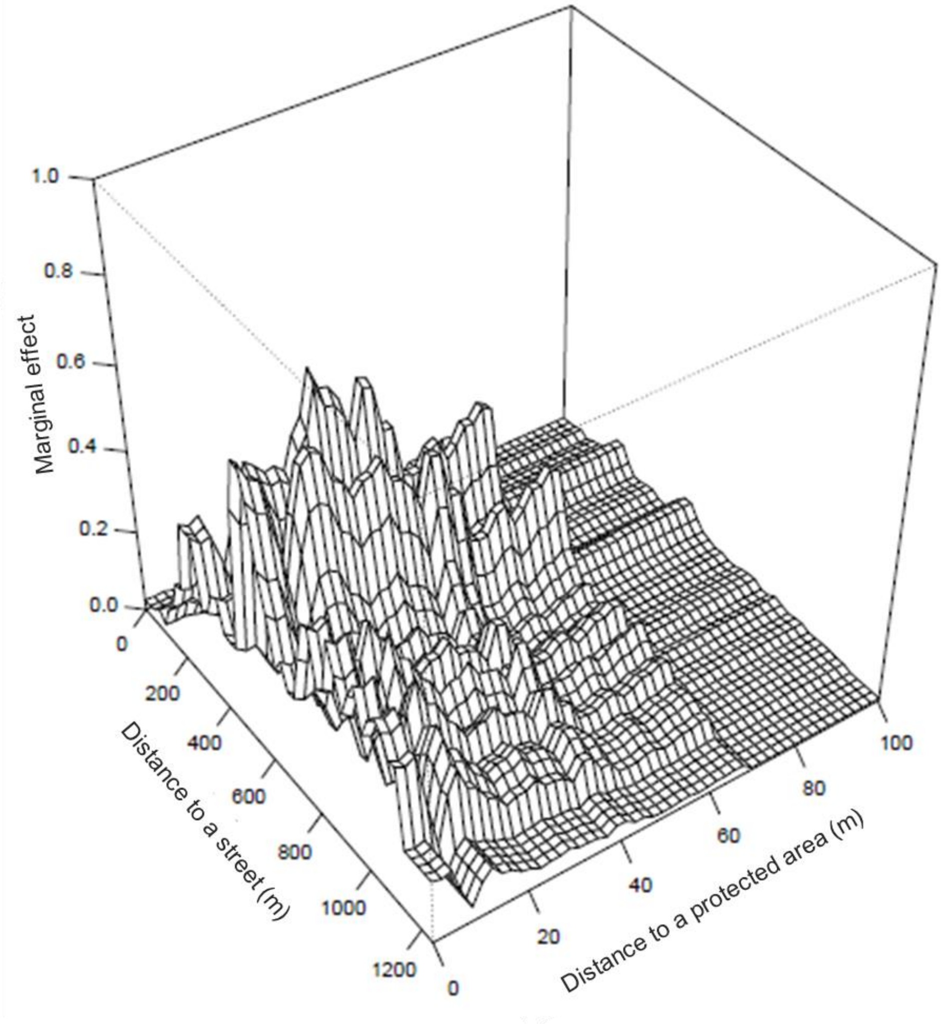

Figure C2. A partial dependence plot for the simplified BRT model depicting the most important pairwise interaction, distance to a street (m) and distance to a protected area (m), when predicting the probability of wire-snare occurrence in the landscape.

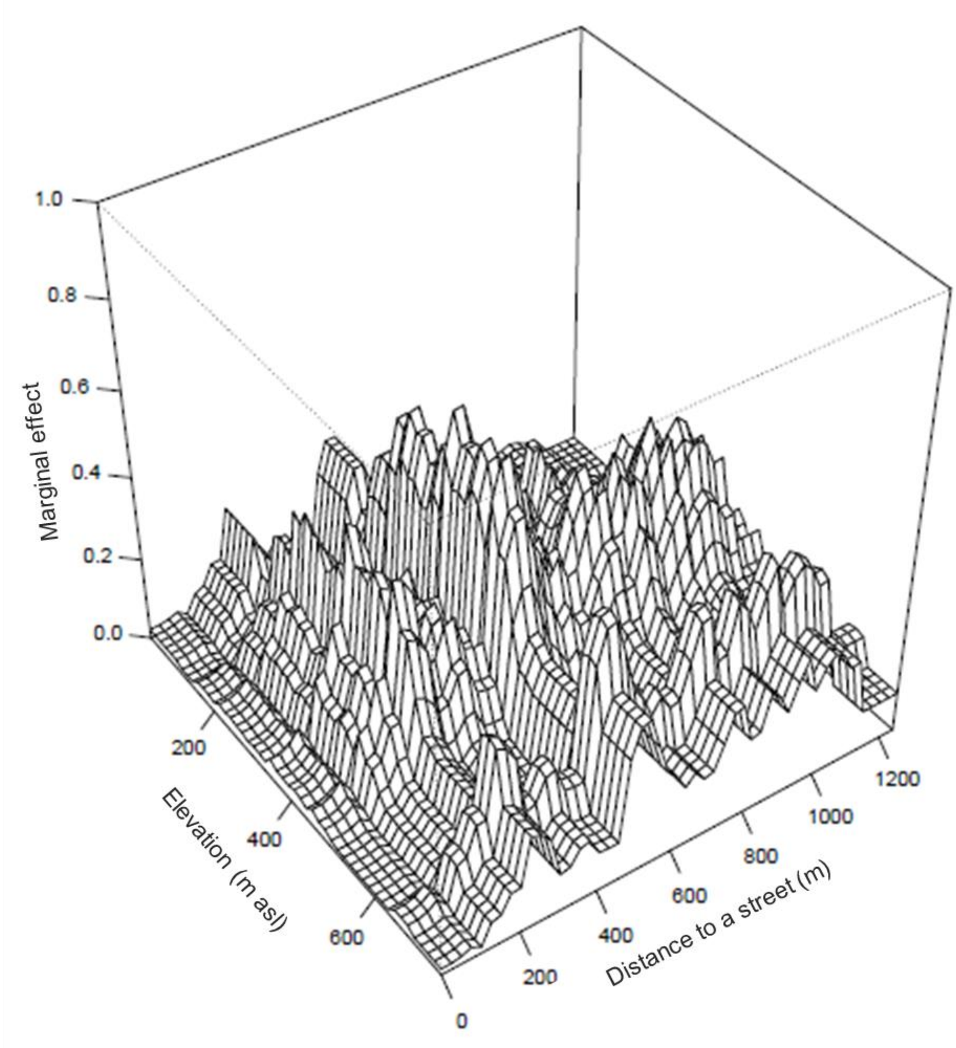

Figure C3. A partial dependence plot for the simplified BRT model depicting the second important pairwise interaction, elevation (m asl) and distance to a street (m), when predicting the probability of wire-snare occurrence in the landscape.