Development and application of novel ornithological survey methods for the detection of cryptic avian indicator species that predict grassland health

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ABSTRACT

The anthropogenic pressure on South African grasslands to meet the needs of the burgeoning human population has exposed them to extensive permanent transformation and degradation. Indicator species may identify changes in the grassland ecosystem. One such indicator species for natural sourveld grassland condition in South Africa is the red-winged francolin (*Scleroptila levaillantii*), whose population density is negatively correlated to grazing intensity and annual burning. Pointing dogs (*Canis lupus familiaris*) have been used extensively to aid ecologists in detecting these and other cryptic gamebirds to establish abundance. Here, a reliable method was developed to count cryptic gamebirds in the Greater uMgeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa, where the route through a survey site was flexible. A variation to the existing distance sampling technique was proposed where the dog global positioning system (GPS) track was the transect line. The study investigated the effect of varying environmental conditions on the distance from which a pointing dog could reliably and consistently detect a bird and allow calculating a detection distance based on influential environmental variables. Between March – October 2021, using pointing dogs fitted with GPS devices, controlled and uncontrolled trials were conducted on Japanese quail (*Coturnix japonica*) and red-winged francolin in their natural habitat, respectively, to establish the environmental conditions that affect detectability and the detection distance from which a dog can detect a bird of known location. A total of 21 surveys were conducted (August 2020 – October 2021), on four survey sites by one or two pointer dogs fitted with GPS devices, to establish the population densities and territory of red-winged francolin. Individual area of search, established from the detection distance based on nominal wind speed and GPS track, was calculated. The redundancy in area of search enabled the evaluation of relative proficiency of detection of red-winged francolin.

Of the environmental variables monitored, only nominal wind speed significantly influenced detection distance, where an increase of one-knot wind strength resulted in an increase in detection distance by 0.64 m. This enabled an area of search, considerate of influential environmental conditions, to be derived and the probability of detection within that search area = 1. Results showed significantly better precision and accuracy when surveying with two dogs when compared with one dog. The calculation of detection distance, where the probability of detecting a bird at this distance = 1, addresses the bias of varying scenting conditions. The established area of search, where the probability of detecting a bird within this area = 1, addresses the situation where known coveys in an area of known size remain undetected. Since the area of search is independent of time spent searching and normalised for redundancy, the bias introduced by varying physical aptitude is mitigated. Consideration for the application of this method should be given to the environmental conditions under which the surveying is planned since the detection distance function is derived for conditions at the present study sites. These techniques, based on a variable survey route through the survey site, may be used by citizen scientists to assist land managers, conservationists, and ecologists in establishing the abundance of red-winged francolin, contributing to burning and grazing regime management to enhance conservation efforts for the species.

PREFACE

The data described in this thesis were collected in KwaZulu-Natal, the Republic of South Africa, from June 2019 to October 2021. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs and the co-supervision of Dr David Ehlers Smith and Dr Yvette Ehlers Smith.

This thesis, submitted for the degree of Master of Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

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Stuart Beaumont

December 2021

I certify that the above statement is correct, and as the candidate's main supervisor I have approved this thesis for submission.

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Professor Colleen T. Downs

Supervisor

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DECLARATION 1 - PLAGIARISM

I, Stuart Beaumont, declare that

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1- in prep.

The influence of environmental factors on the detection of gamebirds by pointing dogs in the Midlands, KwaZulu-Natal, South Africa

Stuart N. Beaumont, David A. Ehlers Smith, Yvette C. Ehlers Smith, Colleen T. Downs

Author contributions:

SNB conceived paper with CTD, DES and YES. SNB collected and analysed data, and wrote the paper. CTD, DES and YES contributed valuable comments to the manuscript.

Publication 2- in prep.

The development and application of a method for estimating red-winged francolin abundance with pointing dogs in the Midlands, KwaZulu-Natal, South Africa

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Author contributions:

SNB conceived paper with CTD, DES and YES. SNB collected and analysed data, and wrote the paper. CTD, DES and YES contributed valuable comments to the manuscript.

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Stuart Beaumont

December 2021

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The idea to undertake this study was formulated in the rolling hills of the KwaZulu-Natal Midlands in the company of a concerned group of field trialling enthusiasts of the Natal Field Trial Club. Although naive to the task, I thank you for the encouragement at the time to pursue developing a method by which we can all contribute further to the wellbeing of our beloved Redwing.

Without the trust and confidence of all the landowners, this study would not have been possible. What started out as a gentle request for access to study the Redwing has turned into a mutually beneficial, meaningful relationship, and for this I thank you; Ezemvelo KZN Wildlife (uMngeni Vlei Nature Reserve); Sonja Krüger; Kobus Kruger; The Lake Lyndhurst Cottage Owner Association; John Campbell; Chris Melouney; Jerome Mitchell; Alfie Messenger and the Stubbs Family.

My wife, Danielle, and three kids, Ava, Rhett and Vivienne, I thank you immensely for the time you sacrificed for me to conduct the innumerable trips to the grasslands to train the dogs and survey for gamebirds. Without your constant motivation and encouragement, while burning the midnight oil, this would not have been possible. I thank my parents for instilling in me a genuine love for nature and appreciation for 'big-sky' country, which I hope to pass on to the next generation.

To Mark Lansdell, I thank you deeply for introducing me to this crazy pastime, for taking me under your wing and training me like you might a pointer – with patience! You are a true gentleman. May we spend many more days walking the misty mountains behind a brace of 'pooches'.

The science is a by-product of the beauty and privilege of watching a brace of pointers discover a covey of Redwing. For this I thank you Whiskey and Jack. Your passion runs deep.

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“Birds away!” Whiskey staunch to the flush

"Point!" - Jack fixed on redwing in the rocks

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CHAPTER 1

INTRODUCTION

1.1 Grasslands

The Grassland Biome makes up approximately 25% of the terrestrial surface, making it a major vegetation type of the world (Shantz 1954; Graetz 1994; Sterling and Ducharne 2008; Gibson and Newman 2019). Grasslands are divided into two climatically controlled types, with these being Temperate and Tropical Grasslands (Mucina et al. 2006). Temperate Grasslands include the Eurasian Steppes from Romania in the west to Manchuria in China in the east, North American prairies, Argentine and Uruguayan Pampas, Australian Alps, New Zealand grasslands and the grasslands of central and eastern South Africa (Mucina et al. 2006). Tropical grasslands are considered part of the Savanna Biome and Indian Ocean Coast Belt (Mucina et al. 2006).

Grasslands are characterised by land dominated by simple herbaceous vegetation (Mucina et al. 2006. The extent of grasslands is limited by available water for plants, primarily from precipitation and influenced by temperature (Sala et al. 2013). Globally, grassland ecosystems have a mean annual temperature of between 0°C and 25°C and rainfall of between 150 mm and 1200 mm annually (Whittaker 1975), which is strongly seasonal and restricted to half a year (Mucina et al. 2006). Where woody plants are present, they are typically confined to specialised habitats like escarpments and moist valleys (Mucina et al. 2006; Adie et al. 2009).

Within southern Africa, the Grassland Biome is further broken down into four bioregions. In order of reducing geographical coverage, these include Drakensberg Grassland, Mesic Highveld Grassland, Dry Highveld Grassland and Sub-Escarpment Grassland (Rutherford et al. 2021), amounting to 21.3% of the surface of South Africa (Fairbanks et al. 2000). These grasslands are divided into two classes based on moisture availability (Ellery et al. 1995). Moist (or mesic) grassland with higher annual rainfall and leeched soil has sour grasses (sourveld) with high canopy cover, plant production and fire frequency (Rutherford and Westfall 1986). The less palatable sour grasses are predominantly from the lower nutrient-rich Panicoideae subfamily (Rutherford and Westfall 1986). Dry grassland with lower annual rainfall and rich soil has sweet grasses (sweetveld) with lower canopy cover, plant production and fire frequency (Rutherford and Westfall 1986). The more palatable sweet grasses are predominantly from the Chloridoideae subfamily (Rutherford and Westfall 1986).

The high lightning flash density in the Grassland Biome increases the likelihood of lightning-induced fires (Schultze 1984), making grassland ecosystems both fire-prone and fire-dependent (Bond and Parr 2010; SANBI 2013; SANBI 2014; Rundel et al. 2016, 2018; He et al. 2019; Pausas and Keeley 2019). Fire is essential in hindering the proliferation of woody plant cover in the mesic grasslands (Bond et al. 2003; Pausas and Keeley 2019). Fire-dependent ecosystems (FDE), with annual rainfall >650 mm, rely on fire to prevent the transformation of the grasslands to forests, often resulting in the decline in the importance of dominant grass species (Bond et al. 2003; Archer et al. 2017; He et al. 2019).

Tainton and Mentis (1984) demonstrated the decline in cover of *Themida triandra* from 70% cover to <10% after 3 years of fire exclusion in the KwaZulu-Natal Midlands, South Africa. The exclusion of fire in a climate-dependent ecosystem (CDE) where rainfall is less than 650 mm p.a. would increase the density of trees without an increase in species composition (Bond et al. 2003; Adie et al. 2009; Archer et al. 2017). Sheffield Dynamic Global Vegetation Modelling (SDGVM) suggests that most of the eastern part of South Africa would become covered in trees in the absence of fire (Bond et al. 2003). Frequency, intensity, and seasonality of fires are key components of a fire regime (Gill 1975; He et al. 2019). Fuel load and moisture, air temperature and wind strength during this time determine the intensity of the fire (Mucina et al. 2006; He et al. 2019).

Like fire, grazing is essential in ensuring a healthy grassland since grasslands are well adapted to defoliation (Mucina et al. 2006). Species composition and standing biomass are significantly impacted by grazing by domestic and wild herbivores (Palmer and Ainslie 2005; Charles et al. 2017). Selective grazers, which graze by preferentially selecting specific, more palatable species, can significantly impact the grassland species composition more than bulk grazers, which are less discriminating in their selection of grass species (Acocks 1966; Tainton 1981; Mentis 1981; SANBI 2014). In South Africa, typical selective (concentrate) grazing livestock in mesic and dry highland grasslands include horses (*Equus caballus*), goats (*Capra aegagrus hircus*) and domestic sheep (*Ovis aries*) and game species include blesbok (*Damaliscus dorcas phillipsi*), common reeduck (*Redunca arundinum*), mountain reedbuck (*Redunca fulvorufula*) and black wildebeest (*Connochaetes gnou*) (Mentis 1981; SANBI 2014). Cattle (*Bos taurus*) are classified as bulk grazers and have relatively less impact on species composition than selective grazers (Mentis 1981; SANBI 2014). Harvester termites, whilst not classified as grazers, can provide defoliation during drought periods (Mucina et al. 2006).

Hoare (2002) compared commercially managed and grazed grasslands to those that were communally grazed and managed in the Eastern Cape Province, South Africa. Commercial grasslands are generally stocked at economical levels, whereas communally grazed grasslands are generally heavily stocked. Their study showed that, per 100 m^2 sample, commercial grasslands had 32.6 species (excluding exotics), whereas the communal grasslands had 23.5 species (excluding exotics). Fewer species were contributing to the species dominance, measured as the proportional cover for the top five species for communal grasslands (88%) compared with the commercial grasslands (66%). Proportional cover was more evenly distributed among species for the commercial grasslands than for the communal grasslands using Simpson's index for species evenness (Hoare 2002). Recent studies show similar trends (Rutherford and Powrie 2011; Gusha et al. 2017; Dedekind et al. 2020; Shezi et al. 2021).

Climate change, too, has been identified as a significant threat to the grasslands (Sala et al. 2000; Joyce et al. 2016; Gibson and Newman 2019). Using three general circulation models, Rutherford and colleagues (1999) predicted an increase in the mean temperature by 3°C and a decrease in annual rainfall between 5% in the north and 25% in the south of southern Africa, resulting from an increase in atmospheric CO_2. Grasslands, being dominated by Poaceae and predominantly the Panicoideae subfamily in the drier western regions, are a major C_4 photosynthesis group (Mucina et al. 2006; Arthan et al. 2021), thus the increased CO_2 levels and reduced rainfall could destroy the grasslands of the western region and eliminate up to 55% of the entire biome (Mucina et al. 2006).

In South Africa, the abundant water, minerals, rich soils and moderate climate and mineral reserves of grassland environments have made it suitable for agriculture and mining (SANBI 2014; Neke and Du Plessis 2004; Jewitt et al. 2015). The result of this is that at least 30% of the grasslands in South Africa have been permanently transformed, 23% for cultivation, 4% for exotic tree plantations (predominantly *Pinus* and *Eucalyptus* species in the mountainous regions) (Mucina et al. 2006), 2% for urbanisation and 1% for mining (Neke and Du Plessis 2004; Jewitt et al. 2015). A further 7% has been significantly degraded through agriculture and erosion (Fairbanks et al. 2000). Those that are not formally transformed are secondary grasslands or have been severely degraded by a gradual process, like woody plant encroachment (Mucina et al. 2006). Woody plant encroachment has transformed grasslands by reducing burned areas and increasing herbivory

(Venter et al. 2018). Large portions of the untransformed land are fragmented, much of which is only a few hectares in extent (Mucina et al. 2006). In the Highveld, the burgeoning urban densities, along with the suitability for agriculture, will see the transformation of the grassland ecosystems accelerate with economic growth (Mucina et al. 2006; Neke and Du Plessis 2004; Symes et al. 2017).

The grassland reserves in South Africa, predominantly in the Northern Escarpment and mountainous region (Mucina et al. 2013), make up a mere 2.2% of the Grassland Biome. The most significant protected grassland ecosystem in southern Africa is the Maloti-Drakensberg Park, with a total extent of 249 313 ha, comprising The uKhahlamba National Park in South Africa and The Sehlabathebe National Park in Lesotho (https://whc.unesco.org/en/list/985/).

The conservation of threatened species such as the blue swallow (*Hirundo atrocaerulea*), various cranes (*Gruidae spp.*), black (*Diceros bicornis*) and white rhinoceros (*Ceratotherium simum*), and Rudd's lark (*Heteromirafra ruddi*) in the grasslands of southern Africa has highlighted that managing habitat is key to managing the threats since habitat loss is the primary reason for their decline (Mucina et al. 2013; Symes et al. 2017; Andersen and Steidl 2019; Seibold et al. 2019). The Biodiversity Stewardship Programme was established to provide a cost-effective mechanism for private and communal landowners to voluntarily enter into agreements for the long-term protection of biodiversity priority areas, recognising that landowners are the custodians of biodiversity (SANBI 2015; Rawat 2017; Cortes-Capano et al. 2020). A clearly defined management objective for the grassland should be defined by the land manager as part of the Environmental Management Plan (SANBI 2013; Cockburn et al. 2019).

Leupold (1933) famously stated that "continuous census is the yardstick of success or failure in conservation". It follows that a review of the Environmental Management Plan should be conducted regularly to identify gaps in resources and systems required to the defined objectives (SANBI 2013; Pocock et al. 2015). Biodiversity monitoring is undertaken to establish changes in the grassland ecosystem as a result of management practice (Whittaker et al. 2005; SANBI 2013), such that corrective action can be taken. Rangeland assessments are conducted to measure the vegetation's condition or health (Zacharias 2004; Ramoelo et al. 2015; Xu and Guo 2015; Brown and Herrick 2016; Jones et al. 2020). Appropriate, reliable indicators, which are sensitive to management drivers, should be carefully selected based on the management objectives (SANBI 2013; Siddig et al. 2016; Rowland et al. 2018). Inexpensive indicators should be simple to use and targeted such that they respond to the specific ecological drivers of land use (SANBI 2013; Griffiths et al. 2016; Sidding et al. 2016; Rowland et al. 2018; Morris and Scott-Shaw 2019). Since grassland condition changes relatively slowly, typically 5-25 years, a long-term monitoring programme is necessary (SANBI 2013; Bauer and Albrecht 2020; Morris and Everson 2021).

Grasslands are complex ecosystems, and the monitoring of their health has, in the past, focused on various areas including "*productivity evaluation, classification, vegetation dynamics, livestock carrying capacity, grazing intensity, natural disaster detecting, fire, climate change, coverage assessment and soil erosion*" (Xu et al. 2015). Rangeland health is defined by National Research Council (1994) as "*the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained*". Whilst it is not appropriate to use a keystone species to define grassland health or productivity (Norton et al. 1992), the presence of red-winged francolin (*Scleroptila levaillantii*) have been negatively correlated to grazing and burning intensity (Jansen et al. 1999). Rangeland health is measured from two approaches: firstly, by evaluating the plant species composition, as it is affected by grazing or other factors, relative to the defined potential species composition for that site and secondly by comparing the functioning of ecological processes against an ecological site description, where the ecological site description uniquely describes the land for its production of vegetation (Adams et al. 2009; Gusha et al. 2017; Xu et al 2019).

1.2 Existing recognised survey methods for cryptic avian species

Dogs (*Canis lupus familiaris*) are used to enhance the capability of an observer to detect wildlife (Novoa et al. 1996; Homan et al. 2001; Arnett 2006; Dahlgren et al. 2010) in conjunction with line and belt transect methods to estimate the densities or indices of abundance of red grouse (*Lagopus lagopus scoticus*) in several studies (Jenkins et al. 1963; Thirgood et al. 2000; Amar et al. 2004; Broseth et al. 2005; Dahlgren et al. 2006). Both transect methods entail a pointing dog searching approximately 75 m on either side of a parallel transect, often spaced 150 m apart (Dahlgren et al. 2012). All birds within this area are assumed to be detected (Dahlgren et al. 2012); however, Sission and Stribling (2000) demonstrated with radiomarked northern bobwhites (*Colinus virginianus*) that pointing dogs only located 53% of available birds. Distance sampling in conjunction with program DISTANCE (Buckland et al. 2001) has been successfully applied to determine the probability of detection, effective strip width (ESW) and error rates (Dahlgren et al. 2012). Several studies (Warren 2006; Warren and Baines 2007) have used Geographic Information Systems (GIS) and applied Kriging to obtain the spatial distribution of densities. Guthery and Mecozzi (2008) introduced the application of global positioning systems (GPS) units attached to pointing dogs whilst surveying to generate a theoretical centerline for distance sampling. Program DISTANCE calculates an ESW for the transect, which is then used to buffer each side of the dog's path to create a polygon, normalised for redundancy where multiple dogs are used. A density estimate is established from the number of birds located within the polygon. However, several biases exist, namely:

- Equal detectability on either side of the dog is assumed, regardless of wind direction.
- Since it is assumed that all birds in a path are detected, normalising for redundancy may not be valid.
- Detection distance measured from an established point to the bird may vary considerably among individual dogs, particularly considering a dog may move well beyond the initial point of detection to approach the bird more closely.

Mentis and Bigalke (1985) compared the density estimate to the index of abundance method (measured as the number of birds found per minute spent searching), concluding that a significant correlation between these existed with density estimates being efficient for survey areas <200 ha in extent and index of abundance for survey areas >200 ha. They further noted that increased effort to locate birds in adverse climatic conditions does not negatively impact the density estimate method as severely as the abundance index since this is a function of searching time (Mentis and Bigalke 1985).

Table 1.1 Existing surveys for cryptic grassland avian species using pointing dogs (adapted from Dahlgren 2012).

Wildlife species	Dog breed or type	Method	Reference
Red grouse (*Lagopus lagopus scoticus*)	Pointing dogs (pointers and setters)	Belt Transect	Jenkins et al. 1963; Redpath and Thirgood et al. 1999; Thirgood et al. 2000; Park et al. 2001; Thirgood et al. 2002; Amar et al. 2004
Greater sage-grouse (*Centrocercus urophasianus*)	Pointing dogs (German shorthaired pointers)	Belt Transect	Dahlgren et al. 2006
Red grouse (*Lagopus lagopus scoticus*)	Pointing Dogs	Line transect distance sampling	Warren and Baines 2007
Ruffed grouse (*Bonasa umbellus*)	Pointing dogs	Belt Transect	Berner and Gysel 1969
Sooty grouse (*Dendragapus fuliginosus*)	Pointing dogs	Belt Transect	Zwickel 1972
Willow ptarmigan (*Lagopus lagopus*)	Pointing dogs	Line transect distance sampling	Pedersen et al. 2004; Broseth et al. 2005
Northern bobwhite (*Colinus virginianus*)	Pointing dogs	Effective strip width sampling	Guthery and Mecozzi 2008
Red-winged francolin (*Scleroptila levailantii*) and Grey-winged francolin (*Scleroptila afra*)	Pointing dogs	Density Estimate and Index of abundance	Mentis and Bigalke 1985

1.3 Red-winged francolins as an indicator species of grassland health

Harrison et al. (1994) defined an indicator species when referring to birds as one that has an obligate relationship to its habitat and further that it will not be found in any other primary habitat. The red-winged francolin (*Scleroptila levaillantii*) is classified as an indicator species of natural sourveld grassland in South Africa (Harrison et al. 1994; Jansen 2001). It can be further noted that the presence of a particular bird species in an area is indicative of the presence of its preferred habitat (Harrison et al. 1994; Catarino et al. 2016; Vallecillo et al. 2016). Jansen (2001) showed that the population density of red-winged francolin in the highland grasslands of Mpumalanga Province was negatively correlated to grazing intensity and annual burning in commercially managed grasslands. Intense grazing and burning of these habitats can cause changes to the grassland structure whereby vegetation height, density and species composition can be altered (Edwards 1981; Little et al. 2015). Jansen (2001) suggested that the meta-population of red-winged francolin is undermined through habitat degradation by excessive defoliation from intensive burning and grazing in these grasslands.

1.4 Scent and the use of pointing dogs to detect gamebirds

Odorants are a group of chemicals produced by animals, mostly as by-products of metabolism (Conover 2007; Bienenstock et al. 2018; Getahun et al. 2020). Saliva deposited on feathers during preening acts much like soap and breaks down organic chemicals stuck to the feathers into smaller molecules that are then volatile enough to become odorants (Conover 2007). Parasites, bacteria, yeast, and other microbes are additional sources of odorants emanating from birds that live in their digestive tract and outer surfaces (Conover 2007; Campagna et al. 2012). Birds also shed "rafts" or small collections of skin cells that contain the skin-degrading bacteria, *Staphylococcus*, which in turn produce unique odorants (Syrotuck 1972; Anrchie and Theis 2011; Campagne et al. 2012). Additionally, birds shed feathers that can contain feather-degrading bacteria such as *Bacillus licheniformus*, which produce unique odorants (Burtt and Ichida 2004). Olfactory predators have developed the ability to detect these odorants for as long as they are above a particular detection level (or concentration) for each predator, thereby tracking down prey (Conover 2007; Price and Banks 2016; Natusch et al. 2017; Lawson et al. 2019). Prey animals release scent primarily through two modes: deposition odour trail and scent plume (Hepper and Wells 2005; Conover 2007; Weldon 2021; Marin et al. 2021). Animals moving through an environment deposit an odour trail which an olfactory predator can use to generate a scent picture informing them of the when and in which direction the animal was travelling (Conover 2007; Weldon 2021; Marin et al. 2021). All animals release odorants into the air, even when stationary, creating an odour plume (Conover 2007; Weldon 2021; Marin et al. 2021). Olfactory predators can generally locate the source of an odorant by turning directly upwind since the concentration of an odorant, and previously undetectable odorants are negatively correlated to the distance from the odorant leeward of the source (Conover 2007; Cablk et al. 2008; Damichali and Guo 2020). By observing the behaviour of an olfactory predator, one can determine when it first detects the odour plume from its prey whilst approaching from a downwind position (Conover 2007). The distance a predator can detect prey from its odour plume is influenced by the size of the odorant source and its release rate (Conover 2007; Karp 2020). Nesting birds can reduce their metabolic, respiratory and heart rates by up to 50% when alarmed by a predator (Gabrielsen et al. 1985), thereby reducing their resulting odorants making detection by an olfactory predator more difficult (Conover 2007; Epsmark and Langvatn 1985; Jacobsen 1979).

As the wind strength increases, the concentration of the odorant is reduced until ultimately the concentration is below the detection threshold, whilst turbulence has the effect of dispersing the odorants in the air both laterally and vertically, resulting in an odour plume which starts out being a narrow column and quickly becomes a wide plume (Conover 2007; Cablk et al. 2008; Jinn et al. 2020). The Gaussian dispersion model can be used to effectively predict the impact of turbulence on an odour plume (Conover 2007; Daly and Zannetti 2007; Conti et al. 2020). Wark and Warner (1981) showed this model to be reasonably accurate in the absence of inversions or thermals for predicting the impact of turbulence on odorants. Bossert and Wilson (1963) modified the Gaussian dispersion model such that the maximum downwind distance that an odorant can be detected can be calculated by knowing the rate at which the source releases odorants, the minimum odorant concentration that a predator can detect, and the rate at which odorants diffuse laterally. As wind speed increases, the distance at which an odour plume can be detected is reduced (Bossert and Wilson 1963). Whilst small scale turbulence can be used to explain how high odorant concentration air mixes with adjacent air free from odorants, large-scale turbulence causes the entire odour plume to meander and undulate, resulting in inconsistencies in its detection (Conover 2007; Marin et al. 2021).

Jones (1983) developed two formulae for calculating the radius R of a plume at a distance x downwind of the source for ionised and non-ionised particles. A plume of ionised charged particles expand at a rate of 5°, and neutral particles expand at 4.5° when wind velocities are 5 m/s, although there are limitations to this model when the distance x is very large (approximately 100 m; Jones 1983).

Wark and Warner (1981) demonstrated that the dispersion of an odorant in the lower atmosphere is affected by the atmosphere's stability, where this can be ascertained by comparing the environmental lapse rate to the adiabatic (i.e., no heat transference) lapse rate. Where the environmental lapse rate is higher than the adiabatic lapse rate, the conditions become unstable, resulting in vertical air movements continuing to rise and more rapid dispersion of an odorant than would be predicted. Conversely, where the environmental lapse rate is lower than the adiabatic lapse rate, the conditions are stable, resulting in the vertical movement of a pocket of air and any odorant it is carrying, returning to the source of the odorant. Where the environmental lapse rate is equal to the adiabatic lapse rate, the atmosphere is considered neutral. They concluded that under strongly stable atmospheric conditions, the concentrations of odorants at ground level would remain above detectable levels for greater distances than when less stable (Wark and Warner 1981).

Shivik (2002) demonstrated that the time required for search-and-rescue dogs to locate a person was positively correlated to atmospheric stability and atmospheric pressure. Further evidence to support this was shown by Roberts and Porter (1998), where wild turkey (*Meleagris gallopavo*) nests were more likely depredated during warm, wet conditions when the atmospheric conditions were stable. Pasquill (1961) developed a simple system for evaluating the stability of atmospheric conditions where solar radiation and wind velocity are used to classify stability into one of six categories. Magidi (2013) modified this method by adapting Pasquill's atmospheric stability classes by measuring solar radiation (Table 1.2). Pasquill's method of classification was, however, challenged by Kahl and Chapman (2018), who showed it to perform particularly poorly during daytime at test sites, with only 1%-29% of cases correctly identifying instability.

The use of dogs for wildlife research and management can be economical when compared with alternative methods (Dahlgren et al. 2012; Orkin et al. 2016). Furthermore, when coupled with recent technological developments, like GPS, their use can surpass other known methods (Dahlgren et al. 2012). The ability of dogs to detect odorants is well known (Johnston 1999; Syrotuck 2000; Furton and Myers 2001; Cablk et al. 2008; Angle et al. 2016), resulting in skilled dogs being used to detect carcasses where their detection rates are reportedly superior to human searchers (Syrotuck 2000; Homan et al. 2001; Arnett 2006; Paula et al. 2011; Matthews et al. 2013).

Table 1.2 Modified Method for Atmospheric Stability Classes (day and night) (Source: Magidi 2013).

U	**Stability Class (Day)**			
	$R_D \geq 50$	**$50 \geq R_D \geq 25$**	**$25 \geq RD \geq 12.5$**	**$12.5 > R_D$**
U<2	A	A-B	B	D
2≤U<3	A-B	B	C	D
3≤U<4	B	B-C	C	D
4≤U<6	C	C-D	D	D
6≤U	C	D	D	D

U	**Stability Class (Night)**		
	$R_N \geq -1.8$	**$-1.8 \geq R_N \geq 3.6$**	**$-3.6 \geq R_N$**
U<2	A	A-B	B
2≤U<3	A-B	B	C
3≤U<4	B	B-C	C
4≤U<6	C	C-D	D
6≤U	C	D	D

The innate interest in wildlife game is the primary trait considered when selecting a dog for wildlife work, although within a breed, there are variations in traits, including drive, intelligence, cooperation, trainability, range, and scenting ability which should be considered when selecting a particular dog for the intended task (Dahlgren et al. 2012; Toya 2017; Otto et al. 2019;

DeMatteo et al. 2019). Pointing dogs can maintain a continuous inward flow of air through the nostrils, even while exhaling, whilst hunting for up to 40 respiratory cycles whilst scenting an olfactory plume (Steen et al. 1996), explaining why dogs can detect scent whilst running continuously (Dahlgren et al. 2012; Jenkins et al. 2018; Kokocińska-Kusiak et al. 2021), making them particularly suitable for surveying vast grasslands.

Variability exists between individual dogs to detect scent and prey (Jenkins et al. 1963; Gutzwiller 1990; Shivik 2002; Cablk and Harmon 2013). Gutzwiller (1990) highlighted that this could be because of several factors, including range or ground covered, scenting ability, age, and experience; hence, the number of individual dogs used in a study should be minimised, and these dogs should be used consistently. Environmental conditions have been found to be an important factor in the olfactory performance of dogs with increased humidity and reduced ambient temperature positively correlating increased detection rates (Reed et al. 2011; Jenkins et al. 2018; Lazarowski et al. 2020; Jinn et al. 2020; Kokocińska-Kusiak et al. 2021). Vapour pressure is also said to influence the efficiency of canine olfactory detection (Reed et al. 2011). The performance of an individual dog can vary within a given day, and therefore environmental conditions should be considered (Gutzwiller 1990). A dog's health may also affect its ability to detect the scent and many pointing dogs experience olfactory difficulties (Holloway 1961; Myers et al. 1984; Hayes et al. 2018; Jenkins et al. 2018; Otto et al. 2019; DeMatteo et al. 2019; Kokocińska-Kusiak et al. 2021). Other physiological factors, including parasite loads, poor diets and fatigue, can negatively affect a dog's ability to find birds (Gutzwiller 1990; Hayes et al. 2018; Jenkins et al. 2018; Otto et al. 2019; DeMatteo et al. 2019; Kokocińska-Kusiak et al. 2021). To address the biases introduced by these variables, Gutzwiller (1990) developed standard procedures which should be followed when using dogs as sampling tools, namely:

1. Use the same dog throughout the study or balance the use of each of two or more dogs in time and space to avoid "observer" bias.
2. Ensure dogs are physically fit (before and during searches) and well trained.
3. Search for birds under similar temperature, wind, precipitation, and barometric conditions as possible because these factors can affect bird activity, scent, and dog performance.
4. Restrict searches to certain periods of the day because daily cycles in temperature, humidity, and other variables influence scent production and detection. Bird activity and habitat use also vary with time of day.
5. Balance search efforts by using an equal number of dogs and searchers per unit of time and area.

The advent of purpose-designed GPS technology for dogs may help address some of the assumptions in the belt transect method (Cablk 2008; Reed et al. 2011; Dahlgren et al. 2012; Glen and Veltman 2018; Jinn et al. 2020). Researchers can enhance their ability to collect data for probability detection methods, (e.g., distance sampling) by using GPS technology designed for dogs (Buckland et al. 1993; Cablk 2008; Reed et al. 2011; Dahlgren et al. 2012; Glen and Veltman 2018; Jinn et al. 2020).

1.5 Study area

A study area comprising portions of four properties constituting a total extent of approximately 3200 ha, between 1783 and 2060 m.a.s.l encompassed within the Greater uMngeni Vlei Expansion Area (23,063 ha) in the Impendle district of the KwaZulu-Natal Midlands, South Africa (29°30'S 29°50'E) was selected. Mucina et al. (2006) classify the vegetation type as Drakensberg Foothill Moist Grassland rich in forbs and dominated by short bunch grasses including *Themeda triandra* and *Tristaychya leucothrix* with a mean annual temperature of 14.6°C, mean annual rainfall of 890 mm and 26 frost days per year. The geology comprises of both sedimentary mudstones and sandstones of the Tarkastad subgroup, and Molteno Formation with dominant well-drained soils to a depth of 800 mm and clay content from 15-55% and dolerites of the Jurassic age with soils represented by forms such as Balmoral, Shortlands and Vimy (Mucina et al. 2006).

Historically, a wide assemblage of ungulates, including the localised grey rhebuck (*Pelea capreolus*), common reedbuck (*Redunca arundinum*), mountain reedbuck (*R. fulvorufula*), oribi (*Ourebia ourebi*) and migratory Cape eland (*Taurotragus oryx*), black wildebeest (*Connochaetes gnou*), red hartebeest (*Alcelaphus buselaphus caama*) and blesbok (*Damaliscus pygargus phillipsi*) resided in the region until the late nineteenth century by which time they were exploited (Mentis and Huntley 1982). Presently, sparse populations of grey rhebuck, common reedbuck, mountain reedbuck, oribi and Cape eland have been observed (various pers. comm.).

The primary current land-use practice is stock farming with beef cattle (pers. obs.). A rotational burning programme is deployed to remove unpalatable grass species and defoliate moribund veld, the frequency of which varies according to the rate of litter accumulation (Stuart-Hill and Mentis 1982; Chamane et al. 2017; Chamane 2018; Pooley 2018; Porensky et al. 2021).

The area has avifaunal significance, and so it had subsequent classification as an Important Bird and Biodiversity Area (IBA) (Birdlife International 2021) and RAMSAR site (UNEP-WCMC 2021), including the presence of IBA trigger species wattled crane (*Grus carunculatus),* blue crane (*Anthropoides paradiseus*), ground woodpecker (*Geocolaptes olivaceus),* Drakensberg rockjumper (*Chaetops aurantius*), buff-streaked chat (*Campicoloides bifasciatus*) and yellow-breasted pipit (*Hemimacronyx chloris*).

1.6 Problem statement

Most grassland vegetation types are endangered or vulnerable (Tarboton 1997; Olsen and Dinerstein 1998; Reyers et al. 2001; BirdLife South Africa 2013; Skowno and Monyeki 2021; Prinsloo et al. 2021). These can take many years to recover, despite good management plans. Gamebirds such as the red-winged francolin can be considered an indicator of grassland condition (Harrison et al. 1994). The same may apply to grey-winged francolin. Since these species are cryptic, their abundance is difficult to determine with a high degree of confidence. Pointing dogs can detect these birds. Pointing dogs, sometimes called bird dogs, are a type of gundog typically used in finding wildlife game. Gundogs are traditionally divided into three classes: retrievers, flushing dogs, and pointing breeds. Pointing dogs hunt with high intensity, using available scents to locate upland game birds, at which time they will point intensely, focusing on the bird with their muzzle pointed at the quarry. The dog will remain steady, waiting for the handler to arrive, at which time the bird is flushed. The dog is thereafter released on the handler's command (American Kennel Club 2021). Developing a survey method for gamebird assessment that removes some existing known bias whilst counting will improve the robustness of the results. Further, developing a method that will enable citizen observers (with pointing dogs) to collect the data could be a cost-effective mechanism for conducting gamebird assessments that can contribute to grassland condition assessment and management.

1.7 Aims and objectives

The overall aim of this study was to develop a survey method for the detection of gamebird species using pointing dogs equipped with GPS technology for use by citizen scientists in determining gamebird abundance in a range of grasslands in KwaZulu-Natal Province, South Africa.

The objectives included:

- Assessment of gamebird presence and abundance in a range of grasslands in KwaZulu-Natal Province using pointer dogs.
- Assessment of environmental conditions under which gamebird surveys in grasslands can be conducted such that the gamebird detection probability is high.
- Development of a method for citizen scientists with pointing dogs to follow such that gamebird presence data collected in grasslands can used for conducting gamebird assessments that can contribute to grassland condition assessment and management.
- Assessment of the effectiveness of using pointing dogs to assess gamebird presence and abundance in a range of grasslands in KwaZulu-Natal Province.

The thesis is structured with each data chapter written in a manuscript format for submission to an international peer-reviewed journal. Any repetition was unavoidable.

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CHAPTER 2

The influence of environmental factors on the detection of gamebirds by pointing dogs in the Midlands, KwaZulu-Natal, South Africa

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Running header: Influence of environmental factors on the detection of gamebirds by pointing dogs

2.1 Abstract

Pointing dogs (*Canis lupus familiaris*) are primarily used to locate cryptic species or evidence thereof and often to establish their abundance. Environmental conditions at the time of search may influence the probability that a dog will detect a target. Here, we aimed to determine the environmental factors that affected the detection rate of a pointing dog detecting gamebirds in their natural environment under known atmospheric conditions, including temperature, humidity, barometric pressure, wind strength and solar radiation. We conducted uncontrolled trials in the Greater uMngeni Vlei Expansion Area of the KwaZulu-Natal Midlands, South Africa, between August 2020 – October 2021, where up to two pointing dogs repeatedly (n = 44) surveyed an environment with an abundance of red-winged francolin (*Scleroptila levaillantii*). The index of abundance, measured as birds/minute of search, was compared for each survey whilst simultaneously monitoring the environmental conditions. We conducted controlled trials (n = 34) in the same region concurrently by independently casting two pointing dogs downwind of caged Japanese quail (*Coturnix japonica*) of known location to observe the point where each dog's behaviour changed to indicate scent detection. This enabled us to measure detection distance whilst simultaneously monitoring environmental conditions. We found that the index of abundance showed no correlation with any of the monitored environmental factors in the uncontrolled trials, most probably because of the low incidence of detection. We further established in controlled trials that detection distance was uncorrelated to ambient temperature and relative humidity but significantly positively correlated with solar radiation and wind strength. An increase of one-knot wind strength resulted in an increase in detection distance by 0.64 m. Our study lays the foundation for developing an area-based survey method, considerate of environmental conditions, to detect cryptic bird species by dogs in conservation projects.

Keywords: detection distance; conservation dog; meteorology; sensory ecology; olfaction; ornithological methods

2.2 Introduction

Environmental conditions as a potential bias of survey results are frequently discussed by researchers using conservation dogs for detection, although the impact is rarely examined empirically (Wight 1931; Jenkins 1963; Mentis & Bigalke 1985; Guthery & Mecozzi 2008; Gutzwiller; Reed 2011; Kokocińska-Kusiak 2021). Humidity, temperature and wind strength are cited as the variables having the most significant influence. Typically, high relative humidity has the greatest effect on a dog's detection of a target trail, where the higher the relative humidity, the closer the dogs searched to the experimental trial (Jinn 2020). This is likely because the odorant molecule enters the vapour phase after being displaced from the substrate by water molecules (Unger et al. 1996; Spencer & Cliath 1970), resulting in a high concentration of odorant near its source (Cablk 2008). High humidity may further improve the olfactory skills of the dog (Jenkins et al. 2018) by enabling the odour particles to attach to the olfactory epithelium in the dog's nasal cavity (Jenkins et al. 2018; Kokocińska-Kusiak 2021). Both wind strength and temperature are positively correlated with detection distance (Calbk 2008), where higher temperatures cause more odorant evaporation while stronger winds transport the odorants further (Conover 2007).

Atmospheric stability, derived from a matrix of wind strength and insolation, describes the rate of a vertical movement of a pocket of air (Pasquill 1961; Magidi 2013). Thus, under certain conditions, the odorants therein remain above the detection concentration threshold for longer under more stable conditions (Wark and Warner 1981). The olfaction efficiency of dogs is generally positively correlated to high atmospheric stability (Roberts and Porter 1998; Shivik 2002).

We assessed the influence of several independent environmental factors on the detection rate, measured as the index of abundance (Mentis & Bigalke 1985) of red-winged francolin (*Scleroptila levaillantii*) by two pointing dogs (*Canis lupus familiaris*) in Drakensberg Foothill Moist Grassland in the KwaZulu-Natal Midlands, South Africa, in numerous uncontrolled trials. We also conducted controlled trials to examine the influence of several environmental factors on the detection distance of Japanese quail (*Coturnix japonica*) by the same two pointing dogs within the same study area.

Our study aimed to (1) assess which environmental factors affect the pointing dogs' gamebird detection rates, and (2) establish the detection distance of a gamebird of known location under varying environmental conditions. Since high humidity conditions increase the concentration of airborne odorants (Unger et al. 1996; Spencer & Cliath 1970; Cablk 2008), we predicted that the distance that a dog can detect a gamebird would be greatest under these conditions. Furthermore, as temperature increases, more volatile odorants will enter the lower atmosphere, increasing the concentration resulting in improved scenting (Conover 2007), increasing the detection distance. However, at a high-temperature threshold, we predicted that the scenting conditions would deteriorate because of the turbulence resulting from unstable atmospheric conditions (Pasquill 1961), and therefore detection distance would decrease. Finally, we predicted that detection distance under zero- to low-wind strength conditions would be relatively small and would increase as the wind strength increased since the increased wind strength would carry the scent further (Conover 2007). However, we predicted that the resulting turbulence would cause the odour concentration to fall below the detection threshold at a high wind strength threshold, therefore inhibiting detection.

2.3 Methods

2.3.1 Study area

We selected a study site for the uncontrolled trials as a portion of the uMngeni Vlei Nature Reserve (Site 'A', 364 ha) and a neighbouring study site (Site 'B', 226 ha) for the controlled trial, both encompassed within the Greater uMngeni Vlei Expansion Area (23,063 ha) in the Impendle district of the KwaZulu-Natal Midlands, South Africa (29°30'S 29°50'E, Figure 2.1). Permission to perform this research within the uMngeni Vlei Nature Reserve was granted by Ezemvelo KZN Wildlife under Project W/2156/01.

The altitude of the study sites ranged from 1783 to 1901 m.a.s.l. The geology comprises of well-drained soils to a depth of 800 mm and clay content from 15 -55 %, formed on sedimentary mudstone and sandstone of the Tarkastad subgroup and Molteno Formation, and Balmoral, Shortlands and Vimy soil forms from dolerites of the Jurassic age (Mucina et al. 2006).

The study area forms part of the Drakensberg Foothill Moist Grassland vegetation type (Mucina et al. 2006), which is dominated by short bunch grasses, including *Themeda triandra* and *Tristaychya leucothri*. The area has a mean annual rainfall of 890 mm, mean annual temperature of 14.6°C and 26 frost days per year (Mucina et al. 2006). These provide suitable conditions for the present primary land use of stock farming with beef cattle (pers. obs.). Generally, rotational grazing and a burning programme are used and closely managed (Table 2.1). This management removes unpalatable grass species and defoliated moribund grass conditions. The frequency of burning is varied and typically according to the rate of litter accumulation (uMngeni Vlei Nature

Reserve; Stuart-Hill & Mentis 1982; Chamane et al. 2017; Chamane 2018; Pooley 2018; Porensky et al. 2021).

Historically, a wide assemblage of ungulates, including the localised grey rhebuck (*Pelea capreolus*), common reedbuck (*Redunca arundinum*), mountain reedbuck (*R. fulvorufula*), oribi (*Ourebia ourebi*) and migratory Cape eland (*Taurotragus oryx*), black wildebeest (*Connochaetes gnou*), red hartebeest (*Alcelaphus buselaphus caama*) and blesbok (*Damaliscus pygargus phillipsi*) occurred in the region until the late nineteenth century by which time they were exploited, often to local extinction (Mentis & Huntley 1982). Presently, sparse populations of grey rhebuck, common reedbuck, mountain reedbuck, oribi and Cape eland have been observed (various pers. comm.).

Table 2.1 Veld management for study site A, KwaZulu-Natal Midlands, South Africa (pers. comm.).

Study site A	Extent (ha)	Spring burn	Grazing days/ha (LSU x days/extent)	Grazing season
2018/19	364	Yes	58.3	Oct – May
2019/20	364	No	35.6	Nov - April

1 LSU = 1 x 450kg cow

The study area (uMngeni Vlei Nature Reserve) has avifaunal significance, resulting in subsequent classification as an Important Bird and Biodiversity Area (IBA) (Birdlife International 2021) and RAMSAR site (UNEP-WCMC 2021). The presence of IBA trigger species, including wattled crane (*Grus carunculatus),* blue crane (*Anthropoides paradiseus*), ground woodpecker

(*Geocolaptes olivaceus)*, Drakensberg rockjumper (*Chaetops aurantius*), buff-streaked chat (*Campicoloides bifasciatus*) and yellow-breasted pipit (*Hemimacronyx chloris*), have been observed (pers. obs.). The grasslands are inhabited by red-winged francolin (pers. obs.), but the density varies where plant food and diversity are maximised, and cover is optimised (Mentis & Bigalke 1973, 1981; Mentis & Little 1992; Jansen et al. 2000)

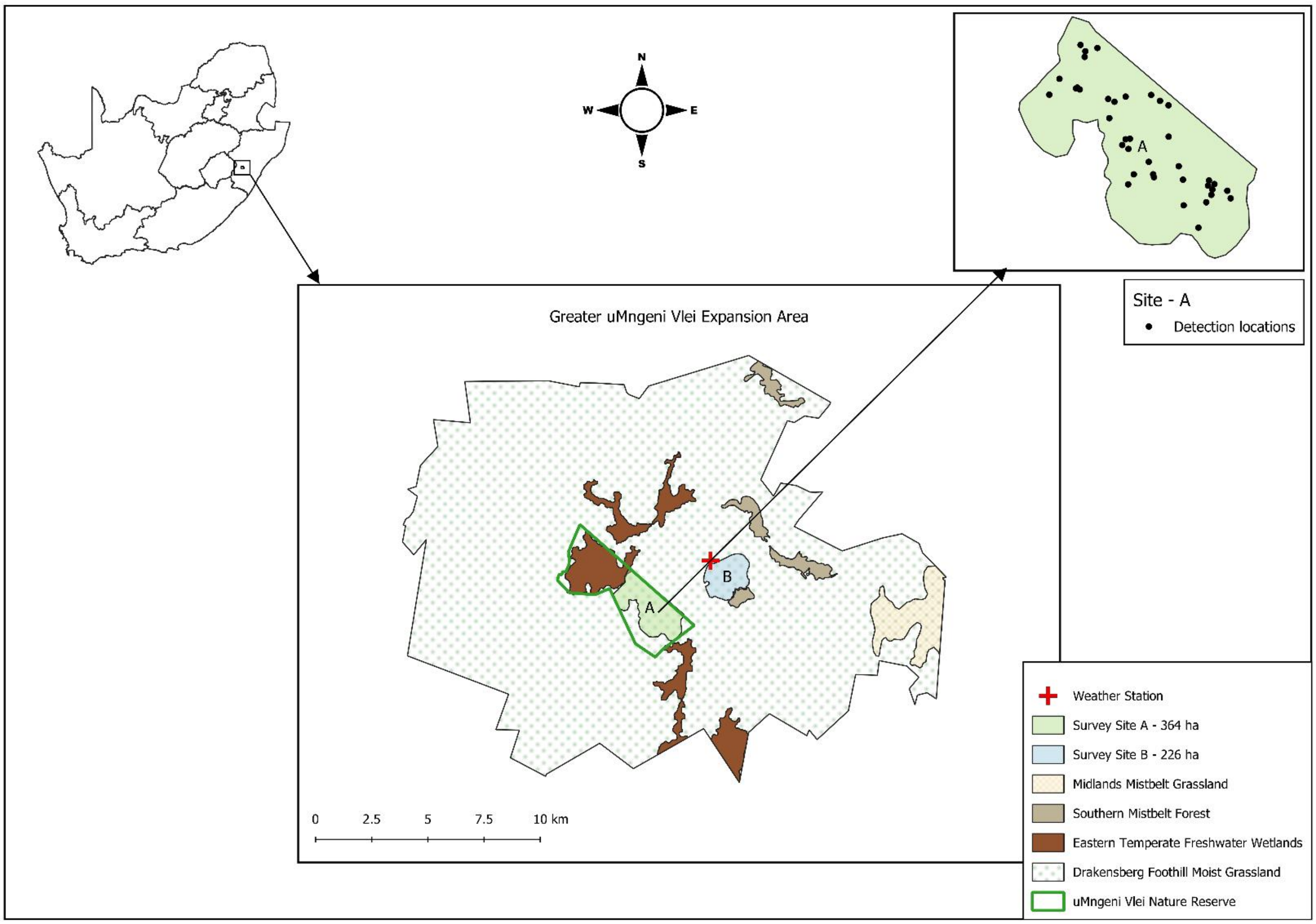

Figure 2.1 Location of the two study sites (A and B) within the Greater uMngeni Vlei Expansion Area, Impendle district, KwaZulu-Natal Province, South Africa. The red-winged francolin detection locations found in the present study in site 'A' are indicated.

2.3.2 Trials

Uncontrolled trials were conducted with wild gamebirds in their natural environment to establish environmental conditions influencing detection rate by pointing dogs, whilst controlled trials were conducted to establish both the detection distance and environmental conditions influencing detectability of 'known' birds.

To test the relationship between environmental conditions and the dog's detection rate, we analysed data collected from 44 uncontrolled surveys conducted on red-winged francolin under surveying conditions at study site 'A' (Figure 2.1) between March 2020 and October 2021. The non-breeding season was chosen since nesting birds can reduce their metabolic, respiratory and heart rates by up to 50% when alarmed by a predator (Gabrielsen et al. 1985), thereby reducing their resulting odorants making detection by an olfactory predator more difficult (Conover 2007).

We selected two physically fit, trained, experienced, and well-disciplined pointing dogs to perform the tests. Dog-A was a six-year-old German Shorthaired Pointer (GSP) bitch, NFTC Championship qualified (KUSA Registration Name: Knapskoot Whiskey, No.: ZA009271B15), and Dog-B was a two-year-old English Setter male, NFTC Championship qualified (NFTA Name: Gorge View Jack, Id: 4487). The handler's chosen route through the survey site was identified to present the dogs the opportunity to search suitable habitat and varied between surveys. The dogs were either cast off individually or in a brace to search for birds. Each dog was fitted with a global positioning system (GPS) tracker (Garmin TT15 Dog Device; https://www.garmin.com/en-ZA/p/160889#overview) incorporating a high sensitivity GPS/GLONASS receiver which relayed the position every 5 s to a handheld receiver unit (Garmin Alpha 100; https://www.garmin.com/en-US/p/107225/pn/010-01041-20) with the handler. The dog pointed or 'froze' on locating a wild bird, at which point the handler would proceed ahead of the dog and flush the bird. The bird's geographical location was recorded on a mobile phone app Epicollect5 (https://five.epicollect.net/), which had been configured to record the location, dog's name, bird species, number of birds in the covey, and a photograph of the grassland. The environmental conditions during each survey were continually recorded on the automated 3G cellular weather station (Ecowitt Model WH6006; https://osswww.ecowitt.net/uploads/20200923/ed76b3643d4040a78abb6c67ba022477.pdf), located within 4 km from the survey locations measuring ambient temperature, relative humidity, dew point temperature, wind chill temperature, heat index temperature, absolute atmospheric pressure, relative atmospheric pressure, nominal wind speed, wind gust speed, wind direction, rainfall, solar radiation, and ultraviolet (UV) index.

We performed controlled trials to eliminate the uncertainty when a dog finds a wild gamebird in its natural environment, yet the detectability is still subject to varying environmental conditions. Japanese quail were selected as a surrogate for red-winged francolin since dogs can generalise (Cablk 2008; Moser et al. 2019). The distance a predator can detect its prey from its odour plume is influenced by the size of the odorant source (Conover 2007; Karp 2020). Therefore, the number of quail used was determined by the biomass of each bird (175 g – 320 g) such that the sum of their biomasses was approximately the sum of the biomass of three red-winged francolins (450 g/bird; mean covey size range = 2.96 – 3.77 birds) (Jansen et al. 2000). The Japanese quail were enclosed in a wire cage (~ 0.7 m x 0.3 m x 0.3 m in size), which was concealed behind a grass tussock by the handler to obscure it from the view of the pointing dog. Since the quail were constrained, an odour deposition trail was not released, resulting in the odour plume being the only mode of scent dissipation. The enclosed Japanese quail were left undisturbed in situ for a mean of 1h10 (min 0h11, max 3h41) for the scent plume to form downwind.

Two pointing dogs performed the controlled trials individually. The handler approached from a downwind position, beyond the distance where the dog may have detected the quail, casting the dog orthogonal to the marked location of the quail. This was done since the objective was to establish the maximum distance at which the dog may detect the quail. The dog naturally quartered in front of the handler, keeping the wind on its cheek before turning. Each cast was up to 100 m on either side of the line from the handler to the marked quail. The dog would remain in front of the handler as he progressively approached the quail. At the point where the behaviour of the dog noticeably changed, the location was marked. The distance from this point to the quail was measured as the detection distance. This was repeated (n = 34) over three days under varying environmental conditions. All controlled trials were conducted within 1 km of the automated 3G cellular weather station, where the same environmental factors as the uncontrolled trials were logged at two-minute intervals and recorded at the point in time at which the dog detected the quail.

2.3.3 Analyses

We retrieved the GPS tracks for the dogs and handlers from the devices using Garmin BaseCamp (Version 4.7.4, Olathe, Kansas, USA). Only searching time, measured as moving time, was considered for the duration of the search, such that wasted time (e.g., when dogs may have been recovering) did not negatively affect the effort applied. The search duration for each dog was noted and used to calculate the index of abundance by dividing it by the number of birds encountered during the survey (Mentis & Bigalke 1985). We consolidated the dog track and bird location data in QGIS (version 3.14.16-Pi; QGIS.org, 2021). The environmental conditions recorded during each survey on the automated 3G cellular weather station were averaged for the duration of each survey portion (mean: 0h39m24s; median: 00h35m15s).

We tested the environmental data variables for normality using the Kolmogorov-Smirnov Test. We performed a Spearman's Rank Correlation Test to remove correlated variables and avoid multicollinearity. We used multiple linear regression to predict detection distance. We conducted a principal component analysis (PCA) using the Verimax Method and Kaizer Normalisation. The data were checked for unusual and influential data by reviewing the Standard Residual, Centered Leveraged Value, Cook's Distance and DFBETA. We used IBM SPSS Statistics (Version 27) statistical package. All means are presented with standard deviations (SD).

2.4 Results

For our uncontrolled trials, the pointer dogs found 31 coveys with a range of covey sizes of red-winged francolin (Table 2.2). All coveys had more than one bird (Table 2.2).

Table 2.2 Covey size recorded for red-winged francolin (*Scleroptila levaillantii*) between August 2020 – October 2021 at uMngeni Vlei Nature Reserve, KwaZulu-Natal Midlands, South Africa.

	Min	**Max**	**Mean $\pm$ SD**	**No. coveys where covey size = 1**	**No. coveys where covey size >1**	**Total coveys**
Site A	0	10	3.9 ±1.5	0	31	31

A typical example of the distance covered by one of the dogs searching for red-winged francolin is shown in supplementary information Figure S2.1. The mean speed of the dogs whilst surveying was 4.7 ± 96 m/s so they covered approximately 23.5 m in the 5s interval. We were unable to determine the detection distance (Cablk 2008), measured as the distance from the initial location where the searching behaviour of the dog changed because of scent detection (Conover 2007; Cablk 2008) and the location of the birds. The reasons were as follows:

1. The GPS location sampling frequency on the dog was set at 5s intervals. Since the mean speed of the dogs whilst surveying was 4.7 m/s they covered approximately 23.5 m in the 5s interval. When analysed in global information system (GIS), this distance was too great to identify the point at which the dog's behaviour changed when detecting scent.

2. The location of the bird that emitted the scent which caused the dog to change behaviour was impossible to establish since, in all cases, the number of birds at the location was greater than one.

3. Red-winged francolins were observed, on occasions, running ahead of the dogs whilst tracking scent, rendering measurement of the detection distance impossible (pers. obs.).

The environmental data (n = 1245), comprising 12 variables (ambient temperature (°C), relative humidity (%), dew point (°C), wind chill (°C), heat index (°C), absolute pressure (hPa), relative pressure (hPa), wind strength (kn), gust strength (kn), wind direction (deg.), solar radiation (w/m^2) and UV index (UVI)), were evaluated for normality using the Kolmogorov-Smirnov Test, which showed all variables to be nonparametric ($p < 0.0001$). We used a Spearman's Rank Correlation Test to remove correlated variables and thus avoid multicollinearity. However, a high degree of correlation across all variables existed, and we could not identify the predictor variables. We, therefore, performed a PCA using the Verimax Method and Kaizer Normalisation on the same dataset to reveal four components in the rotated component matrix (Table 2.3). The following variables were selected as the predictor variables, one from each of the four components using the

PCA: (1) ambient temperature, (2) relative humidity, (3) solar radiation and (4) wind strength (Table 2.3). A summary of environmental conditions whilst conducting controlled and uncontrolled trials are presented in Table 2.4.

For our uncontrolled trials of detection distance and environmental factors, we first tested for normality of the index of abundance and environmental factors, and these indicated a non-normal distribution (Kolmogorov-Smirnov Test for Normality; $p < 0.0001$, Table 2.5). Furthermore, a test for correlation between the index of abundance and (1) ambient temperature, (2) humidity, (3) wind strength and (4) solar radiation showed no significant correlations existed (Spearman's Rank Correlation Test; Table 2.5).

Table 2.3 Principal Component Analysis identifying environmental condition predictor variables in the present study.

Rotated Component Matrix[a]

	Component			
	1	2	3	4
Wind chill (°C)	.967	.016	.072	.048
Ambient temperature (°C)	.959	.011	.156	.103
Heat index (°C)	.959	.011	.156	.103
Relative pressure (hpa)	-.650	-.624	-.024	-.027
Absolute pressure (hpa)	-.650	-.624	-.024	-.027
Relative humidity (%)	-.268	.913	.035	.075
Dew point (C)	.250	.846	.156	.135
Solar rad (w/m^2)	.160	.047	.957	.098
UV index (UVI)	.153	.058	.954	.107
Wind direction (deg)	.190	-.092	-.079	.779
Wind strength (kn)	-.016	.338	.487	.720
Gust strength (kn)	-.024	.344	.496	.704

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.[a] ; a. Rotation converged in 6 iterations.

Table 2.4 Summary environmental conditions whilst conducting controlled and uncontrolled trials in the present study, between 2020 – 2021 at uMngeni Vlei Nature Reserve, KwaZulu-Natal Midlands, South Africa.

	Controlled trial				
	Range	**Minimum**	**Maximum**	**Mean**	**SD**
Outdoor temperature (^oC)	5.2	10.1	15.3	12.6	1.4
Outdoor humidity (%)	57	42	99	79	22
Wind strength (kn)	23.0	2.7	25.7	12.9	6.0
Solar radiation (w/m^2)	972	121	1093	668	310
	Uncontrolled Trial				
	Range	**Minimum**	**Maximum**	**Mean**	**SD**
Outdoor temperature(^oC)	13.5	5.8	19.3	12.3	2.8
Outdoor humidity (%)	79	20	99	56	18
Wind strength (kn)	16.9	0.0	16.9	6.9	3.4
Solar radiation (w/m^2)	902	0.0	902	292	261

Table 2.5 Test for correlation between the index of abundance (IoA) and environmental factors for gamebird surveys between 2020 – 2021 in the uMngeni Vlei Nature Reserve, KwaZulu-Natal Midlands, South Africa.

				Test for Normality		**Spearman's rho**			
Site	Year	n		K-S		Ambient Temperature	Relative Humidity	Wind Strength	Solar Radiation
A	2021	44	df	0.341	r	-0.158	0.103	0.065	0.052
			p	0.000	p	0.306	0.505	0.675	0.736

For our controlled trials of detection distance and environmental factors, we first tested for normality and found that ambient temperature (D(34) = 0.205, p = 0.001), relative humidity (D(34) = 0.271, p = 0.000) and solar radiation (D(34) = 0.195, p = 0.002) were non-normally distributed while wind strength (D(34) = 0.098, p = 0.200) and detection distance (D(34) = 0.135, p = 0.120) were normally distributed (Kolmogorov-Smirnov test for normality). Detection distance showed a significant positive correlation with wind strength (r = 0.495, p = 0.003) and solar radiation (r = 0.426, p = 0.012) but no correlation with ambient temperature (r = 0.185, p = 0.295) and relative humidity (r = -0.023, p = 0.896). We also found a significant negative correlation between relative humidity and solar radiation (r_s = -.492, p = 0.003) and a significant positive correlation between wind strength and solar radiation (r_s = 0.465, p = 0.006). We used a multiple linear regression to predict detection distance based on wind strength and solar radiation, however solar radiation (β = 0.004, s = 0.004, p = 0.287) was found not to be statistically significant and was therefore removed from the model.

Using linear regression, we found the relationship between the response (detection distance) and predictor (wind strength) variables was zero, since the relationship of standardised predicted value to standardised residuals was roughly linear around zero on the Loess curve, and random (therefore passing the test for homoscedasticity). The normal probability plot (P-P Plot) and Q-Q Plot confirmed that residuals were normally distributed.

When we checked the data for unusual and influential data by reviewing the Standard Residual, Centered Leveraged Value, Cook's Distance and DFBETA, these identified the following trials for further investigation: 1016-2-W; 1016-10-W; 1016-9-W; 1121-4-W; and 1121-5-W (Figure 2.2). The requirement for null mean residual and standardised residual was met. We calculated a simple linear regression to predict detection distance based on wind strength which was significant ($F_{(1,32)}$ = 13.378, p = 0.001; R^2 = 0.295). The probability of detection of a bird of known location, under varying wind strength = 1 since the distance was progressively reduced until the dog detected the bird.

The detection distance was found to be defined by the following function:

$$DD_i = 0.64\,\overline{V}w_i + 19.2$$

Where DDi = detection distance (m) for survey portion i, and $\overline{V}w_i$ = nominal wind speed (kn) for survey portion i

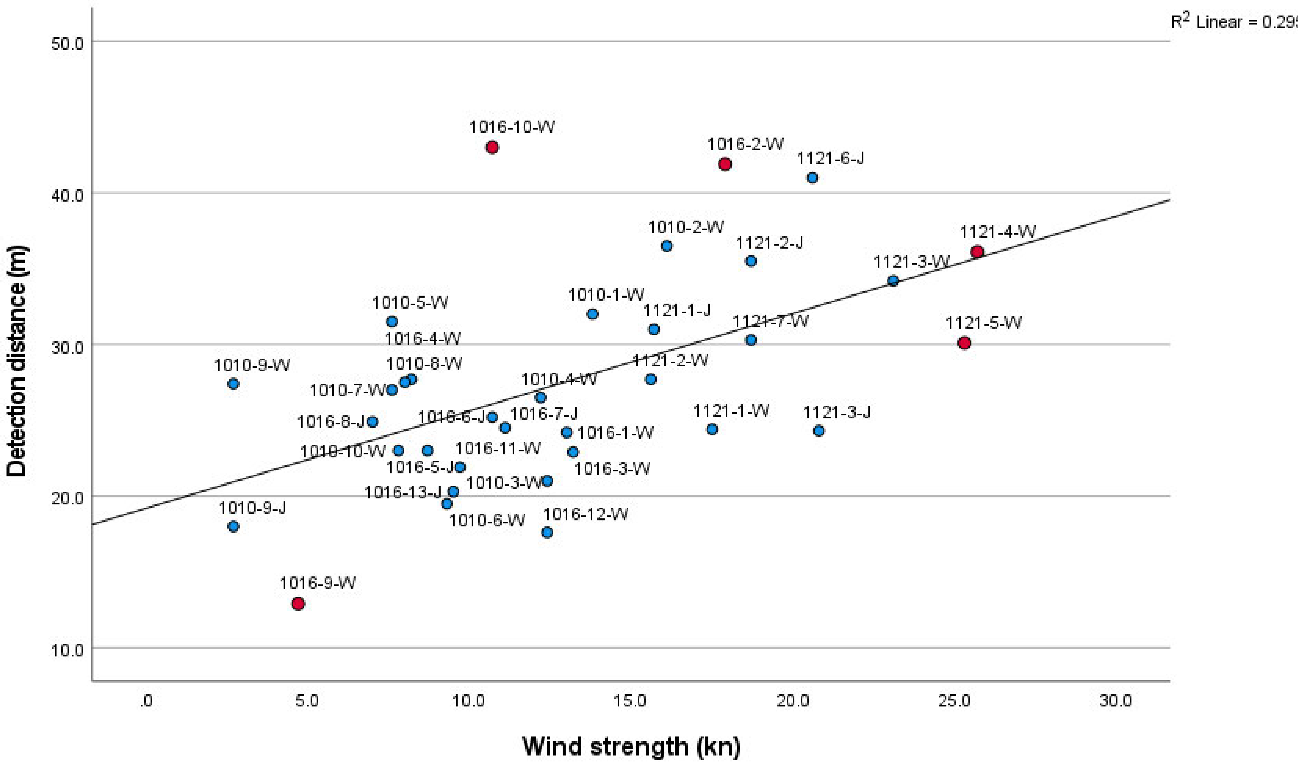

Figure 2.2 Scatter plot representing the simple linear regression of detection distance versus wind strength in the present study. (Note: Red markers identify potential outliers from Standard Residual, Centered Leveraged Value, Cook's Distance and DFBETA tests).

Detection distance may therefore be described as equal to 19.20 + 0.64 (wind strength) m, where wind strength was measured in knots. The detection distance increased by 0.64 m for each knot of wind speed. Wind strength was a significant predictor of detection distance.

In the controlled trials, dog-A and dog-B initially enthusiastically pursued scent emanating from the Japanese quail, where the behavioural change at the initial location of detection was clearly evident, resulting in a staunch point. Progressively, within each subsequent trial on a particular day and on subsequent days, the enthusiasm deteriorated until ultimately no behavioural change was observed, and neither dog pointed the Japanese quail (pers. obs.).

2.5 Discussion

A known metric in determining detection of wild gamebirds by pointing dogs is the detection distance (Cablk 2008), measured as the distance from the initial location where the searching behaviour of the dog changed because of scent detection (Conover 2007; Cablk 2008) and the location of the birds. However, for the uncontrolled trials, and for comparison with the results from the controlled trials where 'known' birds were located, we were unable to do this for the following reasons: The GPS location sampling frequency on the dog was set at 5s intervals, location of the bird that emitted the scent which caused the dog to change behaviour was impossible to establish, and red-winged francolins were observed, on occasions, running ahead of the dogs whilst tracking scent, rendering measurement of the detection distance impossible.

Consequently, to overcome these problems, we selected the index of abundance as a dependent variable to test for the influence of the environmental conditions at our study site (Site 'A' > 200 ha) since it has been used effectively to count francolins in a similar environment (Mentis & Bigalke 1985). Our results showed no significant correlation with any of the four identified environmental factors, despite being regularly reported to the contrary (Wight 1931; Jenkins 1963; Mentis & Bigalke 1985; Gutzwiller 1990; Roberts & Porter 1998; Shivik 2002; Guthery & Mecozzi 2008; Reed 2011; Kokocińska-Kusiak 2021). We offer the following explanation: The relatively low detection rates of red-winged francolin, based on sparse population density (Janssen 2000), suggested that even under ideal scenting conditions, a dog may not detect the presence of a bird (Sission & Stribling 2000) because it did not pass within the detection distance of a bird. Furthermore, since the birds and dogs are both free ranging, the encounter is left to a degree of a chance despite the handler following a predefined and repeated route (Jinn 2020). The probability of encounter is thought to increase as the detection distance is increased. Further research into calculating the searched area based on detection distance could significantly improve the understanding of the abundance of a population of red-winged francolin within a landscape.

As a dog fatigues, its work rate can begin to wane, resulting in its pace reducing, thus covering less ground in the same amount of time (Mentis & Bigalke 1985). This will reduce the index of abundance independently of environmental conditions, further explaining our results, although dogs generally fatigue quicker in warmer conditions (Conover 2007).

To remove the degree of chance introduced by the low population density of red-winged francolins, controlled trials were conducted to measure the detection distance where the presence of a bird was guaranteed. This, although not directly comparable to the index of abundance, was introduced as a relevant dependent variable when correlated with the same four identified environmental conditions as per the uncontrolled trials.

Whilst relative humidity and ambient temperature generally significantly correlate to detection distance (Cablk 2008; Jinn 2020), this was not supported in the present study. The local atmospheric thermodynamic conditions in conjunction with light to strong local atmospheric flow conditions experienced during the study's trials created a highly dynamic environment for the odour plume, possibly explaining this result. There was likely insufficient variation in the relative humidity and ambient temperature, producing non-normally distributed data, for a correlation with a detection distance to be established. Through its influence on atmospheric stability, solar radiation (Pasquill 1961; Magidi 2013) is positively correlated to scent detection by dogs (Roberts & Porter 1998; Shivik 2002), where updrafts cause turbulence resulting in dissipation of odorants. Our results showed a significant positive correlation with detection distance, thus confirming this influence; however, solar radiation was statistically insignificant in the prediction thereof.

In contrast, and consistent with Cablk (2008) and Jinn (2020), we showed that wind strength was positively and significantly correlated with detection distance, where an increase in wind strength resulted in an increase in detection distance, thus contradicting Bossert and Wilson (1963) and confirming our prediction. We were unable to test a negative correlation at high wind speeds as the environmental conditions at the time of the trial were not suitable. The identified potential outliers explained the influence that large scale turbulence, caused by the confounding effects of wind strength, atmospheric stability, and terrain, may have on the odour plume (Conover 2007; Marin et al. 2021), thus enabling a dog to detect an odorant at unpredictable distances from the source. Our results (Figure 2.2) highlighted the imprecision in determining the detection distance as a function of wind speed.

Our analyses of the range of environmental variables identified four factors for correlation tests with detection distance. We concluded that since ambient temperature and relative humidity were not significantly correlated to detection distance, this also holds true for wind chill, heat index, relative pressure, ambient pressure, and dew point, and since solar radiation was significantly positively correlated to detection distance, so too would UV index be. Wind speed was significantly positively correlated to detection distance; thus, we concluded that gust strength and wind direction were also correlated with detection distance.

Although dogs are known to generalise, whereby they respond to unfamiliar although similar odours in the same way they respond to the originally trained odour (Cablk 2008; Moser et al. 2019), we caution against this practice with pointing dogs. Whilst Japanese quail were selected as a surrogate for red-winged francolin for the controlled trials, and both dog-A and dog-B initially pursued the scent with enthusiasm and pointing staunchly, the novelty deteriorated until ultimately both dogs, whilst acknowledging the scent, declined to point the birds. This is presumably since the dogs become desensitised in the absence of the natural reward for detecting wild gamebirds, being the whirr of wings as the quarry escapes, since the quail were restrained in a cage resulting in disappointment for the dog. Future research should consider using constrained wild birds which are familiar to the dogs. It is further recommended that trials with constrained birds are interspersed with unconstrained birds to maintain the dog's motivation.

2.5.1 Conclusions and further research

Our study showed that the olfactory detection by conservation dogs is a complex topic influenced by many environmental factors under different circumstances. Our results show that whilst solar radiation and possibly other environmental factors may have an influence on the detection distance of a gamebird by a pointing dog; only wind strength can predict this distance. We propose the following method as a future research opportunity to address some of the challenges experienced with the uncontrolled and controlled trials: a high sampling frequency GPS tracking devices fitted to both the red-winged francolin and the pointing dogs such that the relative position can be established that has the following advantages: the precise detection distance at the time the dogs' behaviour changes, regardless of the movement of the bird, can be measured, thus deriving influential environmental factors; the probability of detecting a gamebird within the established detection distance can be established, and olfactory fatigue experienced by dogs with surrogate birds will be obviated. These factors will better aid scientists and wildlife managers in the conservation of gamebirds and their habitats.

2.6 Acknowledgements

We thank the farmers, land managers and landowners of the Greater uMngeni Vlei Expansion Area for providing access to their lands, particularly Sonja Krüger (Ezemvelo KZN Wildlife), John Campbell, Jerome Mitchell, Chris Melouney, Alfie Messenger, and Kobus Kruger. We also thank Mark Lansdell for assisting with fieldwork.

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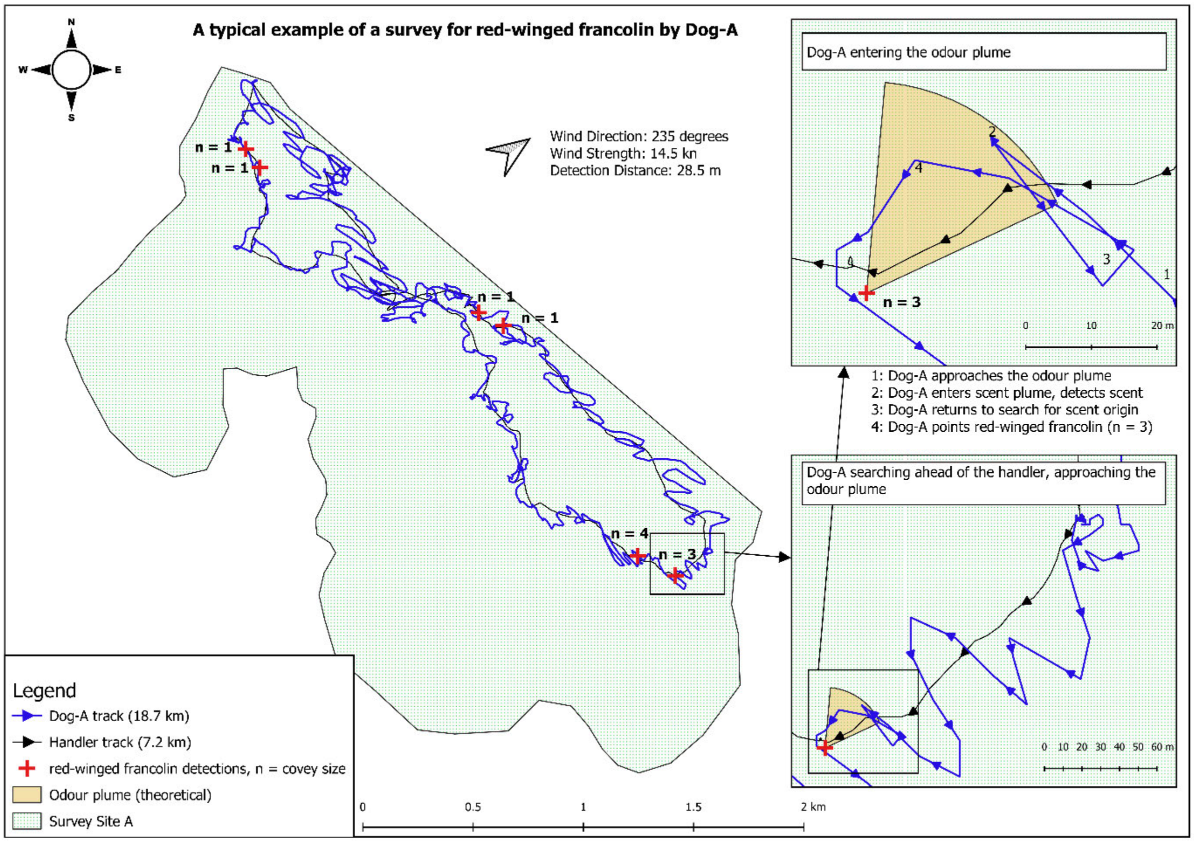
2.8 Supplementary information



Supplementary information Figure S2.1 A typical example of a survey conducted by one pointing dog searching for red-winged francolin in uncontrolled trials in the present study.

CHAPTER 3

The development and application of a method for estimating red-winged francolin abundance with pointing dogs in the Midlands, KwaZulu-Natal, South Africa

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Running header: Development and application of a method for estimating red-winged francolin abundance with pointing dogs

3.1 Abstract

Understanding changes in the abundance of cryptic gamebirds may be useful for land managers when designing or adjusting grassland management regimes to conserve these species and the grassland biome. An abundance of red-winged francolin (*Scleroptila levaillantii*) indicates the presence of their preferred grassland habitat. Pointing dogs (*Canis lupus familiaris*) are often used to locate these and other cryptic gamebirds either for conservation or recreational purposes. Here we aimed to develop a reliable method to count cryptic gamebirds using pointing dogs where the route chosen through a survey site is flexible. Between August 2020 – October 2021, we conducted surveys (n = 21) to determine the presence and abundance of red-winged francolin, a grassland indicator species. These comprised of survey portions (n = 77) on four survey sites in the Greater uMngeni Vlei Expansion Area of the KwaZulu-Natal Midlands, South Africa. We used up to two pointing dogs fitted with global positioning system (GPS) devices to survey, and we recorded the nominal wind speed. These data were used to calculate the detection distance and establish the search area. The redundancy of search, where a dog or possibly two dogs covered their own tracks, enabled us to evaluate the relative proficiency of detecting red-winged francolin. We used this method to establish the abundance and territory of coveys and birds within the sourveld grassland region of the four study sites. We found that two dogs surveying together 'over-searched' (Mean ± SD; 37 ± 13%) of the area compared with a straight-line track area. We further established the territory when searching with one dog to be 5.8 ± 8.2 ha (CV: 141%) compared with 15.5 ± 7.9 ha (CV: 51%) for a two-dog survey demonstrating significantly better precision for the latter. The four study sites' mean birds per covey (3.42 ± 1.44) and covey territory (14.76 ha ± 7.5) were consistent with previous studies indicating the grassland status as good. Our study outlines the foundation for a methodology that citizen scientists and ecologists can adopt to establish the

abundance of red-winged francolin and other cryptic gamebirds with conservation and land management applications.

Keywords: indicator species, ornithological survey, population density, pointing dog; sensory ecology; ornithological methods

3.2 Introduction

Abundance of water, minerals reserves, rich soils and moderate climate in South African grasslands have made it suitable for agriculture and mining (Neke & Du Plessis 2004; SANBI 2014; Jewitt et al. 2015). This has resulted in at least 30% of grasslands being permanently transformed (Mucina et al. 2006). A further 7% has been significantly degraded through agriculture and erosion (Fairbanks et al. 2000). Woody plant encroachment and secondary grasslands have further threatened the natural grasslands (Mucina et al. 2006). Economic growth, resulting in unrelenting anthropogenic effects, will see the accelerated transformation of the grassland ecosystem (Neke & Du Plessis 2004; Mucina et al. 2006; Symes et al. 2017).

Fire is an essential tool available to land managers to manage the health of the grasslands where the exclusion thereof in the KwaZulu-Natal Midlands, South Africa, resulted in the decline of *Themeda triandra* from 70% cover to <10% after 3 years (Tainton & Mentis 1984). Woody-plant encroachment in a pyric-dependent ecosystem is enhanced by excluding fire (Bond et al. 2003; Adie et al. 2009; Archer et al. 2017). Since grasslands are well adapted to defoliation, grazing is essential (Mucina et al. 2006). Domestic and wild herbivores' grazing significantly impacts grass species composition and standing biomass (Palmer & Ainslie 2005; Charles et al. 2017). Management of grazing intensity is crucial, with high intensities negatively impacting grass species composition and proportional cover (Hoare 2003; Rutherford & Powrie 2011; Gusha et al. 2017; Dedekind et al. 2020; Shezi et al. 2021).

Leopold (1933) famously stated "Continuous census is the yardstick of success or failure in conservation" and it follows that corrective actions should be identified through biodiversity monitoring which establishes changes in the grassland ecosystem (Whittaker et al. 2005; SANBI 2013). Inexpensive, reliable, and appropriate indicators should be selected based on the management objectives (SANBI 2013; Siddig et al. 2016; Rowland et al. 2018) such that they respond to the ecological drivers of the land use (SANBI 2013; Griffiths et al. 2016; Siddig et al. 2016; Rowland et al. 2018; Morris & Scott-Shaw 2019).

The presence of a particular bird species in an area is indicative of the presence of its preferred habitat (Harrison et al. 1994; Catarino et al. 2016; Vallecillo et al. 2016). The red-winged francolin (*Scleroptila levaillantii*) is an indicator species of natural sourveld grassland in South Africa (Harrison et al. 1994; Jansen 2001). In these grasslands, grazing intensity and annual burning are negatively correlated with the population density of red-winged francolin (Jansen 2001; Mentis & Bigalke 1973; Mentis & Bigalke 1981a; Mentis & Little 1992).

Conservation dogs (*Canis lupus familiaris*) are used extensively by scientists and conservationists to enhance the capability of the observer to detect wildlife (Novoa et al. 1996; Homan et al. 2001; Arnett 2006; Dahlgren et al. 2010) and may be used in conjunction with line and belt transect methods to estimate abundance of red grouse (*Lagopus lagopus scoticus*) (Jenkins et al. 1963; Thirgood et al. 2000; Amar et al. 2004; Brøseth et al. 2005; Dahlgren et al. 2006) amongst other species (Berner & Gysel 1969; Zwickel 1972; Dahlgren et al. 2006). The dog searches approximately 75 m on either side of a parallel transect line where all birds within this region are assumed to be detected (Dahlgren et al. 2012). However, previous studies showed that pointing dogs detect only 40 to 56 % of known coveys in an area of known size (Kellogg 1982; Sisson 2000; Hardin 2005). Varying environmental conditions are regularly referenced as factors influencing the dogs' ability to detect odorants (Conover 2007; Cablk et al. 2008; Jinn et al. 2020; Gutzwiller 1990; Shivik 2000) and may contribute to low detection efficiency. In some studies, distance sampling in conjunction with the programme DISTANCE (Buckland et al. 2001) have been used. In these studies, the probability of detection and the effective strip width (ESW) were determined using a geographic information system (GIS). The transect line was the global positioning system (GPS) track generated by a pointing dog (with GPS attached), and the perpendicular distance from the transect line was measured as the positive point-to-bird detection distance (Guthery & Mecozzi 2008). The ESW is then used to buffer each side of the dog's path to create a polygon search area, for which a density estimate is calculated. However, several biases exist:

1. The point-to-bird distance may vary between individual dogs as they approach the bird, where individual dogs may move beyond the initial point of detection to approach the bird.
2. Equal detectability on either side of the dog is assumed regardless of wind direction (Guthery & Mecozzi 2008), while it is known dogs can only detect an odour plume upwind of their position (Conover 2007; Cablk et al. 2008).
3. The redundancy of search, where a dog or possibly two dogs cover their own tracks, is common occurrence, unlike human observers (Hardin et al 2005). Redundancy may create an overestimation of search area and corresponding underestimation of abundance and must therefore be corrected (Guthery & Mecozzi 2008).

An index of abundance, developed by Mentis and Bigalke (1985), has been used extensively for establishing abundance of red-winged francolin and grey-winged francolin (*S.*

afra) in the grasslands of the Drakensberg Midlands, KwaZulu-Natal Province as well as in Mpumalanga Province, South Africa, where the francolins abundance indicates the grassland health status (Mentis & Biglake 1981a, b, c, 1985; Mentis & Little 1992; Jansen et al. 2000, 2001). This method, measured as the number of birds found per minute spent searching, where the handler must traverse a similar route through a survey site repeatedly, is also prone to bias. The rate of search of a pointing dog can diminish because of fitness, fatigue, or adverse weather conditions, thereby increasing the duration of the search, negatively impacting the index (Mentis & Bigalke 1985; Gutzwiller 1990).

Our objective was to develop a method of surveying for red-winged francolin with pointing dogs that could be used by surveyors, including citizen scientists, where a predefined transect line need not be strictly followed or accurately repeated. We predicted that the accuracy and precision of the abundance and territory data for red-winged francolin would be improved when two dogs were surveying compared with one dog surveying alone.

3.3 Methods

3.3.1 Study area

We selected four neighbouring study sites (‘A’ = 364 ha, ‘B’ = 226 ha, ‘C’ = 55 ha, ‘D’ = 131 ha) for the surveys encompassed within the Greater uMngeni Vlei Expansion Area (23 063 ha) in the Impendle district of the KwaZulu-Natal Midlands, South Africa (29°30’S 29°50’E, Figure 3.1). Permission to perform this research on Study Site ‘A’, which is a portion of the uMngeni Vlei Nature Reserve, was granted by Ezemvelo KZN Wildlife under Project W/2156/01.

The study area forms part of the Drakensberg Foothill Moist Grassland vegetation type (Mucina et al. 2006), dominated by short bunch grasses, including *Themeda triandra* and

Tristaychya leucothri. This was specifically selected because red-winged francolin can be considered an indicator species of this habitat (Harrison et al. 1994). The area has a mean annual rainfall of 890 mm, a mean annual temperature of 14.6°C and 26 frost days per year (Mucina et al. 2006). These provide suitable conditions for the present primary land use of stock farming with beef cattle (pers. obs.). Generally, rotational grazing and a burning programme are used and closely managed. This management removes unpalatable grass species and defoliated moribund grass conditions. The frequency of burning is varied and typically according to the rate of litter accumulation (uMngeni Vlei Nature Reserve; Stuart-Hill & Mentis 1982; Chamane et al. 2017; Chamane 2018; Pooley 2018; Porensky et al. 2021).

The altitude of the study sites ranged from 1783 to 1901 m.a.s.l. The geology comprises of well-drained soils to a depth of 800 mm and clay content from 15 - 55 %, formed on sedimentary mudstone and sandstone of the Tarkastad subgroup and Molteno Formation, and Balmoral, Shortlands and Vimy soil forms from dolerites of the Jurassic age (Mucina et al. 2006).

Historically, a wide assemblage of ungulates occurred in the region until the late nineteenth century, by which time they were exploited, often to local extinction (Mentis & Huntley 1982). Presently, sparse populations of grey rhebuck (*Pelea capreolus*), common reedbuck (*Redunca arundinum*), mountain reedbuck (*R. fulvorufula*), oribi (*Ourebia ourebi*) and Cape eland (*Taurotragus oryx*) have been observed (various pers. comm.). The study area has avifaunal significance, resulting in the subsequent classification of a portion (uMngeni Vlei Nature Reserve) including Study Site 'A' as an Important Bird and Biodiversity Area (IBA) (Birdlife International 2021) and RAMSAR site (UNEP-WCMC 2021). The grasslands are inhabited by red-winged francolin (pers. obs.), but the density varies where plant food and diversity are maximised, and the cover is optimised (Mentis & Bigalke 1973, 1981a; Mentis & Little 1992; Jansen et al. 2000).

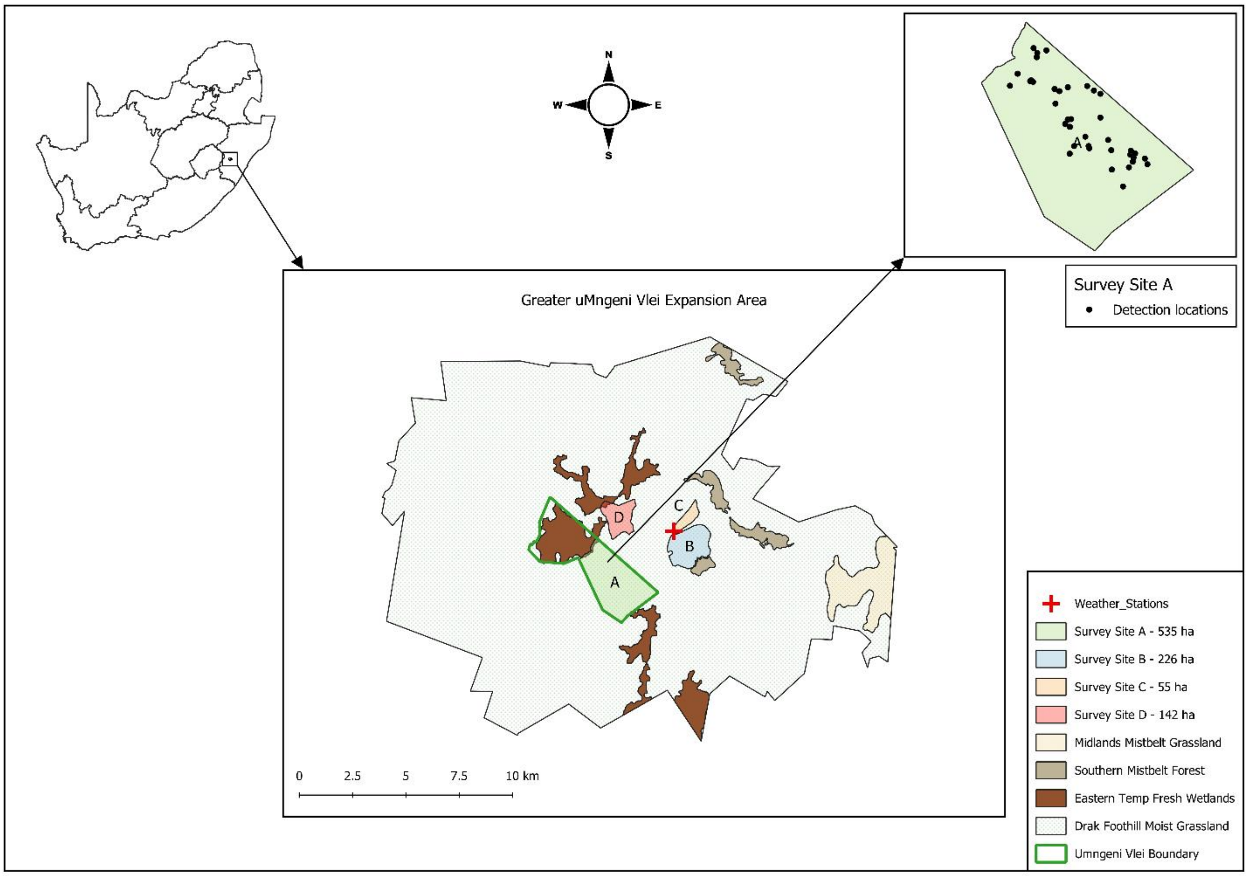

Figure 3.1 Location of the four study sites (A, B, C, D) within the Greater uMngeni Vlei Expansion Area, Impendle district, KwaZulu-Natal Province, South Africa. The red-winged francolin detection locations found in the present study in site 'A' are indicated.

3.3.2 Surveys

To test the relationship between search effort and the precision of a metric of the abundance of red-winged francolin, we analysed data collected from 77 survey portions, comprising 21 surveys conducted under surveying conditions at the four study sites (Figure 3.1) between August 2020 and October 2021.

We chose the non-breeding season of red-winged francolin for surveys. Nesting birds can reduce their metabolic, respiratory and heart rates by up to 50% when alarmed by a predator (Gabrielsen et al. 1985), thereby reducing their resulting odorants making detection by an olfactory predator more difficult (Conover 2007).

We used two physically fit, trained, experienced, and well-disciplined pointing dogs to perform the tests. Dog-A was a six-year-old German Shorthaired Pointer (GSP) bitch, NFTC Championship qualified (KUSA Registration Name: Knapskoot Whiskey, No.: ZA009271B15), and Dog-B was a two-year-old English Setter male, NFTC Championship qualified (NFTA Name: Gorge View Jack, Id: 4487).

The handler's chosen route through the survey site was identified to present the dogs the opportunity to search suitable habitat and varied between surveys. The handler either cast the dogs off individually or in a brace to search for birds. Each dog had a global positioning system (GPS) tracker (Garmin TT15 Dog Device; https://www.garmin.com/en-ZA/p/160889#overview) attached with a high sensitivity GPS/GLONASS receiver which relayed the position every 5 s to a handheld receiver unit (Garmin Alpha 100; https://www.garmin.com/en-US/p/107225/pn/010-01041-20) with the handler. On locating a wild bird, the dog pointed or 'froze', at which point the handler would proceed ahead of the dog and flush the bird/s. The bird's geographical location was recorded on a mobile phone app Epicollect5 (https://five.epicollect.net/), which was configured to record the location, the dog's name, bird species detected, the number of birds in the covey, and a photograph of the grassland. Care was taken to note the location where the birds landed such that if they were relocated within the same survey, they could be subtracted from the total number of birds encountered. Nominal wind speed and direction were continually recorded on the automated 3G cellular weather station (Ecowitt Model WH6006;

https://osswww.ecowitt.net/uploads/20200923/ed76b3643d4040a78abb6c67ba022477.pdf), located within 4 km from the survey locations because wind speed is known to influence the distance from which a pointing dog can detect a target (Chapter 2).

3.3.3 Analyses

We retrieved the GPS tracks for the dogs and handler from the devices using Garmin BaseCamp (Version 4.7.4, Olathe, Kansas, USA). Only dog track distance whilst surveying was considered for the calculation of search area, such that wasted effort (e.g., when dogs may have been walking on-lead with the handler) did not negatively affect the effort applied. We consolidated the dog track and bird location data in QGIS (version 3.14.16-Pi; QGIS.org, 2021).

We derived search area (A) as a function of detection distance (DD) and track distance (D_T) as follows (Supplementary Appendix S3.1):

$$A \propto \int_S^F DD(Vw; t_d) dD_T \qquad (1)$$

Where S = track distance at the time of day when the survey portion starts and F = track distance at the time of day when the survey portion ends.

For simplicity, we assumed constant wind speed during each survey portion and therefore recorded the average of wind speed ($\overline{V}w$) (and direction) on the automated 3G cellular weather station for the duration of each survey portion (mean: 0 h 42 m 41 s; SD: 00 h 34 m 13 s). Detection distance (Chapter 2) is thus calculated by the following expression:

$$DD = 0.64\,\overline{V}w + 19.2$$

The expression at (1) is thus reduced to:

$$A \propto DD \times D_T$$

The straight-line track area (A_{SLT}) (ha) is the theoretical area searched by a dog had the dog run a straight line for the duration of the survey portion, and calculated as the product of straight-line track distance (D_{SLT}) (km) and detection distance (DD) (m) for each survey portion:

$$A_{SLT} = \frac{D_{SLT} \times DD}{10}$$

Since dogs can cover their own tracks, or tracks of another dog, the search area may be normalised for this redundancy. To create the actual area searched by one-dog ($A1dog$) we buffered the dog track by the detection distance using QGIS 3.14 (version 3.14.16-Pi; QGIS.org, 2021).

We determined the percentage search area redundancy (R_1) of a single dog's search area as the percentage difference between the straight-line track area (A_{SLT}) and the one-dog search area ($A1dog$) as per the expression:

$$R_1 = \frac{(A_{SLT} - A1dog)}{(A_{SLT})} \times 100\%$$

For two dogs, we described the between-dog redundancy (R_2) as follows using set theory notation:

$$A2dog_I = (Dog_A A1dog \cap Dog_B A1dog)$$

Where $A2dog_I$ is the intersection portion of the two-dog search area where they overlap, measured in ha, and:

$$A2dog = (Dog_A A1dog \cup Dog_B A1dog)$$

$A2dog$ is the union of the two-dog searched areas, measured in ha.

It follows that between-dog redundancy (R_2) was described as follows:

$$R_2 = \frac{A2dog_I}{A2dog} \times 100\%$$

Compounded redundancy (R_3) is described as the redundancy in the area between the union of the dogs' search areas and the sum of the straight-line track area (A_{SLT}) for two dogs according to the following expression:

$$R_3 = \frac{(Dog_A A_{SLT} + Dog_B A_{SLT}) - A2dog}{(Dog_A A_{SLT} + Dog_B A_{SLT})} \times 100\%$$

We described the area where the abundance of red-winged francolin was determined as the area within the survey site representing their suitable habitat (Harrison et al. 1994). Woodland and aquatic habitat regions were demarcated using QGIS (version 3.14.16-Pi; QGIS.org, 2021) and subtracted from the extent of the survey site area resulting in a clearly described shapefile that represented the area of interest, and we described this as the nett survey site (SSn).

Since dogs cannot detect an odour plume downwind of their position (Conover 2007, Jones 1983, Bossert & Wilson 1963, Karp 2020, Marin et al. 2021), we shifted the search area ($A1dog$) by a vector equal to half the detection distance in magnitude, and in a direction equal to the nominal wind direction to describe the region actually searched ($A1dog_s$).

We established the covey and bird density as a function of both one-dog search area ($A1dog$) and two-dog search area ($A2dog$) of a population of red-winged francolin, and when recorded within the nett survey site is described with suffix SSn (i.e. Coveys/$A1dog_{SSn}$ and Coveys/$A2dog_{SSn}$).

We reported all redundancies using descriptive statistics. Abundance metrics were also reported with descriptive statistics. We used the IBM SPSS Statistics (Version 27) statistical package. All means are presented with standard deviations (SD).

3.4 Results

For our surveys, the pointing dogs traversed a total distance of 644 km in a duration of 54 h 46 min, constituting 21 surveys. A total of 68 coveys were detected, excluding coveys flushed for a second time, comprising 221 red-winged francolins in total. No other gamebird species were detected during these surveys.

The mean (± SD) nominal wind speed was 7.5 ± 5.7 knots for the surveys resulting in a mean detection distance of 24.0 ± 3.7. The mean survey portion track length was 20.45 ± 15.0 km for the 77 survey portions resulting in a total of 899 ha being surveyed ($A2dog_{SSn}$).

The redundancy as defined earlier is presented in Table 3.1. The mean R_1 redundancy explained that 23 ± 8 % of the area surveyed by a single dog was 'over-searched'. Furthermore, R_3 redundancy explained that when two dogs were running together, 37 ± 13 % of the area was over-searched (Table 3.1). A typical example of a survey illustrating redundancy is shown in Supplementary information Figure S3.1.

Table 3.1 Descriptive statistics for redundancy during surveys performed between 2020 – 2021 at the Greater uMngeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa.

Redundancy	n	Mean (%)	SD (%)	CV (%)	95% CI (%)	SE (%)
R_1	77	23	8	35	21.4 - 24.9	0.89
R_2	21	20	10	50	15.6 - 24.4	2.10
R_3	21	37	13	35	31.8 - 43.2	2.70

n = number of observations; SD = standard deviation; CV = coefficient of variation; 95%CI = 95% confidence interval; SE = standard error

We compared the density of coveys and birds, respectively, detected with one dog searching versus two dogs searching (Table 3.2). Differences in the mean number of coveys and the mean number of birds detected, 75% and 57% respectively, were significantly greater when two dogs searched. The coefficient of variation (CV) for two dogs searching versus one dog was significantly lower when detecting both coveys (40%) and birds (36%) (Table 3.2).

The nett survey sites for the four study sites were established as per Table 3.3. A typical example of a survey illustrating the nett survey site together with irrelevant habitat (woodland and aquatic) is shown in Supplementary information Figure S3.2. No red-winged francolins were located in woodland or aquatic habitats. The reduction in the extent of the survey site because of irrelevant habitat varied per location (Table 3.3). The nett survey site established the mean density of coveys, mean density of birds, mean territory per covey, and mean territory per bird (Table 3.4). We found sites C and D to have similar covey densities (0.14 $\pm$ 0.05 coveys/ha and 0.12 $\pm$ 0.06 coveys/ha respectively), however, the bird density of site C (0.43 $\pm$ 0.18 coveys/ha) was approximately 48% greater than site D (0.29 $\pm$ 0.17 coveys/ha) whereas sites A (0.24 $\pm$ 0.11 coveys/ha) and B (0.21 $\pm$ 0.14 coveys/ha) had similar covey and bird densities. The average covey densities of sites C and D were approximately 100% greater than sites A and B and bird densities were 60% greater when averaged for these sites. The mean covey size for all surveys was established (Table 3.5). The mean covey size ranged from 2.8 $\pm$ 0.4 francolin to 3.88 $\pm$ 1.5 francolin among the study sites. We found the territory for red-winged francolin when calculated with one-dog search area to be 5.8 ha (SD: 8.2; 95% CI: 3.9 – 7.6; CV: 141%) and for two-dog search area to be 15.5 ha (SD: 7.9; 95% CI: 11.9 – 19.1; CV: 51%) (Table 3.2),

Table 3.2 Covey and bird density and territory as a function of one-dog and two-dog search areas for red-winged francolin (*Scleroptila levaillantii*) between 2020 – 2021 at the Greater uMngeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa.

Density	n	Mean	SD	CV (%)	95% CI	SE
Coveys/A1dog	77	0.048	0.064	133	0.03-0.06	0.01
Coveys/A2dog	21	0.084	0.045	54	0.06-0.1	0.01
A1dog/Covey	77	5.8	8.2	141	3.9-7.6	0.93
A2dog/Covey	21	15.5	7.9	51	11.9-19.1	1.7
Birds/A1dog	77	0.17	0.26	153	0.11-.23	0.03
Birds/A2dog	21	0.267	0.147	55	0.20-0.33	0.03
A1dog/Bird	77	2.11	3.43	163	1.3-2.9	0.39
A2dog/Bird	21	5.27	3.5	66	3.7-6.9	0.77

n = number of observations; SD = standard deviation; CV = coefficient of variation; 95%CI = 95% confidence interval; SE = standard error

Table 3.3 Four selected survey sites indicated a reduction in extent because of irrelevant habitat type for surveys for red-winged francolin between 2020 – 2021 in the Greater uMngeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa.

Survey site	Extent (ha)	SSn (ha)	Irrelevant habitat: woodland & aquatic (ha)	Reduction (%)	No. birds detected in irrelevant habitat
A	535	471	64	12	0
B	226	202	24	11	0
C	55	55	0	0	0
D	142	136	6	4	0

SSn = Nett survey site area

Table 3.4 Abundance and territory metrics for red-winged francolin (*Scleroptila levaillantii*) at four nett survey sites between 2020 – 2021 at the Greater uMngeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa.

Nett survey Site	n	Coveys/A2dog$_{SSn}$		Birds/A2dog$_{SSn}$		A2dog$_{SSn}$/Covey		A2dog$_{SSn}$/Bird	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
A	9	0.07	0.03	0.24	0.11	16.61	7.15	5.20	2.76
B	5	0.06	0.02	0.21	0.14	20.11	7.18	7.24	5.13
C	5	0.14	0.05	0.43	0.18	8.08	3.06	2.85	1.66
D	2	0.12	0.06	0.29	0.17	9.77	5.09	4.20	2.46
ALL	21	0.09	0.05	0.28	0.16	14.76	7.50	5.03	3.41

n = number of observations; SD = standard deviation; A2dog$_{SSn}$ = the union of dog search areas within the nett survey site (ha)

Table 3.5 Covey size recorded for red-winged francolin (*Scleroptila levaillantii*) at four nett survey sites between 2020 – 2021 at the Greater uMngeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa.

Nett survey site	No. coveys detected	No. birds observed	Mean	SD
A	31	113	3.88	1.5
B	11	35	3.22	1.3
C	16	49	3.06	1.5
D	10	24	2.8	0.4
ALL	68	221	3.42	1.44

SD = standard deviation

3.5 Discussion

In this study, we derived an expression for area of search as a function of detection distance and track distance (Supplementary Appendix S3.1), where detection distance is derived as a function of wind speed (Chapter 2) for a particular survey portion. For simplicity, wind speed was averaged for the duration of the survey portion, however, the surveyor is alerted to the potential error introduced to detection distance when calculating the nominal wind speed and direction in this way resulting from variability in atmospheric flow conditions. This can be overcome by fragmenting the survey portion into sub-portions for which the conditions are stable.

In the present study, we were able to show that a single pointing dog 'over-searches' 23 ± 8% of the area generated, approximately 23 - 40% less than observed by Guthery and Mecozzi (2008). In addition, two dogs working together 'over-searched' 37 ± 13 %, further reducing the unlikely event where a pointer dog fails to detect a bird within the detection distance.

In our study, the mean territory and mean covey size of red-winged francolin in the four nett survey sites were consistent with the home range (7.6 – 15.4 ha) and mean covey size (2.96 – 3.77) described in previous studies (Mentis & Bigalke 1980; Jansen et al. 2000), confirming the validity of a flexibly survey route. We found the territory for red-winged francolin when calculated with one-dog search area to be 5.8 ± 8.2 ha and for the two-dog search area to be 15.5 ± 7.9 ha. Therefore, the two-dog search area data showed improved accuracy and precision compared with the one-dog search area and previously known information, confirming our prediction.

The reduction in the extent of the survey site because of irrelevant habitat varied per location. In this study, the handler could navigate these habitats with relative ease, although the dogs did enter them at times. No red-winged francolins were detected in these irrelevant habitats, concurring that they are an indicator species of grassland habitat (Harrison et al. 1994). However, it is conceivable that they may enter these habitats temporarily to drink or escape predation.

Previous studies have shown that pointing dogs detected only 40 to 56 % of known coveys in an area of known size (Kellogg 1982; Sisson 2000; Hardin 2005); however, these studies do not consider the actual region searched by the dog. Distance sampling theory states that the probability of detecting a target animal diminishes as the perpendicular distance from the transect increases but assumes that all target species on the transect line are detected with certainty (i.e., probability of detection on the transect line = 1) (Buckland et al. 2001). Here we demonstrate that the perpendicular distance from the transect line to the target is such that the probability of detecting a target at that distance was 1 when wind speed is known (Chapter 2). It follows that the probability of a dog detecting a bird within the search area also was 1. Therefore, birds not detected within a defined area are more likely because the dog does not pass within the detection distance of the bird.

The methods presented in the present study address some of the known biases mentioned earlier. Offsetting the search area upwind of the dog addressed equal odour detectability on either side of the dog. The calculation of detection distance, where the probability of detecting a bird at this distance = 1, addresses the biases introduced by varying scenting conditions resulting from varying environmental conditions (Gutzwiller 1990; Szuba 1982; Cablk 2008; Jinn 2020). Establishing an area of search from the detection distance further addresses other know biases. Since this area too has a probability of detection = 1, the situation where known coveys in an area of known size remain undetected (Kellogg 1982; Sisson 2000; Hardin 2005) is no longer troublesome. Furthermore, the influence of varying physical aptitude or fatigue of the dog (Gutzwiller 1990; Mentis & Bigalke 1985) is mitigated since the area of search is a function of detection distance normalised for redundancy and independent of time spent searching.

3.5.1 Conclusions

Our study showed that reliable results for the abundance of red-winged francolin could be derived from meandering tracks generated by two pointing dogs, where the handler followed a flexible route through the survey area, whilst surveying for this cryptic species. This method may well suit other cryptic gamebirds, including grey-winged francolin. It is of particular significance that this method is cognisant of the environmental conditions that are well documented to affect a pointing dog's proficiency in detecting a gamebird. We recommend the method of surveying presented in this study to establish the abundance of red-winged francolin or other cryptic gamebirds in grasslands. Furthermore, citizen scientists can use the techniques to assist land managers, conservationists, and ecologists in establishing the abundance of red-winged francolin and contributing to burning and grazing regime management to enhance conservation efforts for the species. Future research should consider the influence of > 2 dogs in the survey team.

3.6 Acknowledgements

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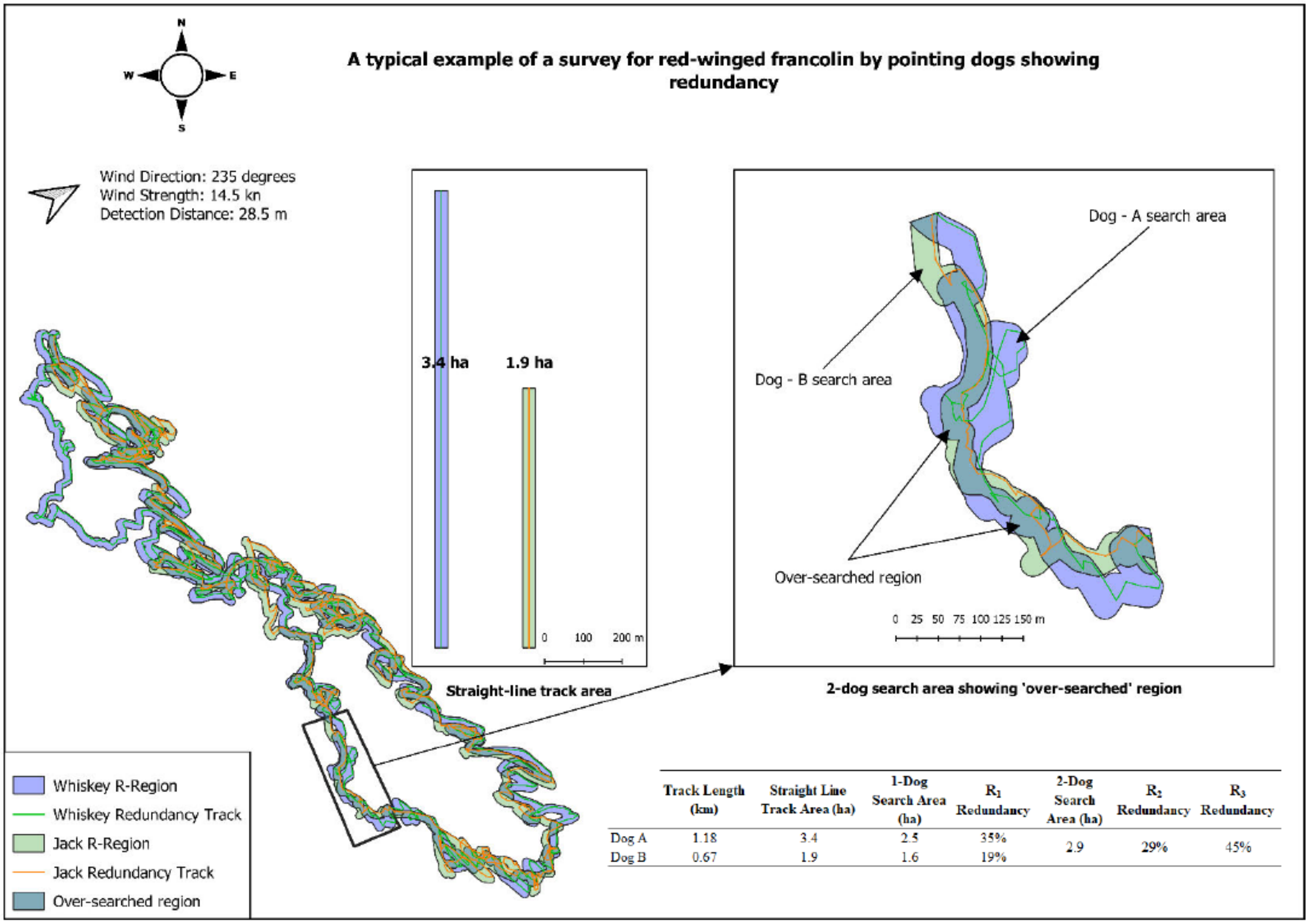
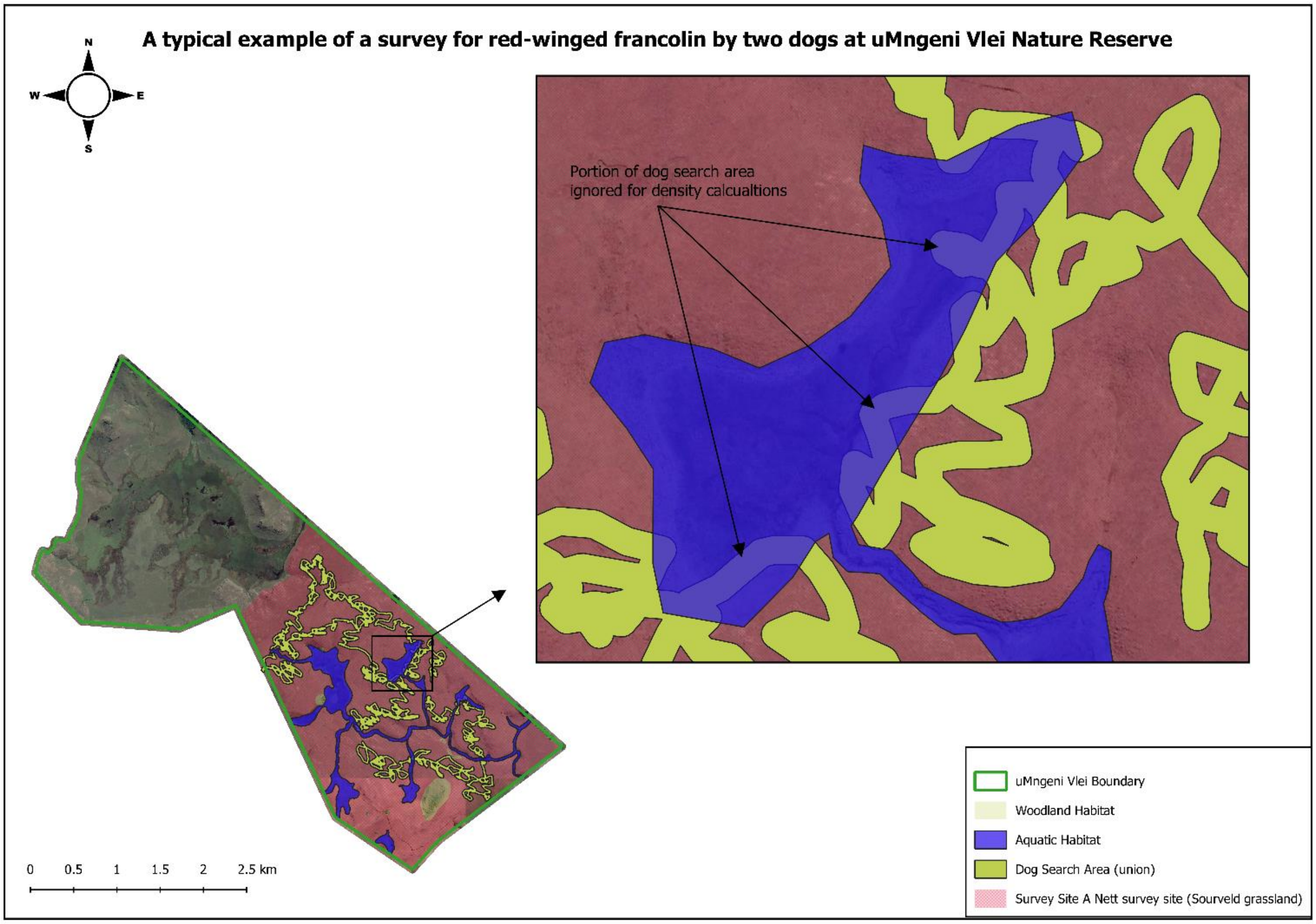
3.8 Supplementary information



	Track Length (km)	Straight Line Track Area (ha)	1-Dog Search Area (ha)	R_1 Redundancy	2-Dog Search Area (ha)	R_2 Redundancy	R_3 Redundancy
Dog A	1.18	3.4	2.5	35%	2.9	29%	45%
Dog B	0.67	1.9	1.6	19%			

Supplementary Figure S3.1 A typical example of a survey illustrating redundancy with one and two dogs surveying for red-winged francolin in the present study.



Supplementary Figure S3.2 A typical example of a survey for red-winged francolin in the present study illustrates the nett survey site with excluded woodland and aquatic habitat. Inset shows the search area excluded from the density calculation.

Supplementary Appendix S3.1 Derivation of function for area of search.

We derive search area (A) as a function of detection distance (DD) and track distance (D_T) as follows:

Since dog track distance (D_T) varies with time of day (t_d),

$$D_T = f(t_d)$$

And wind speed (Vw) varies with time of day (t_d),

$$Vw = f(t_d)$$

And where detection distance is derived from nominal wind speed according to this function:

$$DD = 0.64\,\overline{V}w + 19.2$$

DD = detection distance; $\overline{V}w$ = nominal wind speed for each survey portion

So, detection distance is a function of wind speed:

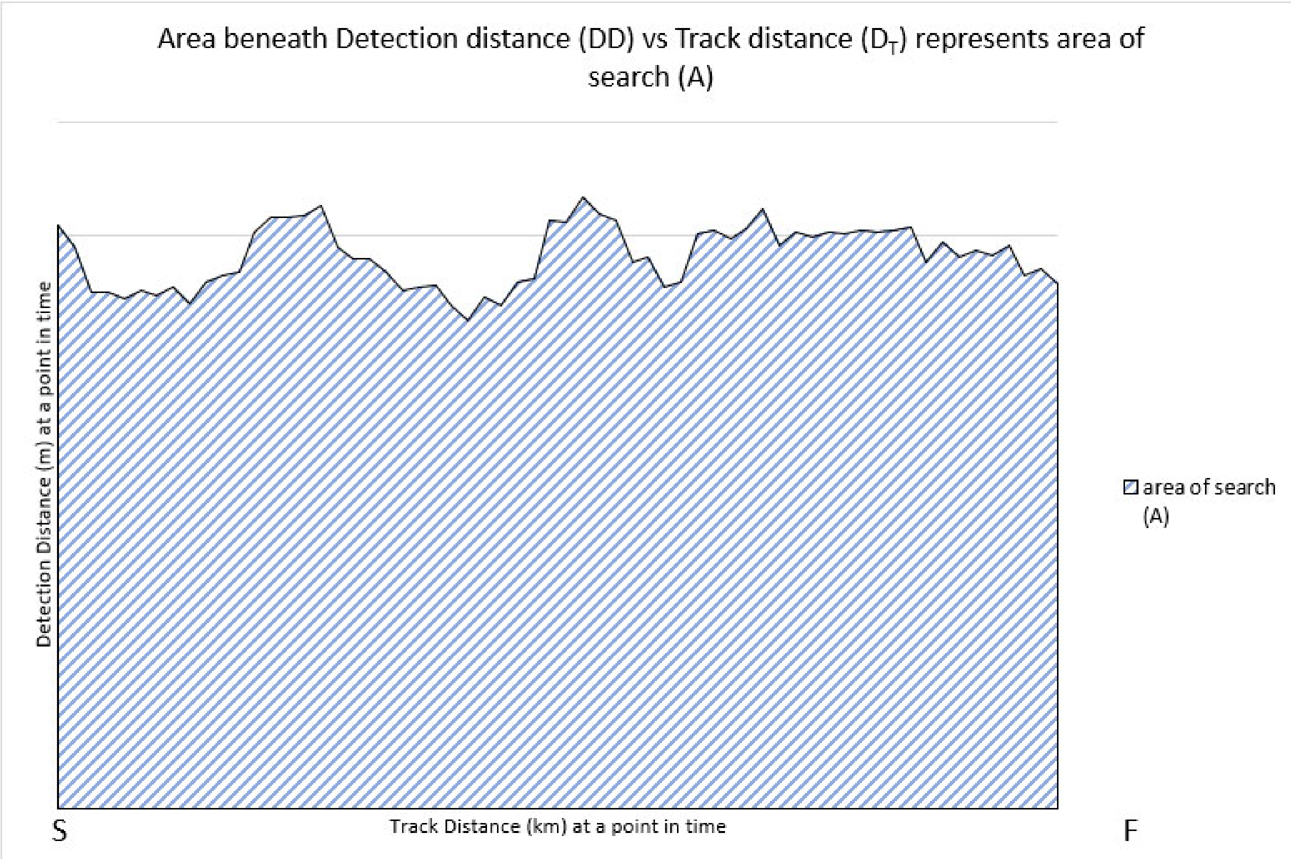
$$DD = f(Vw)$$

And therefore,

$$DD = f(t_d)$$

Since $area = width \times length$, Search area (A) can be expressed as a function of detection distance (DD) and track distance (D_T),

$$A = f(DD, D_T)$$



Supplementary Figure S3.3 Illustration of Detection distance (DD) vs Track distance (DT) curve where the area below the curve represents the area of search (A).

As the dog is running its track, the wind speed may be changing, therefore the detection distance may be changing. So, the area calculated is the sum of the product of every increment in track distance and the corresponding detection distance at that point in time for the whole survey portion. Therefore, search area (A) is the area under the detection distance ($DD(t_d)$) vs track distance ($D_T(t_d)$) curve. This can be described with an integral function.

We defined the function for search area as follows:

$$A \propto \int_S^F DD(Vw;\ t_d) dD_T$$

Where S = track distance at the time of day when the survey portion starts, F = track distance at the time of day when the survey portion ends.

For simplicity, we assumed constant wind speed during each survey portion thus reducing the above integral to:

$$A \propto D_T \times DD$$

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Background

The abundant resources and moderate climate in South African grasslands have rendered it highly exposed to the anthropogenic effects of agriculture, mining and economic growth resulting in extensive permanent transformation and degradation (Fairbanks et al. 2000; Neke & Du Plessis 2004; Mucina et al. 2006; SANBI 2014; Jewitt et al. 2015, Symes et al. 2017). The ensuing deleterious effects of woody plant encroachment and erosion in mesic pyric grasslands are mitigated through judicious application of a considered burning (Bond et al. 2003; Pausas & Keeley 2019) and grazing regime (Palmer & Ainslie 2005; Shezi et al. 2021). These changes in the grassland ecosystem, identified through biodiversity monitoring, may be supported by the identification of inexpensive, reliable, and appropriate indicators selected based on management objectives (Whittaker et al. 2005; SANBI 2013; Rowland et al. 2018; Morris & Scott-Shaw 2019). One such indicator species for natural sourveld grassland condition in South Africa is the red-winged francolin (*Scleroptila levaillantii*) (Harrison et al. 1994; Jansen 2001). This is because grazing intensity and annual burning are negatively correlated with their population density (Mentis & Bigalke 1973; Mentis & Bigalke 1981; Mentis & Little 1992; Jansen et al. 1999). The contribution made by pointing dogs (*Canis lupus familiaris*) to aid ecologists in detecting or locating these and other cryptic gamebirds has been well documented (Jenkins et al. 1963; Mentis 1985; Jansen 2000; Thirgood et al. 2000; Amar et al. 2004; Broseth et al. 2005; Dahlgren et al. 2006). However, the rigorous survey methodologies demanded by present protocols mean that surveying is inevitably limited to ecologists intentionally surveying a site for biodiversity monitoring purposes alone. The time and dedication required to train both the handler and dog to perform these surveys results in a constrained resource (Conover 2007) to perform biodiversity monitoring in this way. Citizen scientists with consumptive or non-consumptive intentions provide an underutilised resource that may be deployed in a more flexible but equally rigorous survey methodology.

4.2 Research findings

In the present study, a variation to the existing distance sampling technique was proposed, where the dog global positioning system (GPS) track is the transect line (Chapters 2 and 3). The aim was to develop a reliable method to count cryptic gamebirds using pointing dogs where the route chosen through a survey site was flexible. The study investigated the effect of varying environmental conditions on the detection distance from which a pointing dog could confidently and consistently detect a bird and allow calculating a detection distance based on influential environmental variables (Chapters 2 and 3).

The study region comprised up to four study sites in the Drakensberg Foothill Moist Grassland vegetation type (Mucina et al. 2006) in the Greater uMngeni Vlei Expansion Area, KwaZulu-Natal Midlands, South Africa, including one site within the uMngeni Vlei Nature Reserve (Chapters 1-3).

Using one or two pointing dogs, each fitted with GPS devices, uncontrolled trials were conducted to establish environmental conditions that affect detection rates of red-winged francolin in their natural environment in the southern African non-breeding season (March – October 2021) (Chapter 2). In addition, controlled trials using Japanese quail (*Coturnix japonica*) as surrogates for red-winged francolin to establish both detection distance and environmental conditions affecting their detectability were conducted (Chapter 3). A total of 21 surveys in the four sites with the study region (August 2020 – October 2021) were conducted to determine the presence and abundance of red-winged francolin. The handlers chosen route through the survey site was identified to provide opportunities and enable the pointer dogs to search suitable habitats, and these varied between surveys (Chapters 2 and 3). Recorded dog GPS tracks and nominal wind speed were used to calculate the detection distance and establish an expression to describe area of search as a function of detection distance and track distance (Chapters 2 and 3). The redundancy of search, where a single dog or possibly two dogs cover their own tracks, enabled evaluation of their relative proficiency of detecting red-winged francolin. This method was used to establish red-winged francolin's population density and territories in the study sites (Chapter 3).

The results showed that although atmospheric pressure, ambient temperature and relative humidity are regularly reported to affect olfaction in conservation dogs (Cablk 2008; Jinn 2020), only nominal wind speed and solar radiation were positively correlated with detection distance (Chapter 2). Of these, only the influence of nominal wind speed was statistically significant. An increase of one-knot wind strength resulted in an increase in detection distance by 0.64 m (Chapter 2).

This established relationship between detection distance and nominal wind speed is significant for two reasons (Chapter 2). Firstly, it enabled an area of search to be derived, considerate of environmental conditions. Secondly, the probability of detection within that search area = 1 where previous studies have shown that pointing dogs only detect 40 – 56% of known coveys in an area of known size (Kellogg 1982; Sisson 2000; Hardin 2005, Chapter 2). Furthermore, the accuracy and precision when surveying with two dogs were significantly better than when surveying with one dog (Chapter 2). The mean birds per covey and mean covey territory for our four sites was consistent with previous studies (Mentis & Bigalke 1981; Jansen et al. 2000), validating the use of the flexible survey route (Chapters 2 and 3).

The methods derived through the application of modern technology (i.e. GPS and geographic information systems) in this study (Chapters 2 and 3) addressed many of the biases that have negatively affected the use of pointing dogs in gamebird research. The calculation of detection distance, where the probability of detecting a bird at this distance = 1, addresses the biases introduced by varying scenting conditions resulting from varying environmental conditions (Gutzwiller 1990; Szuba 1982; Cablk 2008; Jinn 2020).

Establishing an area of search from the detection distance further addressed other known biases. Since this area also has a probability of detection = 1, the situation where known coveys in an area of known size remain undetected (Kellogg 1982; Sisson 2000; Hardin 2005) is no longer troublesome. Furthermore, the influence of varying physical aptitude of the dog (Gutzwiller 1990; Mentis & Bigalke 1985; Shivik 2000; Cablk and Harmon 2013) is mitigated since the area of search is a function of the detection distance, normalised for redundancy and independent of time spent searching.

However, the broad application of this method should be approached with caution. The detection distance derived in this study was done under environmental conditions during the surveys at the present study sites. The influence of environmental conditions outside of those tested here is unknown. Furthermore, and consistent with other studies (Mentis & Bigalke 1985; Gutzwiller 1990), this study was based only on dog-A and dog-B. The uncertainty introduced by using different individual dogs is unknown.

In conclusion, the methods used in the present study produced reliable results for the abundance of red-winged francolin, which were derived from meandering tracks generated by two pointing dogs, where the handler followed a flexible route through the survey area whilst surveying for this cryptic species. This method may well suit other cryptic gamebirds, including grey-winged francolin *S. afra* and buttonquails (Turnicidae). Consequently, the method of surveying presented in this study to establish the abundance of red-winged francolin or other cryptic gamebirds in grasslands is recommended. Furthermore, citizen scientists can use the techniques to assist land managers, conservationists, and ecologists in establishing the abundance of red-winged francolin and other cryptic gamebirds, contributing to burning and grazing regime management to enhance conservation efforts for the species.

4.3 Recommendations for future research

Since the present study was conducted under environmental conditions typical of the study site, the application of these techniques is also limited to comparable sites with comparable environmental conditions. Further research should consider performing the controlled detection distance trial under relevant environmental conditions which may, for example, include snow.

This trial was performed using two dogs and demonstrated that surveying with two dogs increased the precision and accuracy of determining the abundance of red-winged francolin than surveying with a single dog. An increase in the number of surveying dogs is significantly positively correlated with redundancy (Guthery and Mecozzi 2008) and is likely correlated with the accuracy and precision of determining the abundance of red-winged francolin. Further research on the topic may confirm this hypothesis.

To perform the controlled trials, caged Japanese quails (in significant numbers to represent the biomass of a covey of red-winged francolin) were used as surrogates for red-winged francolins since dogs can generalise (Cablk 2008; Moser et al. 2019; Chapter 2). Although this was adequate for this study, we found the dogs experienced olfactory fatigue resulting in apathy to detect the Japanese quail. We propose future research to be performed using free-ranging wild birds of the same species being surveyed for, fitted with high recording rate frequency GPS tags, for uncontrolled trials. The relative position of the bird and dog under known environmental conditions may then be used to establish accurate detection distance.

Since the red-winged francolin is an indicator of natural sourveld, and their abundance is impacted by burning and grazing intensity, further research may consider using abundance (and possibly covey size) as a surrogate for a rangeland biodiversity assessment. This would enable citizen scientists to contribute by alleviating the constraint that exists in performing rangeland biodiversity assessments; a requirement that exists for all grassland nature reserves protected under the Biodiversity Stewardship Programme.

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