The prevalence and implications of non- native wild boar *Sus scrofa* in KwaZulu-Natal, South Africa

Claudette Njabulo James

Submitted in fulfilment of the academic requirements for the degree of

Masters in Science

in the Discipline of Ecological Sciences

School of Life Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg Campus

2023

ABSTRACT

Humans' introduction of species into areas where they do not naturally occur has led to ecological and economic havoc. Introduced species can become invasive, exerting negative pressures on native species and the environment. Wild boar (*Sus scrofa*) is distributed worldwide except for Antarctica. The species is highly destructive and has been regarded as an invasive alien species in many parts of the world. Researchers have done many studies on wild boar investigating various aspects of the species, such as its biology, biochemistry, ecology, epidemiology, genetics, and archaeology. Invasive animals' effects on the environment and ecological systems were explored and focused on the impacts of exotic mammals, with wild boar as the species of interest. The potential for invasive spread by the European wild boar in South Africa was assessed by determining potentially suitable habitats using bioclimatic variables and the maximum entropy model, and then related to the present distribution records of the species in the country. Wild boars were found to have great potential to extend their invasive distribution range in South Africa. The prevalence of feral wild boar in KwaZulu-Natal (KZN) Province, South Africa, was investigated using camera trap surveys. The camera trap surveys revealed that there were no feral wild boar populations in the Midlands of KZN, but in other parts of KZN. The selling of wild boar in relation to the present legislation on wild boar in South Africa is illegal. The selling of wild boar contributes to the spread of the species in the country, as determined in this study. We recommend that the sale of wild boar should be monitored in South Africa by conservation authorities and the animals confiscated from the offenders and euthanised to prevent the further uncontrolled spread of the species. Moreover, we recommend the revision of the legislation regulating wild boar in South Africa to prevent the uncontrolled spread of the species in the country.

PREFACE

The data described in this thesis were collected in KwaZulu-Natal, Republic of South Africa, from October 2021 to February 2022, July 2022, and November 2022. 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 Mr Brent Coverdale.

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.

Claudette N. James

January 2023

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

……..

Prof Colleen T. Downs

Supervisor

January 2023

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DECLARATION 1 - PLAGIARISM

I, Claudette James, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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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

Potential climatic suitability distribution model for wild boar (*Sus scrofa*) in South Africa and their presence in KwaZulu-Natal Province

Claudette N. James, Brent Coverdale, Tinyiko C. Shivambu and Colleen T. Downs

Author contributions:

CNJ conceived the paper with CTD and BC. CTD and BC sought funding. CNJ and TCS collected and analysed data. CNJ wrote the paper. CTD, TCS, and BC contributed valuable comments to the manuscript.

Publication 2

Wild boar *Sus scrofa*: a review showing no evidence of research in Africa

Claudette N. James, Brent Coverdale and Colleen T. Downs

Author contributions:

CNJ conceived the paper with CTD and BC. CTD and BC sought funding. CNJ collected and analysed data. CNJ wrote the paper. CTD and BC contributed valuable comments to the manuscript.

Publication 3

The occurrence of wild boar (*Sus scrofa*) in KwaZulu-Natal, South Africa

Claudette N. James, Brent Coverdale and Colleen T. Downs

Author contributions:

CNJ conceived the paper with CTD and BC. CTD and BC sought funding. CNJ collected and analysed data. CNJ wrote the paper. CTD and BC contributed valuable comments to the manuscript.

Signed: Claudette N. James
January 2023

ACKNOWLEDGEMENTS

I would first like to thank my supervisors, Prof Colleen Downs of the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, and Mr Brent Coverdale, Animal Scientist at Ezemvelo KZN Wildlife, Pietermaritzburg. Their encouragement and support carried me through, right to the completion of this thesis. My supervisors consistently allowed this research to be my own work, but steered me in the right direction whenever I needed it. I thank them for their availability and open-door policy for all enquiries.

I would also like to thank the experts involved in this research project's GIS aspects: Mr Nhlakanipho Nkwanyana, Dr David Ehlers Smith, Dr Yvette Ehlers Smith, and Dr T. Cavin Shivambu. Without their passionate participation and input, the GIS work could not have been successfully conducted.

I would also like to acknowledge and thank the University of KwaZulu-Natal, and the National Research Foundation (ZA) for funding. We thank Ezemvelo KZN Wildlife for vehicle support and fieldwork equipment.

Finally, I must express my very profound gratitude to my family for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

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Claudette N. James

January 2023

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CHAPTER 1

Introduction

1.1 Background

Humans' introduction of species into areas where they do not naturally occur has led to ecological and economic havoc (Salamin et al., 2006; Pyšek et al., 2020; Tedeschi et al., 2021). Introduced species can become invasive, where they exert negative pressures on native species and the environment (Chen and Fong, 2010; Bush et al., 2014; Siriwat and Nijman, 2018; Boardman et al., 2019). Biological invasions are one of the most critical threats to biodiversity apart from anthropogenic activities (Carwardine et al., 2018; Taillie et al., 2021).

Biodiversity comprises different ecosystems and ecological features in an environment (Ceyhan et al., 2012; Haahtela, 2019). Trees and green plants comprise a vast component of the earth's biomass at about 80%, followed by bacteria, fungi, archaea and protists at 15%. The remainder is animals where terrestrial arthropods dominate in terms of the number of species (Bar-On et al., 2018; Corlett, 2020). Plants and animals provide a wide variety of products for humans, such as food, medicine, and genetic resources, as well as regulatory services such as water supply and carbon sequestration (Harrop, 2011; Corlett, 2020; Prudhomme et al., 2020). Thus, the protection of biodiversity is also essential for human survival (Singh, 2015; Bertolino et al., 2020). The biodiversity in an environment is in a state of natural balance, where nature takes its course through regulatory mechanisms (Ehrenfeld, 2010; Harrop, 2011; Ochoa-Hueso et al., 2021). Biological invasions by exotic species disturb the balance of natural ecosystems (Ehrenfeld, 2010; Milardi et al., 2019). These disturbances include affecting the biogeochemical pools and fluxes of materials and energy, thus, altering the fundamental structure and function of the ecosystem (Ehrenfeld, 2010; Pyšek et al., 2020). Exotic species invasion can negatively impact the population dynamics of native species

(Chew et al., 2006; Santicchia et al., 2018). Moreover, exotic species invasions are accepted as directly related to biodiversity loss (Didham et al., 2005; Santicchia et al., 2018).

Cleland and Mooney (2001) documented the effects of invasive species and showed that they alter the evolutionary pathway of native species by competitive exclusion, niche displacement, hybridisation, introgression, predation and, ultimately, extinction. Carwardine et al. (2018) stated that the threats to biodiversity and ecological systems' integrity are escalating globally, both in and outside protected areas. These major threats include predation, habitat loss, competition and disease transmission brought on by alien invasive species (McClure et al., 2018). The effects of exotic species having a negative impact on their introduced environment, highlighted by Cleland and Mooney (2001), still hold true today. This literature review explores invasive animals' effects on the environment and ecological systems. The review will focus more on the impacts of exotic mammals, large exotic mammals and specifically the European wild boar (*Sus scrofa*).

1.2 Exotic invasive species

Exotic species can have detrimental impacts on the environment in which they are introduced (Chew et al., 2006; Gentili et al., 2021). The global legal and illegal species trade has led to the introduction of non-native species into areas where they do not naturally occur for reasons such as pet trade, ornamentation, research and food (Lockwood et al., 2019; Shivambu et al., 2021a; Gentili et al., 2021). However, exotic species can also be introduced accidentally (Bradley et al., 2013), for example, through seed contamination of intentionally introduced agricultural plants (grains, fruit, vegetables). Some of these introduced species can establish feral populations and become invasive (Shivambu et al., 2021a; Smyser et al., 2020). For instance, in South Africa, the rose-ringed parakeet (*Psittacula krameri*) was initially introduced as a pet species; however, this bird has now established feral populations and has

become invasive in urban areas of the country (Shivambu et al., 2021a). According to a study (Shivambu et al., 2021b), parakeets feed on the flowers, seeds and fruit of native angiosperms (flowering plants), thus affecting their reproduction and as a result posing a threat to our biodiversity. There are more than 120 000 known species of plants, animals and microbes that have invaded South Africa, the United States of America (USA), the United Kingdom, India, Australia and Brazil (Aquino et al., 2001). However, many of these introduced species are for food security and commercial benefit; these include maize, wheat, domestic chicken, rice, cattle, and plantation forests (Aquino et al., 2001). Other exotic species are used for land restoration, biological pest control, pets and food processing (Aquino et al., 2001; Lockwood et al., 2019; Stenberg et al., 2021).

Ecologists (Hairston et al., 1960; Murdoch, 1966) described the forces that exotic species have on native species as either top-down or bottom-up. These forces can be broken down as follows; top-down forces are brought on by natural enemy invasion, whereas bottom-up forces are brought on generally through plant invasion (Chew et al., 2006). Moreover, these forces influence the population dynamics within an ecosystem (Chew et al., 2006). The top-down forces hypothesis (Hairston et al., 1960) maintains that natural enemies control herbivore populations and keep their numbers in check to avoid widespread defoliation. In contrast, the bottom-up forces hypothesis (Murdoch, 1966) states that plant quality and/or quantity limits the population of herbivores and, thus, their predators too. However, recent research is more focused on studying the conditions that favour one or the other force rather than focusing on a single force (Chew et al., 2006). Large mammalian species have been documented (Churski et al., 2017) to exert top-down forces on lower trophic levels. Quantifying the damage to the environment and biodiversity loss because of invasive alien species (IAS) is complicated since only a relatively small percentage (1.5%) of the species on earth have been identified and described (Aquino et al., 2001).

Nonetheless, invasive species threaten native species by bringing about competition for resources, predation and hybridisation with the native species and by altering their ecosystems (Aquino et al., 2001; Falaschi et al., 2020; Smyser et al., 2020). Research by Francis et al. (2017) revealed that the global distribution patterns of IAS were highly influenced by colonial history, economic development and trade. Moreover, the dominant pathways of invasive species were similar in different regions of the world (Francis et al., 2017). Francis et al. (2017) further stated that the present trends with IAS suggest that Africa and Central Asia are priority areas for IAS research.

1.3 Economic effects of invasive alien species

Invasive alien species are also known to have a negative impact on the economy; they cause major economic losses in agriculture and forestry (Aquino et al., 2001; Shah et al., 2020; Araos et al., 2020; Diagne et al., 2021). Moreover, invasive alien species also pose socio-economic impacts by affecting the factors that constitute human well-being (Bacher et al., 2018; Evans et al., 2020; Duboscq-Carra et al., 2021). Some of these factors include food security, health, social, spiritual and cultural relations (Bacher et al., 2018; Kull et al., 2019; Sena and Ebi, 2020; Duboscq-Carra et al., 2021). A study conducted by Kull et al. (2019) revealed that the relationship between invasive species and livelihoods is highly complex. Some invasive species are beneficial for some people, while others are harmful to some people (Kull et al., 2019). Moreover, other invasive species can have detrimental impacts on the environment, which can lead to negative impacts on the social-ecological systems (Kull et al., 2019). For instance, invasive alien species can have detrimental impacts on agricultural crops, which also directly affects food security and, thus, the well-being of humans as well as the economy. The European wild boar, our species of interest in this study, was observed feeding on about 39 species of cultivated plants (Chhangani and Mohnot, 2004). Crops such as *Zea*

mays, *Saccharum officinarum*, *Arachis hypogea* and other vegetable species suffered the most damage from wild boar (Chhaangani and Mohnot 2004). Feral populations of wild boar are widespread throughout the world and have caused several negative impacts requiring management and eradication (Waithman et al., 1999; Barrios-Garcia and Ballari, 2012; Taylor et al., 2012). For example, the US Department of Agriculture (USDA) is presently investing ~$75 million in the USA. The present first round of funding, provided $16.7 million for 20 feral swine pilot projects in ten states to help agricultural producers and private landowners trap and control feral swine as part of the Feral Swine Eradication and Control Pilot Program (USDA, 2023, "Feral Swine Eradication,").

The management of invasive alien species is costly (Hanley and Roberts, 2019; Osunkoya et al., 2019; Mill et al., 2020). In Australia, the cost of managing a range of invasive alien species in the financial year of 2001-2002 was quantified to $2.31 billion and increased to $3.77 billion between the financial year of 2011-2012 (Broadhurst and Huffmann, 2016). Moreover, ~$726 million of grants funded through the Commonwealth of Australia were spent on invasive species management from 1996-2013 (Broadhurst and Huffmann, 2016). The invasion by exotic species can have a negative impact on the economy in terms of the cost of managing invasive species (McNeely, 2001).

1.4 Invasive mammals

Invasion by mammal species directly impacts biodiversity through activities such as predation, browsing and competition (Bradley et al., 2019; Kelt et al., 2019; Silveira de Oliveira et al., 2020). Furthermore, they also disrupt the pattern of nutrient flow and trophic cascades (Clout and Russell, 2008). More than 30 exotic free-ranging mammal species have been established in the USA since European colonisation (Engeman et al., 2004).

Mammals were also among the first species to be introduced into new environments by humans, as either livestock, pets or as commensals (Clout and Russell, 2008; Lockwood et al., 2019; Morand, 2020). In more recent years, more mammal species have been introduced into new environments as sporting animals, to provide entertainment in circuses, zoos, and aquariums, for recreational hunting, for conservation purposes or biological control (Clout and Russell, 2008; Bertella, 2018; Escobar-Ibarra et al., 2021; Richardson and Zengeya, 2020). Clout and Russell (2008) documented that of the extant species of land mammals, 2.6% can be classified as successful invaders, whereas 21.6% are classified as threatened. As of 2021, the IUCN Red List documented that biodiversity is declining. Presently, there are more than 134,400 species on the list, with more than 37,400 species threatened with extinction, including 41% of amphibians, 34% of conifers, 33% of reef-building corals, 14% of birds and 26% of mammals (IUCN, 2021; Risch et al., 2021). As mentioned, invasive species are also part of the major driving forces of biodiversity loss. Here the invasive capabilities of mammals are explored to determine the impacts on ecological systems and the environment. Mammals are among the relatively high proportions of successful invaders compared with other animals (Byrom et al., 2017). This group includes Artiodactyla, Carnivora, Lagomorpha and Perissodactyla (Byrom et al., 2017). Factors determining the successful invasion by mammalian species include the number of individuals released, the size of the natural range of the introduced species, and the temperateness of climate in the new range (Clout and Russell, 2008; Blackburn et al., 2019; van der Marel et al., 2021).

The behavioural plasticity of mammal species typically allows for easy establishment in new environments; however, to establish new populations, there must be a considerable number of breeding pairs of the exotic species (Byrom et al., 2017). In a Cuban study investigating the prevalence of invasive mammalian species, a total of 29 mammalian species were found to have invaded the islands of Cuba. Of the invasive species, only nine were

deemed to be important, including the black rat (*Rattus rattus*), feral dog (*Canis lupus familiaris*), feral cat (*Felis catus*), mouse (*Mus musculus*), mongoose (*Herpestidae*), pig (*Sus* spp.), goat (*Capra aegagrus hircus*), brown rat (*Rattus norvegicus*), and cattle (*Bos taurus*) (Borroto-Pa´ez, 2009).

Introduced mammals from Australia and Europe facilitated the co-invasion of invasive North American trees and Northern Hemisphere fungi in New Zealand (Bonner et al., 2014). For example, the dispersal of North American fungi by Australian brushtail possum (*Trichosurus vulpecula*) and European red deer (*Cervus elaphus*) appears to be a key contributing factor in establishing invasive North American pines in New Zealand (Bonner et al., 2014). This phenomenon is referred to as the tripartite "invasional meltdown". It comprised taxa from three kingdoms and three continents and highlighted the consequences of global homogenisation (Bonner et al., 2014).

1.5 Large invasive mammals

Large mammal species are notorious for habitat destruction (Driscoll et al., 2019); moreover, non-native terrestrial mammals can negatively impact native flora and fauna (Leroux and Strong, 2014; Shivambu et al., 2021a; Risch et al., 2021). Mammalian invasive predators generally cause more damage contributing to a considerable number of native species' decline and extinction (Dickman et al., 2016; Al-Delaimy et al., 2020). For example, in Australia, predation by feral cats and red foxes (*Vulpes vulpes*) has led to the decline and extinction of more than half of Australia's digging mammalian species over the past 200 years (Dickman et al., 2016; Roshier et al., 2021). The decline and extinction of native species because of invasive predators directly influence the functioning of the ecosystem in that environment (Doughty et al., 2016). When there is an imbalance in the ecosystem the consequences can be as follows: overpopulation of the invasive predator species because of no natural predators in

the new environment which leads to competition for resources among the species which puts the environment under pressure and ultimately resources such as food will be used up at a faster rate than the environment can replenish leading to the extinction of species (Doughty et al., 2016). This can be described as environmental exploitation because of invasive predators. According to statistics by Dickman et al. (2016), invasive predators played a detrimental role in the extinction of 87 avian, 45 mammalian and 10 reptilian species in Australia.

Feral animals introduced pose a major threat to ecology and conservation values. According to a study by Robinson et al. (2004) in Kakadu National Park, Australia, which involved field-based interviews with landowners, the Jawoyn people stated that not all feral animals pose a threat to the environment. The local people revealed that among the feral animals that occur on their land, which included water buffalo (*Bubalus bubalis*), horses (*Equus caballus*) and pigs, the pigs were considered more of a threat to the environment because of their behaviour and feeding habits (Robinson et al., 2004). They believed that pig populations should be reduced to conserve the land (Robinson et al., 2004). In recent years, this belief still holds and is supported by research (Cunningham et al., 2017; Bengsen et al., 2017). Here the invasive capabilities of feral pigs and the consequences on the environment are explored.

1.6 Feral pigs

Feral pigs can establish themselves in most environments because of their omnivorous diet (Engeman et al., 2004; Sales et al., 2017; Ballari and Barrios-García, 2014). Their diet consists mostly of grasses, fruit, seeds, roots, shoots, forbs, and tubers (Armstrong et al., 2009; Ballari and Barrios-García, 2014). They also feed on invertebrates such as grasshoppers, earthworms, centipedes, leeches, beetles, and other arthropods (Armstrong et al., 2009). Their

predatory behaviour has them feeding on frogs, fish, crabs, snakes, rodents, turtles, eggs, chicks of ground-nesting birds and salamanders; however, this list is not finite as their diet is relatively complex (Muthoka, 2021). For example, in the USA, feral pigs also prey on large mammals, the white-tailed deer fawns (*Odocoileus virginianus*) and livestock (Engeman et al., 2004). Furthermore, they must frequently eat to obtain sufficient nutrients (Pérez-Barbería, 2020). According to Bodenchuck et al. (2017), pigs have simple stomachs which are not as efficient as a multi-chambered digestive system; hence they constantly forage. This further highlights their potential impact on the environment if they are continually foraging; consequently, invasion by feral pigs is a cause for concern (Hegel et al., 2019; Risch et al., 2021).

Feral pigs negatively impact the environment through rooting for food and wallowing; these activities accelerate soil erosion, negatively impact earthworm activity and plant succession, and promote the spread of exotic invasive plant species (Muthoka, 2021). Feral pigs heavily affect plant communities through activities such as trampling, rooting and compaction. These impacts can, directly and indirectly, affect plant regeneration and community structure (Genov and Massei, 2004). According to the South African NEMBA Alien Invasive Species List (25 September 2020), the European wild boar is listed as a category 1b alien invasive species. Thus, its prevalence in South Africa must be controlled. In the subsequent chapter, the species is reviewed to determine what environmental threats it poses and what control measures can be taken against it.

1.7 Problem statement

The European wild boar *S. scrofa* is one of the top 100 invasive alien species in the world. Invasion by wild boar can lead to biodiversity loss, disease transmission and economic losses. This taxon has colonised all continents except Antarctica and has become invasive in five of

the nine continents of the world (Global Invasive Species Database, 2022). Wild boar have the ability to adapt and establish in a wide range of environments; thus, the prevalence of the species in South Africa is of great concern as the species has great potential to establish and possibly become invasive. The prevalence of wild boar in South Africa needs to be monitored and controlled to prevent the establishment of feral populations.

1.8 Aims and objectives

The overall aim of this study was to assess the prevalence of the European wild boar *S. scrofa* in South Africa, with the KwaZulu-Natal Province as the main study area and provide recommendations on how the species can be monitored and controlled to prevent the establishment of feral populations.

1.9 Structure of the thesis

The main body of this thesis is organised as manuscripts prepared for publication in peer-reviewed journal articles. The first chapter (Chapter 1) is the Introduction which provides a literature review of the concepts covered in this study. The next four chapters (Chapters 2, 3, and 4) are review or experimental chapters, each covering a specific objective. Each of these chapters is presented as a manuscript and formatted according to the journal it is intended to be (or has been) submitted. Because of this thesis format, a certain degree of repetition was unavoidable. However, this is deemed to be of little concern as this format allows the reader to read each chapter separately without losing the overall context of the thesis. Chapter 2 was a literature review on wild boar to get more background information on the species. Chapter 3 investigated the potential climatic suitability for wild boar within South Africa to predict the potential for invasion by the species as a result of climatically suitable habitat. Chapter 4 investigated the prevalence of the species in the KwaZulu-Natal Province of South Africa,

where camera traps surveys were conducted to determine prevalence. Chapter 5 provides recommendations for the management and control of the species within South Africa. Chapter 5 is also a summary of the conclusions.

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CHAPTER 2

Wild boar *Sus scrofa*: a review showing no evidence of research on wild boar in Africa

Claudette N. James[1,2], Brent Coverdale[1,2] and Colleen T. Downs[1]*

[1]*Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg, 3209, South Africa*

[2]*Ezemvelo KZN Wildlife, Conservation Research & Assessment, 1 Peter Brown Drive, Montrose, Pietermaritzburg, 3201*

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* **Corresponding author**: Colleen T. Downs

Email: downs@ukzn.ac.za, ORCID: http://orcid.org/0000-0001-8334-1510

Other emails:

C James Email: cnjames0204@gmail.com; ORCID: https://orcid.org/0000-0001-8970-6947

B Coverdale Email: Brent.Coverdale@kznwildlife.com;

Running header: A literature review on wild boar

2.1 Abstract

Wild boar (*Sus scrofa*) is distributed worldwide except for Antarctica. The species is highly destructive and has been regarded as an invasive alien species in many parts of the world. Researchers have done many studies on wild boar investigating various aspects of the species, such as its biology, biochemistry, ecology, epidemiology, genetics, and archaeology. A global literature review on wild boar from 2000 to 2022 was conducted to determine the research efforts on the species as a globally listed invasive alien species. The literature published on wild boar with wild boar or *Sus scrofa* in the title from 2000 to 2022 showed a trend of increasing publications over the years. The leading continent with wild boar research was Europe, followed by Asia, then South America and North America and lastly, Australia. According to our data, the majority of the world has been researching wild boar, with 71.4% (5) of the continents having done research on wild boar. However, there was no record of wild boar research done in Africa. Asia appears to be leading in collaborative research on wild boar with other continents, being involved in up to three collaborative works, followed by Europe with up to two collaborative works. There were a total of eleven research categories identified within the parameters of this research and a total of 29 focus areas within the different categories of research. In South Africa, wild boar is listed as a category 1b alien and invasive species. Management of feral pigs is essential to maintain the integrity of the environment, and human and animal health and to avoid economic losses.

Keywords: European wild boar; wild boar invasiveness; wild boar biology; wild boar impacts; wild boar management; wild boar research

2.2 Introduction

Wild boar (*Sus scrofa*) are distributed worldwide except for Antarctica (Larson et al., 2007; Albarella et al., 2009; Bertolino et al., 2020). The species is highly destructive and has been regarded as an invasive alien species in many parts of the world (Bengsen et al., 2017; Sales et al., 2017; Kim et al., 2019; Cervo and Guadagnin, 2020). Part of the wild boars' worldwide distribution is because of human activity, where the species has been introduced for game meat, hunting, use as a form of biocontrol agent, and some farmers used it for tilling the soil (Sales and Kotrba, 2013; Richardson and Zengeya, 2020). Wild boar, especially when invasive, are associated with major economic losses, which can be induced by damage to crops and transmission of diseases such as swine flu (Broadhurst and Hoffmann, 2016; Luskin et al., 2021; Eschen et al., 2021). Researchers have conducted many studies on wild boar investigating various aspects of the species, such as its biology, biochemistry, ecology, epidemiology, genetics, and archaeology (Yang et al., 2019; Norscia et al., 2021; Bergen, 2022).

Feral pigs introduced to an environment pose a major threat to ecology and conservation values (Gray et al., 2020). Rodríguez-Rodríguez et al. (2022) conducted a study reviewing the threats posed by feral animal populations and found that most feral animals pose a threat to biodiversity and human activities and thus highlighted the importance of managing such species. Feral pigs can establish themselves in most environments because of their omnivorous diet (Sales et al., 2017; Engeman et al., 2004; Ballari and Barrios-García, 2014). Feral pigs negatively impact the environment through rooting for food and wallowing, and these activities accelerate soil erosion, negatively impact earthworm activity, plant succession, and promote the spread of exotic invasive plant species (Muthoka 2021). Feral pigs heavily affect plant communities through activities such as trampling, rooting and compaction (Gray et al., 2020). Their predatory behaviour has them feeding on frogs, fish,

crabs, snakes, rodents, turtles, eggs, and chicks of ground-nesting birds and salamanders; however, this list is not finite as their diet is very complex (Muthoka 2021). According to a survey conducted by Bovy et al. (2013), the number of wild boars has increased in the majority of the countries that participated in the study, with only two countries having an apparent decrease in the number of wild boars. Drimaj et al. (2020) stated that the rapid increase of wild boar in the past decades is largely because of a lack of predation, low hunting pressure, rapid reproductive rate, favourable climatic conditions, and food available. Furthermore, the adaptability of wild boar allows them to sustain themselves in a variety of landscapes (Navas et al., 2012). Wild boar has the highest reproductive rate amongst ungulates (Genov and Massei 2004) and thus has the potential to multiply and spread fast.

We conducted a global literature review on wild boar from 2000 to 2022 to determine the research efforts on the species as a globally listed invasive alien species. We also documented its biology and effects on the environment where it is invasive. We expected little research on wild boar in Africa. Finally, we discuss the trends and implications of wild boar invasion in terms of South Africa.

2.3 Methods

We conducted a thorough literature search to estimate the range and amount of research done on the European wild boar Sus scrofa that is presently available. We used the Harzing Publish or Perish 8 software with Google Scholar, Scopus, and Web of Science search engines. We found article titles using the search phrases “wild boar” AND *Sus scrofa*. We restricted our research period to that published between 2000 and 2022. Only literature sources having a fully accessible abstract were used in the analyses. Book reviews, editorials, letters, editorial reviews, short communications, and review papers were not included. Additionally, we assessed articles based on their main research areas, habitat type, continent, country, year of

publication and invasiveness in the research country. We compiled a summary of all the publications obtained from the literature search in Microsoft Excel, and produced tables and graphs to highlight trends.

Table 2.1: Countries where wild boar (*Sus scrofa*) has established feral populations and their invasiveness status (Source: Global Invasive Species Database, 2022. *Sus scrofa* (http://www.issg.org/database)

Countries	Occurrence	Invasiveness
American Samoa	Established	Unspecified
Argentina	Established	Invasive
Australia	Established	Invasive
Bahamas	Established	Invasive
Brazil	Established	Invasive
Chile	Established	Invasive
Cook Islands	Established	Invasive
Curacao	Established	Invasive
Dominica	Established	Invasive
Dominican Republic	Established	Unspecified
Ecuador	Established	Invasive
Fiji	Established	Unspecified
France	Eradicated	Invasive
French Polynesia	Established	Invasive
French Southern Territories	Extinct	Invasive
Guam	Established	Unspecified
India	Established	Invasive
Jamaica	Established	Invasive
Kiribati	Established	Unspecified
Marshall Islands	Established	Unspecified
Mauritius	Established	Invasive
Mayotte	Present in containment facilities	Unspecified
Mexico	Established	Invasive
Federated States Of Micronesia	Established	Unspecified
Montserrat	Established	Invasive
Nauru	Established	Unspecified
New Caledonia	Established	Invasive
New Guinea	Established	Invasive
New Zealand	Established	Invasive
Niue	Established	Unspecified
Northern Mariana Islands	Established	Unspecified
Pakistan	Established	Unspecified

Palau	Established	Unspecified
Papua New Guinea	Established	Unspecified
Pitcairn	Extinct	Unspecified
Puerto Rico	Established	Invasive
Reunion	Present in containment facilities	Unspecified
Saint Lucia	Established	Invasive
Samoa	Established	Unspecified
Solomon Islands	Established	Unspecified
South America	Established	Unspecified
Tonga	Established	Unspecified
United States	Established	Invasive
Virgin Islands, USA	Established	Invasive
Wallis And Futuna	Established	Unspecified

2.4 Results and Discussion

2.4.1 Research on the European wild boar from 2000 to 2022

From data obtained from the global biodiversity information facility (GBIF) it was evident that wild boar are present on most continents (Fig. 2.1a). Thus, we reviewed the trends on research done on wild boar throughout the world. The literature we found published on wild boar with wild boar or *Sus scrofa* from 2000 to 2022 showed a trend of increasing publications over the years (Fig. 2.1b). There was a peak in the number of publications reaching a high of 278 and 282 in 2016 and 2020, respectively. The number of publications decreased from 2021 to 2022, from 269 in 2021 to 76 in 2022. However, these values are all estimations and not a true reflection of the total number of publications on wild boar from 2000 to 2022, as the data extraction process had filters and only considered a sample of publications. However, this sample data can still be used to highlight trends in wild boar research.

For 2000 – 2022, the leading continent with wild boar research was Europe, followed by Asia, then South America and North America and lastly, Australia (Fig. 2.1c). Of the seven continents in the world, boar were present and researched on five according to our data found (Fig. 2.1d). We found no record of wild boar research conducted in Africa, despite their

presence there (Global Invasive Species Database, 2022). Antarctica was the only continent without wild boar (Larson et al., 2007; Albarella et al., 2009; Bertolino et al., 2020).

From our literature search for the specified time period and filters, Spain conducted the most research on wild boar (about 80% of total publications), with more than 100 publications (Fig. 2.1c). The country with the second most research done (about 60% of total publications) on wild boar was Italy, with more than 80 publications, followed by Germany, with more than 60 publications (~50% of total publications), and then Japan with more than 40 publications (~30% of total publications). The remainder of the countries had fewer than 40 publications (less than 20% of total publications) (Fig. 2.1c).

From 2000 to 2022, in terms of continental collaborations, Asia led collaborative research on wild boar with other continents, having been involved in up to three collaborative works, followed by Europe with up to two collaborative works (Fig. 2.2a). There appears to be a collaborative relationship between Asia and Europe, with up to two collaborative works identified in the literature review (Fig. 2.2a).

From 2000 to 2022, in terms of country collaborations, there was ongoing collaborative research on wild boar between the countries of Spain and Portugal, and France and Spain, with up to four publications within the parameters of this literature review (Fig. 2.2b). We found a total of 17 publications on collaborative work between different countries identified in this literature review. Of those collaborations, 17.4% were between Spain and Portugal, and France and Spain, respectively. The remainder of the collaborations accounted for 4.3% of the collaborative publications.

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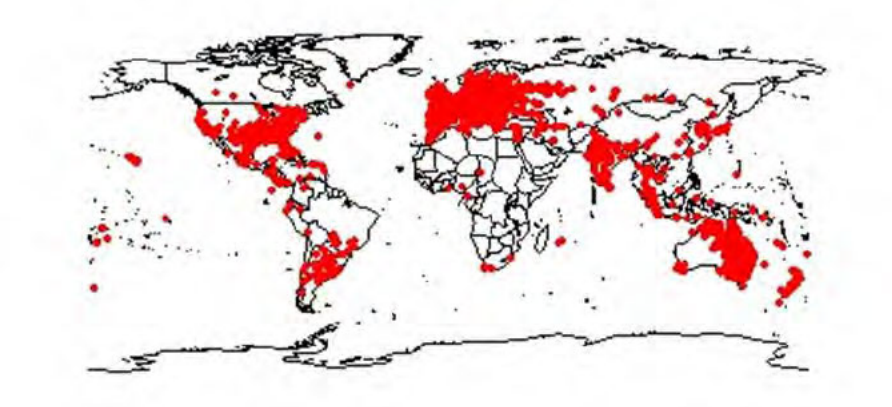

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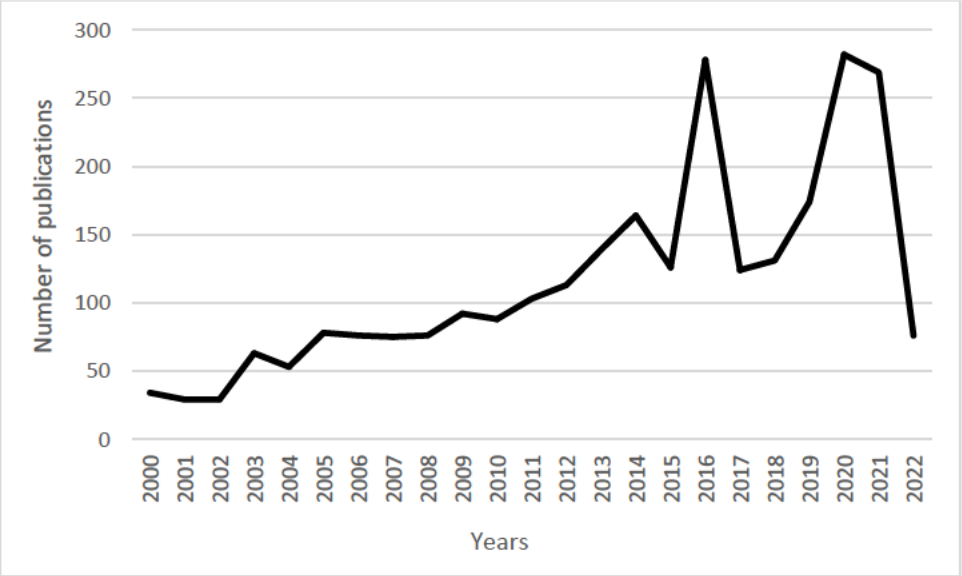
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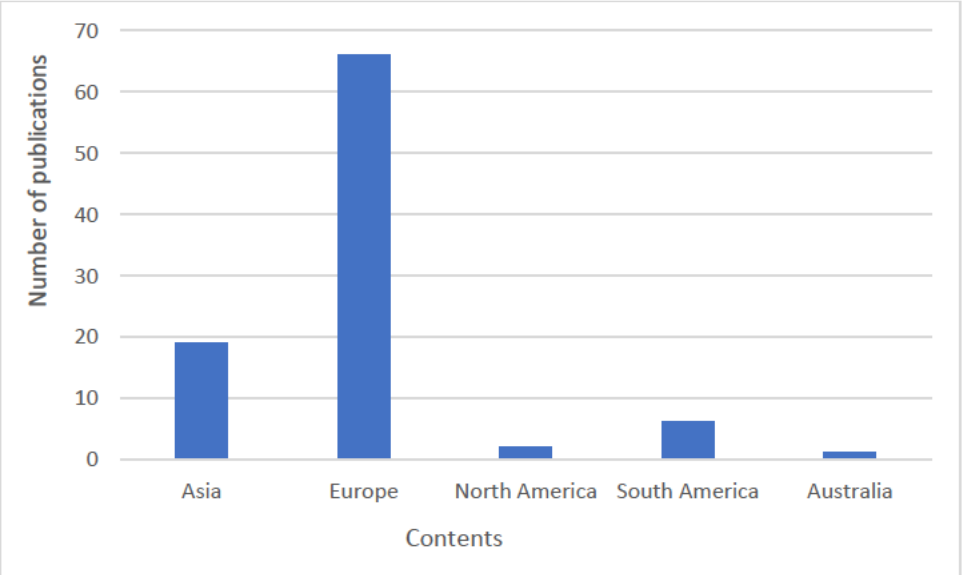
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Asia
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North America
South America
Australia
Contents

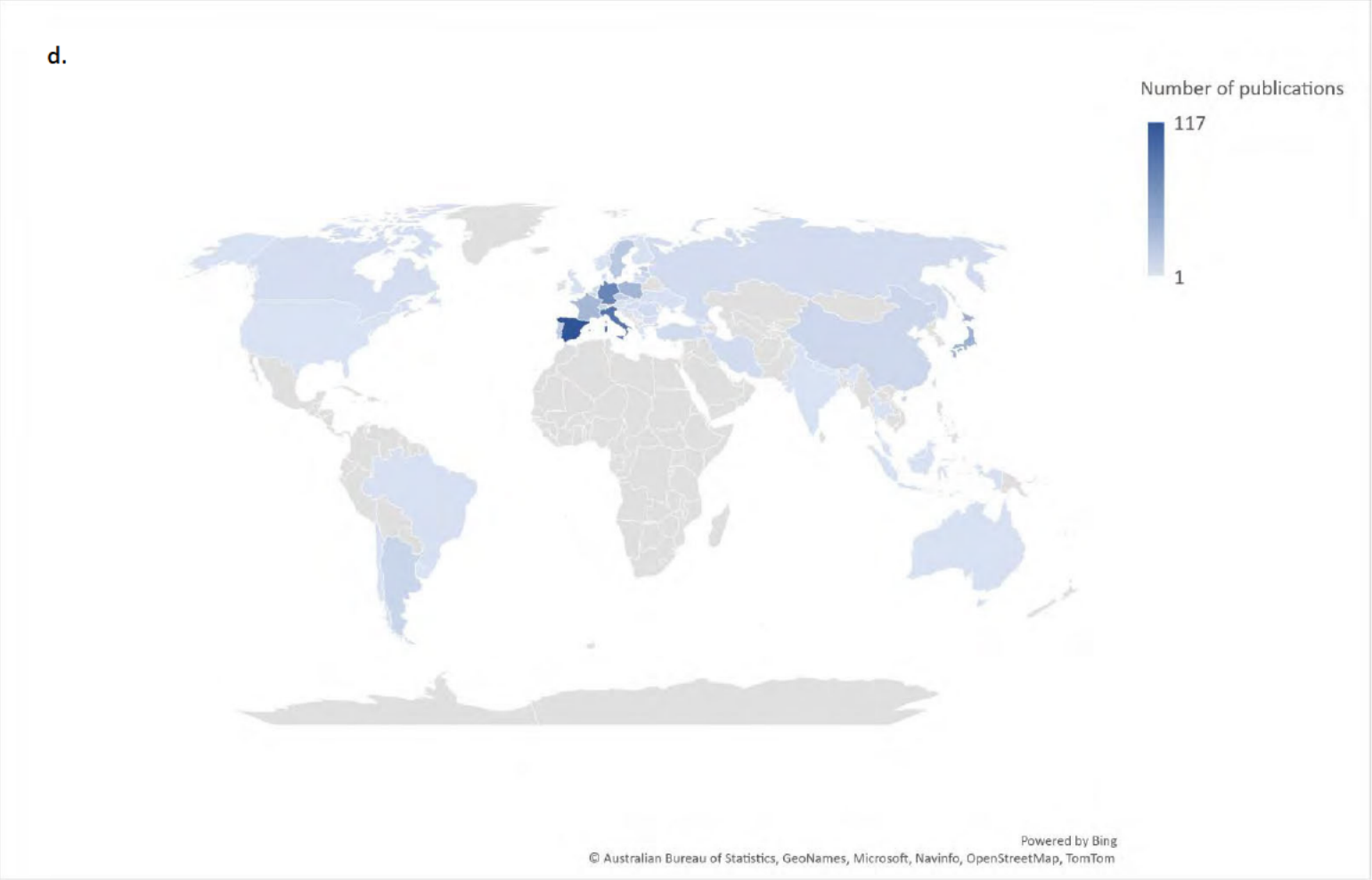
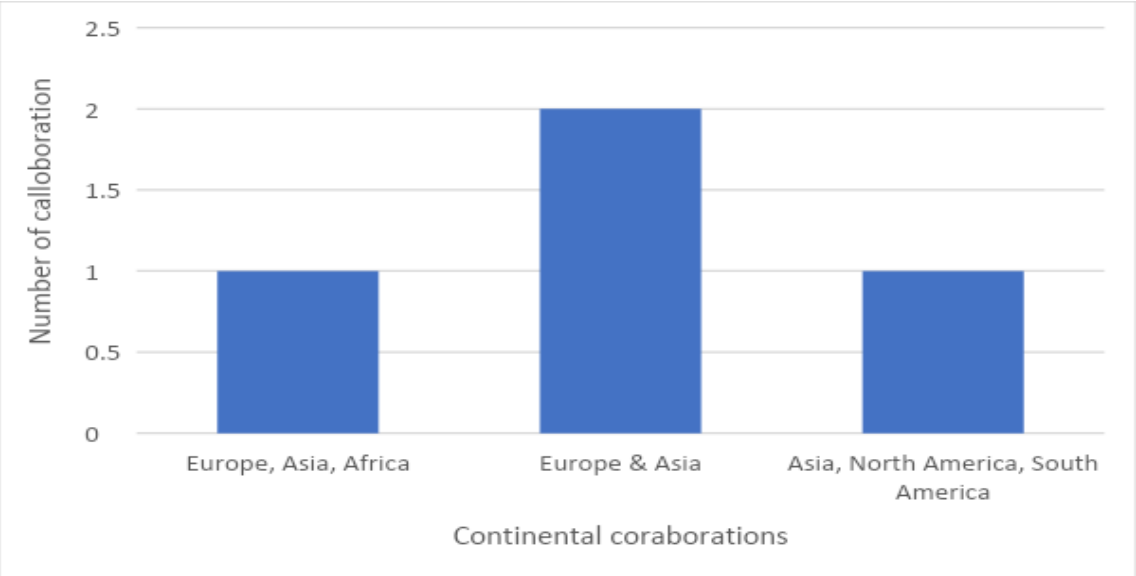


Figure 2.1: The worldwide distribution of wild boar (a), number of publications sourced with wild boar or *Sus scrofa* in the title b. from the year 2000 – 2022, c. per contintent, and d. from countries that conducted research on wild boar from the year 2000 – 2022.

a.



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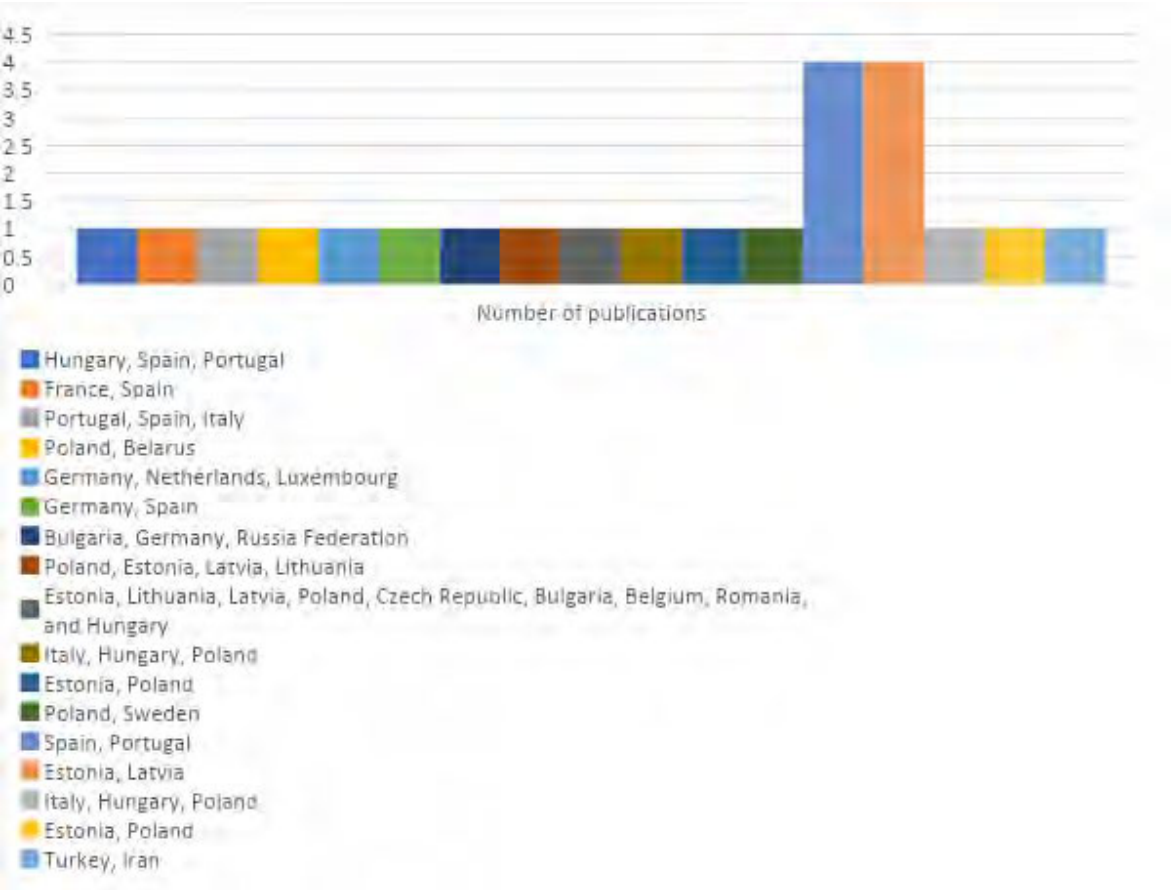

Figure 2.2: Number of publications showing a. continental and b. between countries collaborative work on wild boar research from 2000–2022.

In this literature evaluation, information on the invasiveness of wild boar in the various nations where the research was conducted was found in 64 papers. Of these 64% (n = 41 publications) of the research took place where wild boar invasiveness was not specified (Fig. 2.3). The second most number of publications, 26% (n = 17), were from countries where wild boar were invasive (Fig. 2.3). Only 9.4% (n = 6) of the publications were from countries where wild boar were non-invasive (Fig. 2.3).

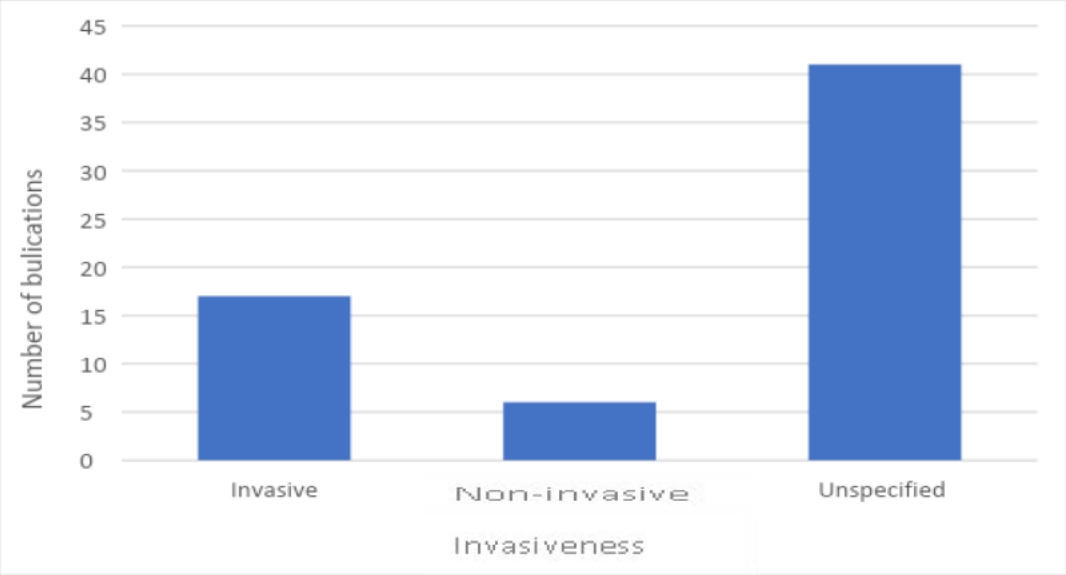

Figure 2.3: Number of publications from countries where research was conducted on wild boar indicating if it was because they were invasive.

We identified a total of eleven research categories identified within the parameters of this research and a total of 29 focus areas within the different categories of research (Table 2.2). The research category biochemistry had the most focus areas, 31.0% (n = 9), followed by biology and ecology with 13.8% (n = 4) respectively then epidemiology and osteology

with 10.3% (n = 3) of the focus areas, respectively (Fig. 2.4). The remainder of the research categories only comprised 3.4% of the research focus areas (Fig. 2.4).

Table 2.2: Research topics on wild boar identified in the literature from 2000 – 2022.

Research categories	Focus
Archaeology	Mesolithic period
Biochemistry	Meat quality, antibodies, ingestion, crossbreeds, anticoagulant rodenticides, hair, stress, blood cells
Biology	Reproduction, growth, inter-specific synchrony, offspring
Ecology	Behaviour, diet, management, human - wild boar interactions
Epidemiology	Parasites, Bacteria, viruses
Engineering	Biological engineering
Genetics	Genome structure
Microbiology	Carcass hygiene
Paleontology	Environmental changes
Toxicology	Radioactivity
Osteology	Teeth, body size, morphology

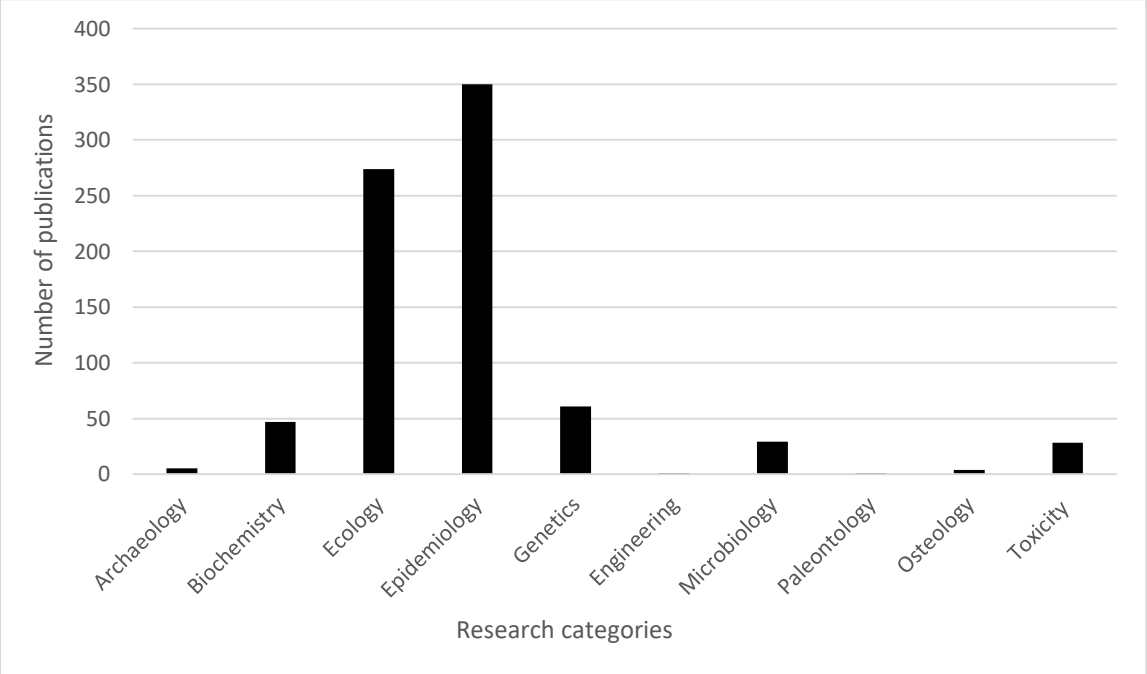

Figure 2.4: The research categories identified in wild boar research articles published from 2000 – 2022.

From the research categories identified in the parameters of this literature review, there were a total of 728 publications assessed. Of the research categories identified, the majority of the research conducted on wild boar involved epidemiology studies (48.1%, n = 350 publications), while 37.6% (n = 274 publications) were ecological studies, 8.4% (n = 61 publications) were genetics studies, and 6.5% (n = 47 publications) were biochemistry studies. The remainder of the publications comprised 3.4% of the research focus areas and below.

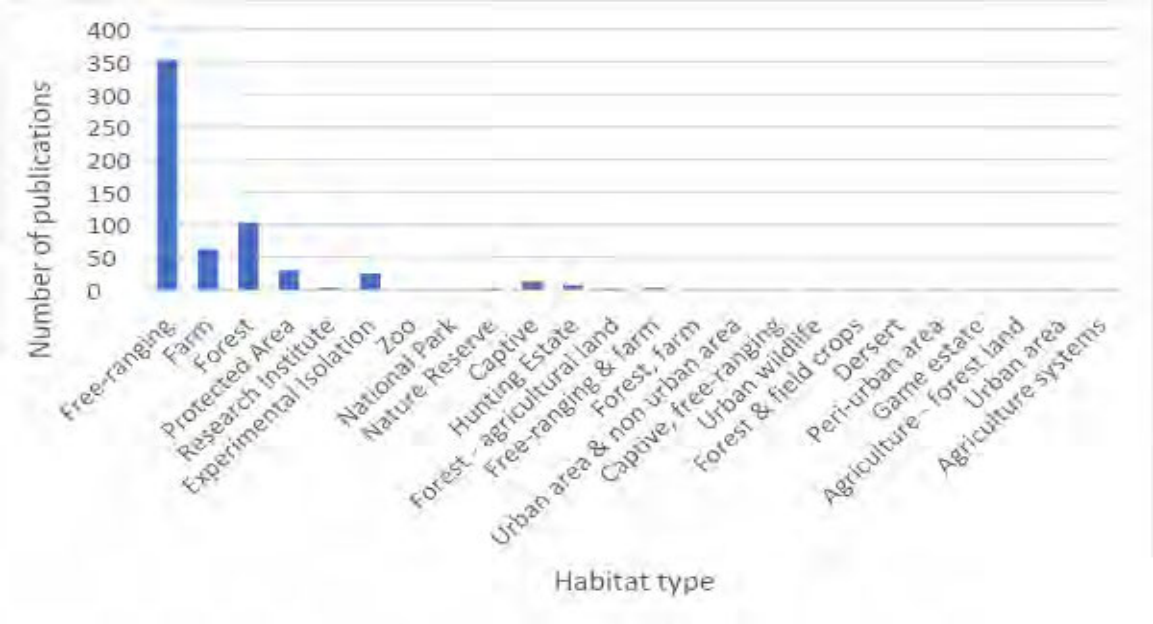

Figure 2.5: The different habitat types identified for the wild boar research articles published from 2000 – 2022.

Free-ranging wild boars were the subject of the majority of research on wild boars from 2000 to 2022 (Fig. 2.5), 57.3% (n = 350), followed by forest habitat, which accounted for 16.7% (n = 103), farms, which made up 10.1% (n = 62), protected areas, which made up 4.9% (n = 30), experimental isolation, which accounted for 4.1% (n = 25), and captives, which accounted for 2.1% (n = 13) of publications. Furthermore, the many habitat types can be

further divided into two main groups, free-ranging and captive. We might infer from this that free-ranging wild boar was the subject of a large portion of research from 2000 to 2022.

2.4.2 European wild boar

All domestic pigs are descendants of the European wild boar (*S. scrofa*), which is now a widely distributed species worldwide, except in Antarctica (Track, 2018; Mihalik et al., 2020; Table 2.1). In many areas outside of their natural distribution range, wild boars have established feral populations that are now invasive, including in North America and Australia (Global Invasive Species Database, 2022).

When the domestication of pigs began about 9000 years ago (Adedeji et al., 2020), the wild boar was prevalent throughout northern Japan in the north-east and New Guinea in the south-east as well as throughout China, tropical South Asia, India, the Middle East and up to the Atlantic coast of Europe and North Africa in the west (Jensen, 2009). A genetic split occurred among the wild boar at least 300 000 years ago, with European populations to the west of Iran differing from populations in the east (Asia) in morphology, genetics and mostly likely behaviour (Jensen, 2009). It is documented that the major modern-day pig breeds arose from the Chinese, Indian and European traditional pig breeds, which are still genetically closer to their regional wild boar counterparts than each other (Jensen, 2009).

In Africa, records about the origin of African domestic pig breeds are unclear. This is because of insufficient archaeological and genetic evidence to establish sound hypotheses about how, when and where they originated (Adedeji et al., 2020). However, it is known that *S. scrofa,* the ancestor of African domestic pigs, is known to be native to North Africa (Adedeji et al., 2020).

The domestication of pigs began early in the Neolithic agricultural transition (Giuffra et al., 2000; Jensen, 2009, Crombé et al., 2020). The domestication of wild boars exposed the

pigs to different selection pressures than the wild; thus, their natural wildlife instincts subsided (Jensen, 2009). However, as far as it is known, there have been no behavioural changes in wild boar (not domesticated) since the onset of domestication of the species. According to Jensen (2009), the selection pressures have not been the same throughout the history of pig domestication. For example, European domestic pigs were smaller than wild boars, but many breeds had a greater proportion of body fat until the Middle Ages (Jensen, 2009). The recent phase of domestication (the past 100 years) has contributed to their abundance worldwide. This recent phase encompasses large-scale breeding programmes mainly for genotypes that produce lean meat efficiently and quickly (Jensen, 2009).

The problem with domesticated pigs arises when they escape from captivity and start interbreeding with the wild boar. When domesticated pigs form feral populations, they quickly become pests (Adams et al., 2019). Wild boars are regarded as pests because of the threats they pose to the environment (Track, 2018; Adams et al., 2019). Wild boar have been reported to be invasive on five continents, North America, South America, Europe, Australia and Asia (Aschim and Brook, 2019; Table 2.1). The activities of the wild boar cause adverse effects on that particular country's environment, society, and economy (Ballari et al., 2015; Track, 2018; McDonough et al., 2022). According to a survey conducted by Bovy et al. (2013), the number of wild boar has increased in the majority of the countries that participated in the study, with only two having an apparent decrease in the number of wild boar. Graitson et al. (2019) stated that the rapid increase of wild boar in the past decades is mainly because of a lack of predation, low hunting pressure, rapid reproductive rate, favourable climatic conditions, and food availability. Furthermore, the behavioural plasticity of wild boars allows them to sustain themselves in various landscapes (Navas et al., 2012). This species has the highest reproductive rate amongst ungulates (Genov and Massei, 2004). The distribution of

wild boar throughout the world is largely through anthropogenic activities, where the species has been introduced intentionally (Johann et al., 2020; Bergmann et al., 2021).

2.4.3 The biology of the European wild boar

Family: Suidae

Genus: *Sus*

Species: S. *scrofa*

The wild boar can be identified by its large head, narrow snout, and small ears (Genov and Massei, 2004). The piglets are more distinct and can be identified by their longitudinal brown and cream stripes (Genov and Massei, 2004). Mature males and females usually have tusks, but the male's tusks are larger (Genov and Massei, 2004).

Adult wild boars can weigh between 35 to 230 kg, and their life expectancy is that they can live for up to a maximum of 12 years (Genov and Massei, 2004; Kim et al., 2019). However, this life expectancy can be reduced because of human hunting activities (Genov and Massei, 2004). Wild boars usually live in groups of 6-23 animals (Chhangani and Mohnot, 2004). The species can start breeding from 7-12 months and produce one or two litters of six piglets per annum. The wild boar's main diet is plant roots, fallen fruits, cultivated crops, nuts and acorns but it also scavenges on large animals and feeds on other vertebrates and invertebrates, making it an omnivore (Chhangani and Mohnot, 2004). This species is most active from sunset to the early hours of the morning (Lemel et al., 2003).

2.4.4 European wild boar effects on the environment, society, and economy

Wild boar are often referred to as pests; they cause damage to the environment through wallowing, rooting for food and selective breeding (Sales et al., 2017; Pitta-Osses et al., 2022). The selectively bred species are usually used for wild meat (Sales et al., 2017).

However, the crossing breeding of the selectively bred species with the wild species can adversely affect the environment because of the transfer of favourable traits for survival and reproduction (Sales et al., 2017). The wild boar is also a reservoir of diseases (Stillfried et al., 2017; Meier and Ryser-Degiorgis, 2018). They can adversely affect a country's economy by increasing epidemics such as tuberculosis and swine flu (Meng and Lindsay, 2009; Shimizu et al., 2021). Furthermore, they also affect the economy by damaging agricultural crops and transferring diseases to livestock and humans (Meng and Lindsay, 2009; Navas et al., 2012; Ballari and Barrios-García, 2014).

2.4.5 The implications of invasion by wild boar

Invasion by wild boar can lead to disturbances in wildlife predation, nest, and habitat destruction, as well as the exclusion of native species because of competition (Sales et al., 2017). Escaped selectively bred pigs cross-breed with the wild boar, leading to the selective traits such as increased fecundity and growth rates being passed onto the feral hybrid and other favourable traits such as fitness and high fertility (Fulgione et al., 2016; Sales et al., 2017). Thus, more and faster-growing populations of feral pigs ultimately lead to greater environmental destruction (Sales et al., 2017; Adams et al., 2019; Lewis et al., 2019).

2.4.6 Impact of wild boar on plant communities

Where there is a high density of wild boar, the herbaceous cover can be reduced by up to 95% because of rooting (Genov and Massei, 2004; Ballari and Barrios-García, 2014). Furthermore, this can lead to the local extinction of individual plant species (Genov and Massei, 2004; Caruso et al., 2018; Gallardo et al., 2019). In addition, rooting is also a contributing factor to soil erosion resulting in the loss of fertile soil on slopes (Pitta-Osses et al., 2022). Biologically, wild boars are less capable of extracting carbohydrates from the cellulose of green plants.

Thus, they prefer energy-rich foods such as acorns, beech mast and grains (Genov and Massei, 2004; Morelle et al., 2015). The consequences of wild boar interacting with a diverse range of plant communities include seed dispersal, alteration of nutrient cycles leading to an increased growth rate of trees, selective feeding on plants or their parts leading to increased or decreased species richness, or an overall decrease in species abundance (Genov and Massei, 2004; Boulanger et al., 2018; Skoták et al., 2021). The rooting behaviour of wild boar results in accelerated nutrient recycling in the top layer of the soil because of aeration of the soil, the incorporation of litter into the soil and the mixing of soil layers, consequently producing fertile soil which is favourable for plant growth (Cohnstaedt et al., 2005). However, they do reduce the abundance of the species they feed on (Genov and Massei, 2004). The factors influencing crop damage include the local density of wild boar, the availability of wild fruits in woodlands and the proximity of cultivated fields to forest areas (Bovy et al., 2013).

2..4.7 Impact of wild boar on animal communities

According to Genov and Massei (2004), invertebrates such as earthworms, larvae and snails appear to be a staple food in the diet of wild boar. They occasionally feed on vertebrates such as rodents, amphibians, fish, and carcasses (Genov and Massei, 2004). Wild boar have also been found to eat the eggs of ground-nesting birds (Couto et al., 2008; Sanders et al., 2020; McDonough et al., 2022). Also, in Spain, wild boar predation on ground-nesting birds such as red-legged partridge (*Alectoris rufa*) has been recorded (Genov and Massei, 2004). However, the impact of wild boar feeding on animal populations has not been extensively quantified (Genov and Massei 2004; Ballari and Barrios-García 2014; Muthoka 2021). Wild boar can also negatively impact other ground-dwelling small animals because of direct predation or habitat destruction (Couto et al., 2008; McDonough et al., 2022). Habitat destruction and food availability are the main factors affecting animal communities because

of the rooting activity of wild boar (Genov and Massei, 2004; McDonough et al., 2022). Repeated rooting destroys the habitat of surface tunnelling rodents and decreases the food available for small insectivores (Cohnstaedt et al., 2005).

2.4.8 Case study: South Africa's regulations about wild boar

In South Africa, there is a legislative document to protect the natural environment (National Environment Management Act (NEMA) 1998 (Act 107 of 1998)). The purpose of this Act was to "To provide for co-operative, environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state; and to provide for matters connected therewith" (NEMA, 1998). From the NEMA (1998) document, other environmental management documents were derived to address specific aspects of environmental management. These documents include the National Environmental Management: Biodiversity Act (NEMBA), 2004 (Act 10 of 2004), National Environmental Management: Protected Areas Act (NEMPAA), 2004 (Act 57 of 2004), National Environmental Management: Air Quality Act (NEMAQA), 2004 (Act 39 of 2004) and National Environmental Management: Integrated Coastal Management Act (NEMICMA), 2008 (Act 24 Of 2008). Each Act has regulatory guidelines that aid decision-making to ensure the environment is protected. Moreover, the regulations for each Act can be subjected to updating and amendments in light of new knowledge.

The occurrence of alien and invasive species in South Africa is governed by the National Environmental Management: Biodiversity Act (Act 10 of 2004): Alien and Invasive Species, 2014. The guidelines for regulatory adherence to the Biodiversity Act (Act 10 of 2004): Alien and Invasive Species are housed in the Biodiversity Act (Act 10 of 2004): Alien and Invasive Species List and the Biodiversity Act (Act 10 of 2004): Alien and Invasive

Species Regulations documents. Hence, wild boar occurrence in South Africa must adhere to the regulations stipulated by the NEMBA (Act 10 of 2004): Alien and Invasive Species List and the Alien and Invasive Regulations. An update to the NEM:BA Alien and Invasive Species List in September of 2020 had wild boar listed as a category 1b alien and invasive species. The NEMBA (Act 10 of 2004): Alien and Invasive Species List provides us with three Notices. According to the Notices of the NEMBA (Act 10 of 2004): Alien and Invasive Species List, 2020, wild boar is a category 1b alien invasive species, which means it is subject to be prohibited from certain restricted activities and according to Notice 2, the minister (Environmental Affairs) can allow for exemptions from the provisions of section 65(1) (restricted activities involving alien species) of the NEMBA (Act 10 of 2004) provided that the species is not listed as a protected species. After reviewing the NEMBA: Alien and Invasive Species Regulations, 2014 and the NEMBA: Alien and Invasive Species List, 2020, the prevalence of wild boar in South Africa should be monitored, managed and controlled to prevent the establishment of feral populations.

2.4.9 Control and management of wild boar

Wild boars are generally managed as game species (Bovy et al., 2013; Froehly et al., 2020; (Davis et al., 2020). Thus, in terms of game management measures, the commonly used methods of control are fencing, culling, and contraception or sterilisation (Bovy et al., 2013; Fulgione and Buglione, 2022). Other means of control include culling the wild boar by shooting (on the ground or aerial), using meat baits to attract the wild boar for poisoning or setting up pig traps to capture them (Massei et al., 2011; Beasley et al., 2021). Hunting is also a means of regulating their numbers (Keuling et al., 2013). Management of feral pigs is essential to maintain the integrity of the environment, and human and animal health, and to avoid economic losses (Gavier-Widén et al., 2015; Fischer et al., 2020; Risch et al., 2021;

Khomenko et al., 2022). However, the economic costs of controlling and removing wild boar are high. For example, the US Department of Agriculture (USDA) has invested ~$75 million in the USA recently. The present first round of funding provided $16.7 million for 20 feral swine pilot projects in ten states to help agricultural producers and private landowners trap and control feral swine as part of the Feral Swine Eradication and Control Pilot Program (USDA, 2023, “Feral Swine Eradication”).

2.4.10 Conclusions

Our global literature review on wild boar from 2000 to 2022 showed extensive research efforts on the species as a globally listed invasive alien species. These studies documented the wild boar biology and its effects on the environment where it is invasive. Although the studies occurred globally, we found no research on wild boar in Africa. Given the global trends, impacts and economic costs of wild boar invasions, we highlight the implications of wild boar invasion in terms of South Africa and recommend ongoing monitoring and control.

2.5 Acknowledgements

We are grateful to the University of KwaZulu-Natal (ZA) and the National Research Foundation (ZA) for funding. We thank Ezemvelo KZN Wildlife for its support.

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CHAPTER 3

Potential climatic suitability distribution model for wild boar (*Sus scrofa*) in South Africa and their presence in KwaZulu-Natal Province

Claudette N. James[1, 2], Brent Coverdale[1, 2], Tinyiko C. Shivambu[1] and Colleen T. Downs[1,*]

[1]*Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg, 3209, South Africa*

[2]*Ezemvelo KZN Wildlife, Conservation Research and Assessment, 1 Peter Brown Drive, Montrose, Pietermaritzburg, 3201*

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* Corresponding author: Colleen T. Downs

Email: downs@ukzn.ac.za; ORCID: http://orcid.org/0000-0001-8334-1510

Other emails ORCIDs:

C James Email: cnjames0204@gmail.com; ORCID: https://orcid.org/0000-0001-8970-6947

B Coverdale Email: Brent.Coverdale@kznwildlife.com;

TC Shivambu Email: shivambucavin@gmail.com; ORCID: https://orcid.org/0000–0003–3157–4712

Running header: Distribution of wild boar in South Africa

3.1 Abstract

European wild boars (*Sus scrofa*) are invasive in many parts of the world. We assessed the potential for invasive spread by the wild boar in South Africa by determining potentially suitable habitats using bioclimatic variables and the maximum entropy model, which we then related to the present distribution records of the species in the country. We found that the wild boar has great potential to extend its invasive distribution range in South Africa. The most suitable habitats were in provinces with coastal boundaries, namely the Western Cape, Eastern Cape and KwaZulu-Natal provinces. Additionally, through an online questionnaire, we found out that of the participants, only 26.9% knew of the prevalence of wild boar, 29.5% about human-wild boar conflict, and 29.6% knew of hunting sites for the species; however, the majority (62.9%) knew of the species on the National Alien and Invasive Species List. Moreover, we also got localities of prevalence and hunting sites within KwaZulu-Natal Province. The prevalence of wild boar in South Africa needs to be strictly monitored and controlled as stipulated by the NEM:BA regulations to prevent its spread and negative impacts on biodiversity and the agriculture sector, as evident elsewhere.

Keywords: Wild boar; habitat; crops; distribution model; climate; vegetation

3.2 Introduction

Introduced species can become invasive and exert negative pressures on native species and the environment (Fong & Chen, 2010; Siriwat & Nijman, 2018; Spee, Hazel, Dal Grande, Boardman, & Chaber, 2019). According to Carwardine *et al*. (2019), biological invasions are the most critical threat to biodiversity apart from anthropogenic activities. Non-native species have been introduced into regions where they do not naturally occur as a result of the global legal and illegal species trade (Mantintsilili, Shivambu, Shivambu, & Downs, 2022) or for adornment, study, and food (da Rosa, Zenni, Ziller, de Almeida Curi, & Passamani, 2018; Lockwood *et al*., 2019; Moshobane, Nelufule, Shivambu & Shivambu, 2020). Species trade is a major contributing factor to species introduction (Lockwood *et al*., 2019). For example, Marshall, Strine, and Hughes (2020) reported on the trade of reptiles, mostly captured from the wild and sold illegally online, and highlighted that the gaps in regulating species trade could negatively impact threatened species. Introducing non-native animals into new regions has often negatively impacted the native fauna, environment and the economy (Vitousek, D'antonio, Loope, Rejmanek, & Westbrooks, 1997; Strauss, Webb, & Salamin, 2006; Risch, Ringma, & Price, 2019).

One such species introduced almost throughout the world is the European wild boar (*Sus scrofa*, hereafter wild boar), the wild species of the domesticated pig species (*Sus scrofa domesticus*) (Barrios-Garcia & Ballari 2012). The distribution of wild boar throughout the world is largely through anthropogenic activities, where the species has been introduced intentionally or unintentionally (Barrios-Garcia & Ballari, 2012; Rutten, Casaer, Strubbe, & Leirs, 2020). The wild boar can be distinguished by its relatively large skull, thin snout, and short ears (Massei, 2004). Adult wild boars weigh between 35 and 230 kg and have a life expectancy of up to 12 years (Massei, 2004; Drimaj *et al*., 2019). Tusks are normally present

in mature males and females, but males' tusks are larger (Massei, 2004). Piglets have distinct brown and cream longitudinal stripes (Massei, 2004).

Wild boar can alter ecosystems through their habits like wallowing and rooting for food, where they negatively impact soil fertility and species (plants and animals) abundance (Ballari *et al*., 2015; Burrascano *et al*., 2015). Furthermore, wild boar can have an economic impact by destroying crops and transmitting diseases to cattle (Rutten *et al*., 2020). Furthermore, Miller *et al*. (2017) documented that spatial overlaps between livestock and wild boar are important points for disease transmission. Moreover, in a study conducted by Barasona *et al*. (2014) in North America, there were 34 pathogens prevalent in wild boar that cause clinical diseases in wildlife, poultry, livestock and humans. In recent years, wild boars were farmed on free-range pig farms for wild meat (Ballari, Cuevas, Cirignoli & Valenzuela, 2015; Sales *et al*., 2017). This increased the possibility of selectively bred domestic pigs crossbreeding with wild boar (Fulgione & Buglione, 2022). The feral hybrid inherits the selected features of higher fecundity and growth rates and other desirable traits, including fitness and high fertility (Sales *et al*., 2017). As a result, if such crossbred pigs escape, more fast-growing feral pig populations will contribute to increased environmental degradation (Sales *et al*., 2017; Adams, Fontaine, Huston, & Fleming, 2019; Lewis *et al*., 2019). Moreover, the sex-biased dispersal pattern of wild boars, where the adult female drives the male offspring off, can be a possible contributing factor for wild boar crossbreeding with domestic pigs (Podgórski, Scandura, & Jędrzejewska, 2014). The wild boar has a relatively high success rate for colonising new environments because of its omnivorous diet and large litter size (Pastick, 2012; Sales *et al*., 2017). Once established, the costs to eliminate them are high (Courtois, Figuieres, Mulier, & Weill, 2018; Gaskamp, Gee, Campbell, Silvy & Webb, 2018; Fischer *et al*., 2020).

In South Africa, wild boars were likely introduced around the late 1920s as biological control agents against the pine emperor moth (*Imbrasia cytheria*) invading pine forests in the Western Cape Province (Botha, 1989; Skead, 2011). Despite the wild boar's initial introduction here as a biological control agent, it is invasive because of its biology and range spread (Adams *et al*., 2019). In South Africa, it is listed as a category 1b alien invasive species and, therefore, must be removed/ eradicated (National Environmental Management: Biodiversity Act (NEM: BA) 2020).

The use of species distribution modelling has been an effective means of determining the potential a species has for colonising a new environment based on determining the elements that constitute the most suitable niche (Liu, Wolter, Xian, & Jeschke, 2004; Urbina-Cardona *et al*., 2019). Species distribution modelling has been successfully used for decision-making for the implementation of control measures for invasive species (Guisan & Thuiller, 2005; Pearson, 2010; Sofaer *et al*., 2019). Srivastava, Lafond, and Griess (2019) reviewed the application of species distribution modelling and its applicability in invasive species decision-making. In this study, we applied species distribution modelling based on climatic suitability to assess the present potential distribution range for wild boar in South Africa. We predicted that extensive areas in South Africa would be suitable, highlighting its invasion potential and need for control. This prediction was based on the knowledge of the species invasion success (Risch *et al*., 2021). Additionally, we used an online questionnaire to determine the prevalence of wild boar in the province of KwaZulu-Natal, South Africa, the awareness of the listing of the species on the National Alien List of Alien and Invasive Species, human-wildlife conflict with wild boar, the prevalence of hunting of wild boar and control measures being employed for wild boar.

3.3 Methods

3.3.1 Study area

The focus of our study was on South Africa (Figure 3.1). The climatic conditions of the nine provinces, namely KwaZulu-Natal, Western Cape, Gauteng, Limpopo, North West, Mpumalanga, Free States, Eastern Cape and Northern Cape, were used to determine suitability for wild boar occurrence (Figure 3.1).

The natural vegetation of South African provinces varies (Potts, Bond, & Cowling, 2015; Dayaram *et al*., 2019). However, there are seven vegetative types (Rutherford, Mucina, & Powrie, 2006; Skowno *et al*., 2021). The forest biome is most significant in the Western Cape Province, while the fynbos (natural shrubland or heathland vegetation) biome is the most dominant in the province and partially extends into the Northern Cape and Eastern Cape Provinces (Poulsen & Hoffman, 2015; Dexter *et al*., 2018; Cramer *et al*., 2019). The grassland biome is the most widespread (Muller, Siebert, Ntloko, Siebert *et al*., 2021a), and is found in the Eastern Cape, part of the Northern Cape, KwaZulu-Natal, the Free State, North West, Gauteng, Mpumalanga and part of Limpopo Province (Muller *et al*., 2021b). The Nama Karoo biome (semi-arid inland biome dominated by dwarf shrubs with grasses, shrubs, geophytes and herbs) is found mostly in the Northern Cape and extends into the Western Cape, Eastern Cape and the Free State Provinces (Henschel, Hoffman & Walker, 2018). The savanna biome (forest and grassland) is found in the Eastern Cape, KwaZulu-Natal, Free State, Northern Cape, North West, Gauteng, Mpumalanga and Limpopo Provinces (Andreu *et al*., 2019). The Succulent Karoo biome (arid with succulent flora) is found mostly in the Northern Cape and only extends into the Western Cape (Weber, Tamm, Maier, & Rodríguez-Caballero, 2018). The thicket biome (dense, woody, semi-succulent and thorny vegetation) is found only in the provinces of the Western Cape, mostly in the Eastern Cape and KwaZulu-Natal (Cowling,

Procheş, Vlok & van Staden, 2005). The type of biome can be correlated with the type of climate in the area (Phiri *et al*., 2020; Zevallos & Lavado-Casimiro, 2022).

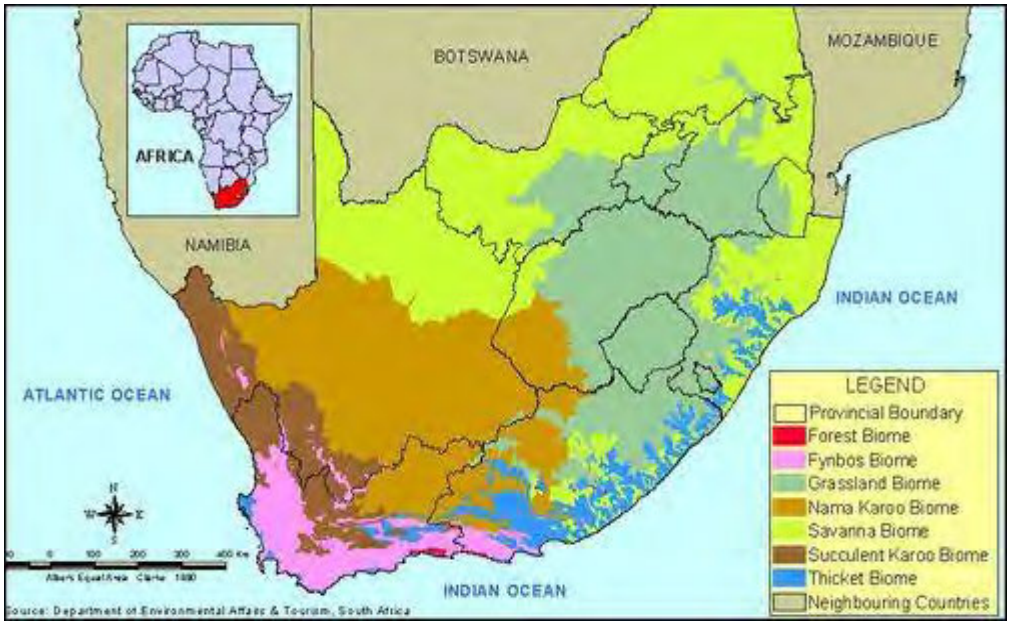

Figure 3.1: Main biomes found in South Africa (Source: Department of Environmental Affairs and Tourism, South Africa: http://iblog.co.za/wpcontent/blogs.dir/21355/files/2010/02/south-african-map-showing-climate-change.jpg)

3.3.2 Sampling techniques

The worldwide distribution records for wild boar were downloaded from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org). The GBIF is an online dataset platform that contains data on species observations from worldwide and from different sources. Additional records (selling points) of their presence in South Africa were obtained through the internet, Google© (https://www.google.com) using search phrases such as "wild boar for sale in South Africa", "*Sus scrofa* in South Africa" "wild boar meat in South Africa", "Published literature on wild boar in South Africa" etc.

The presence of wild boar in KwaZulu-Natal, South Africa, was also determined through an online questionnaire using the survey platform, SurveyMonkey

(https://www.surveymonkey.com) (Supplementary information Table S3.1). The questionnaire's link (https://www.surveymonkey.com/r/6WSBW3C) was emailed to Conservation Conservancies, taxidermists, hunting groups, and private landowners. The questionnaire had six yes/no questions and four short answer questions, and it was expected to take about 10 min. to complete and submit. Important questions asked in the survey were around awareness of the prevalence of wild boar in KwaZulu-Natal, wild boar listing in the NEM: BA Alien Invasive Species List, knowledge of any hunting sites for wild boar, human-wildlife conflict involving wild boar, and measures being instituted to address human-boar conflict (Supplementary information Table S3.1). We had ethical clearance from the University of KwaZulu-Natal Humanities Ethics Committee (Reference no. HSSREC/00003263/2021) for the questionnaire.

3.3.3 Species distribution modelling

We downloaded occurrence records for wild boar from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org) to develop a climatic suitability model based on occurrence records and bioclimatic variables. Bioclimatic variables were downloaded from WorldClim (https://www.worldclim.org/; Fick & Hijmans, 2017) and were used as environmental predictor variables to determine the climate suitability of wild boar in South Africa. A species distribution model based on climatic suitability was developed using the statistical software R version 4.1.1 (R Core Team, 2021). We assessed and improved the quality of the occurrence data using the Biogeo package in R (Robertson *et al.*, 2016). This included occurrence records that fell outside geographic boundaries, and duplicates were eliminated from the model. We used the SDM package in R version 4.1.1 to create an ecological niche model for the wild boar in South Africa (Naimi & Araújo, 2016; Hijmans & Elith, 2017).

There are 19 bioclimatic variables used for predicting climatic suitability, and only those that contributed towards predicting potential suitability for wild boar were selected (Table 3.1). We tested for correlations between bioclimatic variables using the variance inflation factor function (VIF) and Pearson (r) correlation coefficients to detect collinearity

(Naimi & Araújo, 2016). The collinear bioclimatic variables were excluded when building the model to ensure that all predictor variables were independent of each other. The spatial resolution of the bioclimatic variables was approximately 1 $km^{2,}$ as specified by Fick and Hijmans (2017).

Table 3.1: Percentage contribution of climatic variables that contributed the most in modelling for wild boar in South Africa. Dashes (-) represents predictor variables excluded from the model.

Variables	**Percentage contribution (%)**
BIO1 = Annual Mean Temperature	-
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))	3.5
BIO3 = Isothermality (BIO2/BIO7) (×100)	20
BIO4 = Temperature Seasonality (standard deviation ×100)	-
BIO5 = Max Temperature of Warmest Month	-
BIO6 = Min Temperature of Coldest Month	-
BIO7 = Temperature Annual Range (BIO5-BIO6)	-
BIO8 = Mean Temperature of Wettest Quarter	0
BIO9 = Mean Temperature of Driest Quarter	26
BIO10 = Mean Temperature of Warmest Quarter	-
BIO11 = Mean Temperature of Coldest Quarter	-
BIO12 = Annual Precipitation	-
BIO13 = Precipitation of Wettest Month	9
BIO14 = Precipitation of Driest Month	6
BIO15 = Precipitation Seasonality (Coefficient of Variation)	0
BIO16 = Precipitation of Wettest Quarter	-
BIO17 = Precipitation of Driest Quarter	-
BIO18 = Precipitation of Warmest Quarter	0
BIO19 = Precipitation of Coldest Quarter	36

We modelled the potential suitability for wild boar in South Africa using maximum entropy (MaxEnt version 3.4.4; Phillips, Anderson, & Schapire, 2006) with all default values in RStudio (R Core Team, 2021). Maxent requires presence and pseudoabsences records to predict potential species distribution models based on the species' environmental requirements (Phillips *et al*., 2006). One thousand pseudoabsences records were selected based on unfavourable environmental conditions for occurrence, with 100 bootstrap replications to improve the accuracy of the modelling (Rubin, 1981; Vaughan & Ormerod, 2005; Phillips *et al*., 2006).

The performance of the model was evaluated using 5-fold cross-validation (Zhang, 1993). The dataset was divided into a training dataset (80%) to generalise the model and a testing dataset (20%) to determine the model's performance. The model's performance in predicting climatic suitability for wild boar in South Africa was evaluated using the area under the receiver operation curve (AUC). The AUC, which is the independent-threshold statistic of the receiver operating characteristic curve (ROC), was used to assess model performance for wild boar in South Africa (Jiménez-Valverde, 2012) (Supplementary Information Figure S3.1). An AUC value of >0.9 is considered great, between 0.7 and 0.9 is considered decent, and below 0.7 is considered poor (Fielding & Bell, 1997). Models are rated by how close the AUC is to the value 1 (Fielding & Bell, 1997). For the analyses, R statistical software R version 4.1.1 (R Core Team, 2021) was used to plot the possible distribution map for wild boar in South Africa.

3.4 Results

3.4.1 Species distribution modelling

Of all the climatic variables (Table 3.1), BIO3, BIO9, and BIO19 contributed the most in determining areas of climatic suitability for wild boar in South Africa. The model performed well in estimating potential suitability for wild boar in South Africa, having an AUC value of 0.927 (Supplementary Information Figure S3.2). In South Africa, wild boar have an extensive potential distribution range (Figure 3.2). The Western Cape Province had the greatest predicted area of climatically suitable habitat for wild boar, followed by the Eastern Cape, and then KwaZulu-Natal Province (Figure 3.2). The climatic suitability decreased moving east along the coastal areas of the Indian Ocean (Figure 3.2). There was relatively little to no climatic suitability for wild boar moving north along the coastal areas alongside the Atlantic Ocean (Figure 3.2). The landlocked provinces such as the Free State, North West and Gauteng had the lowest climatic suitability for wild boar, falling below the 0.5 threshold for climatic suitability (Figure 3.2).

In South Africa, according to the distribution records from GBIF, wild boar have been reported to be prevalent in the Western Cape and KwaZulu-Natal Provinces (Figure 3.2). The occurrence records from this study do not reflect the abundance of the species in the country. The presented records reflect the known presence of wild boar in South Africa (Figure 3.2). From our online survey, we received distribution records for wild boar in the KwaZulu-Natal and Limpopo Provinces (Figure 3.2). From our online searches to identify selling points for wild boar, we found that the selling points of wild boar are presently in Gauteng, and Limpopo Provinces (Figure 3.2).

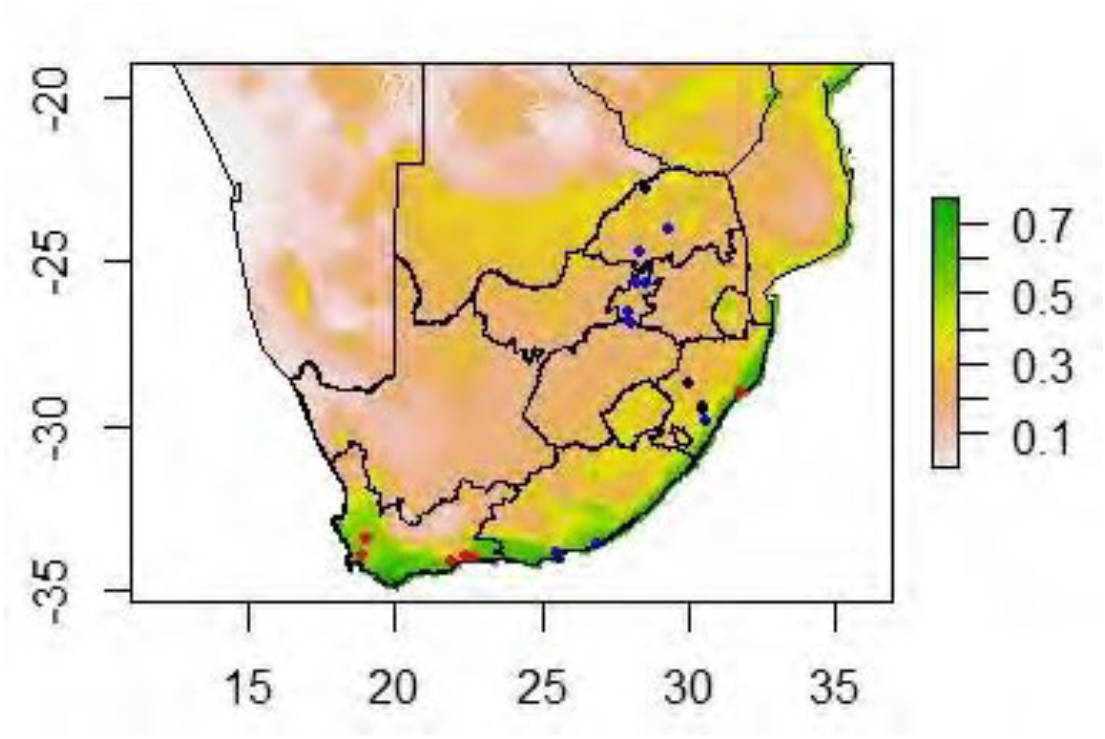

Figure 3.2: Map of potential climatic suitability for wild boar in South Africa and also showing present distribution and selling points. (Climatic suitability is represented by the colour ramp, with increasing colour intensity from light pink to green, the suitability for wild boar inhabitation increases. The red points indicate their present distribution records obtained from GBIF, blue points indicate their selling points in South Africa, and the black points show the distribution records obtained from the online survey).

3.4.2 Survey questionnaire

From the online questionnaire using SurveyMonkey (https://www.surveymonkey.com), which was active for five months (November 2021 – March 2022) and had 27 responses, we were able to determine that of the stakeholders that participated, only 26.9% knew of the prevalence of wild boar in KwaZulu-Natal Province (Figure 3.2, Supplementary information Figure S3.3 and Table S3.2), 29.5% had knowledge on human- wild boar conflict (Supplementary information Figure S3.6), 29.6% knew of hunting sites for the species (Figure 3.2, Supplementary information Figure S3.5 and Table S3.3); moreover, the majority (62.9%)

of the participants knew of the listing of the species on the National Alien and Invasive Species List (Supplementary information Figure S3.4). Furthermore, we were also able to get information on the measures being employed to address human-wildlife conflict with wild boar in the KwaZulu-Natal Province, South Africa; at present, these are hunting, culling and capture (Supplementary information Table S3.4).

3.5 Discussion

Three provinces in South Africa were found to be climatically suitable for wild boar (Figure 3.2). Despite having varying weather conditions for summer and winter, these provinces are considered climatically suitable for wild boar. Thus, we can deduce that the weather conditions determining the potential for wild boar persistence in South Africa can vary. In a study to determine the potential distribution of wild boar in Spain, the bioclimatic variables found to contribute the most in determining climatic suitability (BIO3, BIO5, BIO6, BIO8, BIO12 and BIO15) (Bosch, Mardones, Pérez, De la Torre, & Muñoz, 2004) differed to our results. From this, it appears that climatic suitability for wild boar varies in different regions of the world, or that climatic suitability has minimal influence on wild boar range distribution. Furthermore, other studies (Rosvold & Andersen, 2008; Bisi *et al*., 2018) showed that weather conditions are not a limiting factor in the range distribution of wild boar as it is found almost worldwide. Climatic suitability may not be a limiting factor for wild boar (Rosvold & Andersen, 2008); however, the prevailing climatic conditions influence the vegetation type (food availability), thus influencing the prevalence or establishment of wild boar.

Pittiglio, Khomenko and Beltran-Alcrudo (2018) showed that vegetative cover, specifically tree cover and crops have the most influence in determining the potential range distribution of wild boar. Similarly, other studies have shown wild boar persistence in environments highly depends on the vegetative cover (Cuevas, Ojeda, Dacar, & Jaksic, 2013).

In South Africa, we can deduce that the suitable climatic conditions for wild boar determined in this study are significant as these regions also have suitable vegetative cover for wild boar to seek refuge (Cuevas *et al*., 2013). There is a cause for concern for the occurrence of wild boar in South Africa as some of the distribution records (Figure 3.2) for the species are in regions with climatic suitability which is complemented by great agricultural activity (Paini *et al*., 2016; Jayne, Chamberlin & Benfica, 2018; Eschen *et al*., 2021), specifically the Western Cape, Eastern Cape, KwaZulu-Natal and Limpopo Provinces (Figure 3.3). South Africa has three main agricultural activities: crop and cattle farming and forestry (Figure 3.3). Crop farming (mainly consists of grains, sugarcane, vegetables, and fruits), cattle farming (mainly consists of cattle and sheep), and commercial forestry (mainly consists of exotic timber plantations) are dominant on the eastern seaboard (Figure 3). These agricultural activities occur in mosaic landscapes of natural, agricultural and built environments.

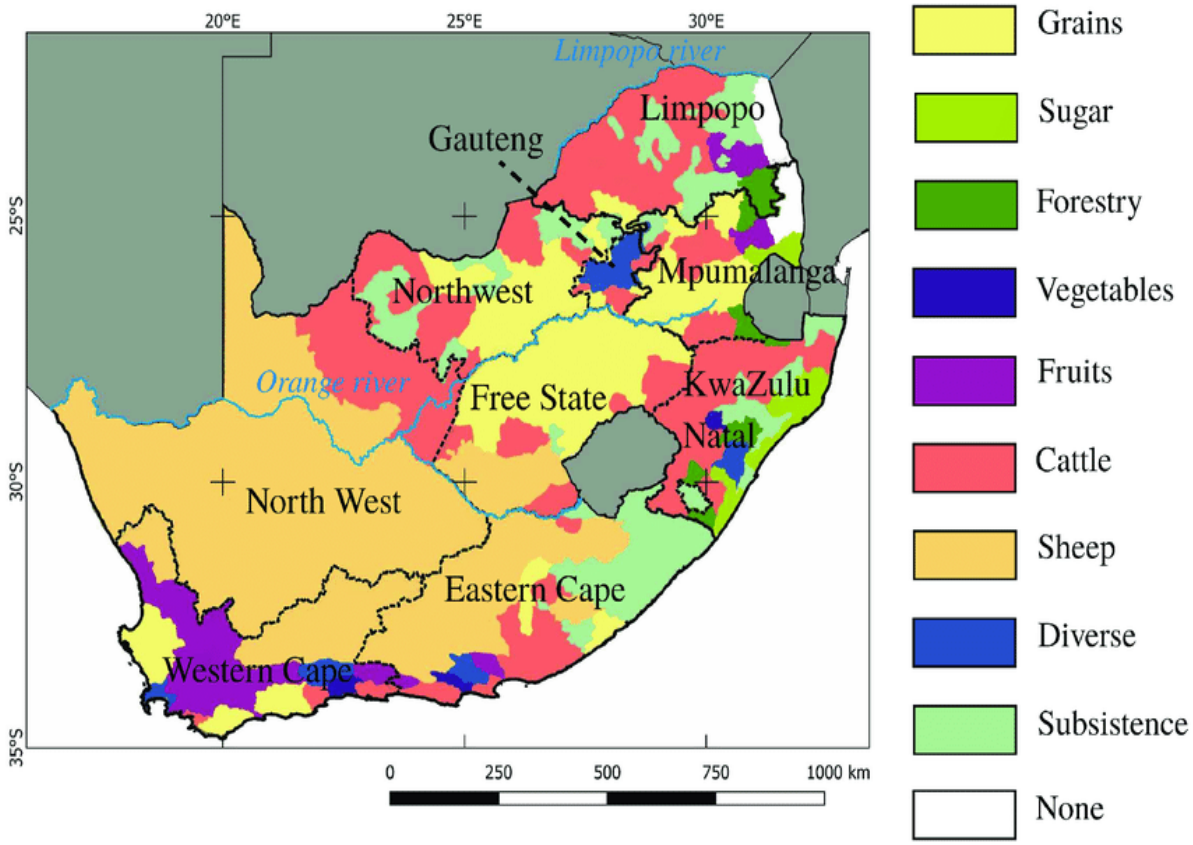

Figure 3.3: The provinces of South Africa and the various agricultural activities. (Source: https://www.researchgate.net/figure/Agricultural-regions-of-South-Africa-and-provincial-breakdown-Commercial-grain-growing_fig1_319168967).

Wild boars have a high affinity for high-energy food and, like any animal, prefer easier access to their diet preferences (Lee & Lee, 2019). Hence, wild boars have a high probability of invading crops as they are relatively high in energy and easy to access (Robeson *et al*., 2018). Wild boar are most likely to invade agricultural lands because of easy access to high-energy foods such as fruits and vegetables (Lee & Lee, 2019). This further highlights the concern about the prevalence of wild boar in South Africa. As a result, we can deduce that wild boar can potentially invade all provinces in South Africa with occurrence records that have crop farms. Thus, land use, such as agriculture, may be a major factor in predicting wild boar invasion. Moreover, Lewis *et al*. (2017) conducted research that revealed that including biotic factors such as agriculture and vegetation cover could improve model fit for distribution models for large invasive mammals. The wild boar is listed as one of the top 100 invasive alien species in the world (IUCN, GISD). The behavioural plasticity of mammal species typically allows for easy establishment in new environments (Latham, Warburton, Byrom & Pech, 2017). This taxon has colonised all continents except Antarctica and has become invasive in five of the nine continents of the world (Global Invasive Species Database, 2022). This demonstrates the ability of wild boars to adapt and establish themselves in a wide range of environments.

The Global Invasive Species Database (2022) lists the impacts associated with wild boar prevalence as competition, predation, grazing/herbivory/browsing, rooting/digging, trampling and interaction with other invasive species. The ramifications of these activities are modification of water regulation, purification and quality of soil moisture in native biodiversity**,** habitat degradation, modification of successional patterns and major economic losses to forestry as described in the Global Invasive Species Database (2022). Consequently, the occurrence of wild boar in South Africa must be monitored and controlled as the species

has a great potential to invade agricultural lands and has the potential to establish feral populations.

We realize that our survey's total response rate was relatively low (27 respondents). However, this could be explained by the fact that this questionnaire was intended for a certain group of stakeholders, especially those involved in farming or hunting, which may have marginalised our overall findings. However, the findings are important to this study since they represent the South African and KwaZulu-Natal wild boar stakeholders.

The majority of stakeholders in this study in the KwaZulu-Natal Province were aware of the legislative listing of wild boar (Supplementary information Figure S3.4); this is an important factor for management plans. The management of wild boar requires integrated management involving relevant stakeholder groups. In a study conducted by Geeraerts *et al*. (2021), for the control and management of wild boar, it was shown that reducing or preventing crop damage and the risk of car accidents were the most important management objectives of all three stakeholder groups (hunters, farmers and conservationists).

The present measures in place for controlling wild boar in KwaZulu-Natal Province are effective in other regions where wild boar are invasive (Poché *et al*., 2018; Keuling & Massei, 2021; Gaskamp *et al*., 2021). Thus, these practices (hunting, culling and capture) should be continued in KwaZulu-Natal Province, South Africa, to mitigate the potential for invasion by wild boar. However, the permitting of hunting of wild boar can also be seen as a contributing factor to the occurrence of feral wild boar, as hunters can release breeding pairs to increase the population for hunting purposes (Giacomelli, Gibbert & Viganò, 2018). The permitting of wild boar hunting as a control measure should be strictly regulated to prevent the release of illegal populations into the wild (Giacomelli *et al*., 2018). Moreover, when it comes to regulatory processes, the selling and buying of a listed invasive alien species, such as wild boar in South Africa, are prohibited (NEM:BA Alien and Invasive Species

Regulations); thus, the selling points identified in this study are illegal and will require biosecurity intervention to ensure cooperation with the law.

3.6 Conclusions

The prevalence of wild boar in South Africa needs to be monitored and controlled as stipulated by the NEM:BA Alien and Invasive Species Regulations; as it has the potential to be invasive and negatively impact the agriculture sector and biodiversity. Moreover, they are also a reservoir for diseases such as swine flu and tuberculosis, which poses health risks to humans and cattle (Ruiz-Fons *et al*., 2008; O'Neill *et al*., 2021). Furthermore, in accordance with the Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983), the prevalence of wild boar in agricultural lands can affect the production potential of agricultural land because of their activities of wallowing and rooting, causing the loss of fertile soil thus reducing the production potential of the land. As a listed invasive alien species and a potential threat to agricultural resources and biodiversity, a monitoring, controlling, and eradication plan needs to be developed for wild boar following the "Guidelines for monitoring, control and eradication plans as required by section 76 of the National Environmental Management: Biodiversity Act, 2004 (Act no. 10 of 2004) (NEM:BA) for species listed as invasive in terms of section 70 of this Act".

3.7 Acknowledgements

We are grateful to the University of KwaZulu-Natal (ZA), and the National Research Foundation (ZA, Grant 98404) for funding. We thank Ezemvelo KZN Wildlife (ZA) for vehicle support.

3.8 Data availability

The data belong to the University of KwaZulu-Natal and Ezemvelo KZN Wildlife. They are available on reasonable request.

3.9 Conflict of interests

We declare no conflict of interest in connection with the work submitted.

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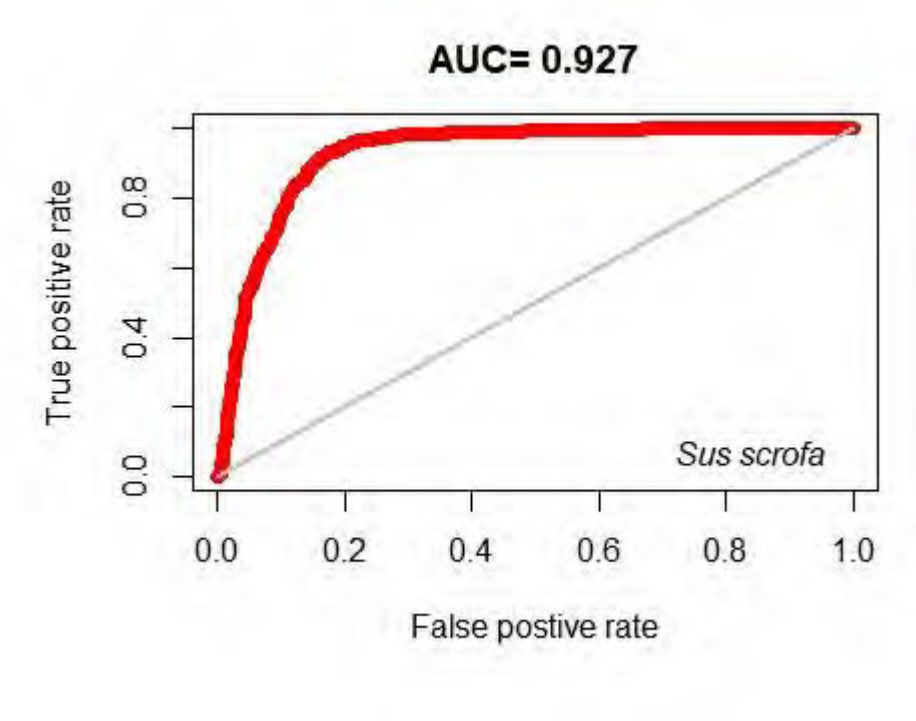
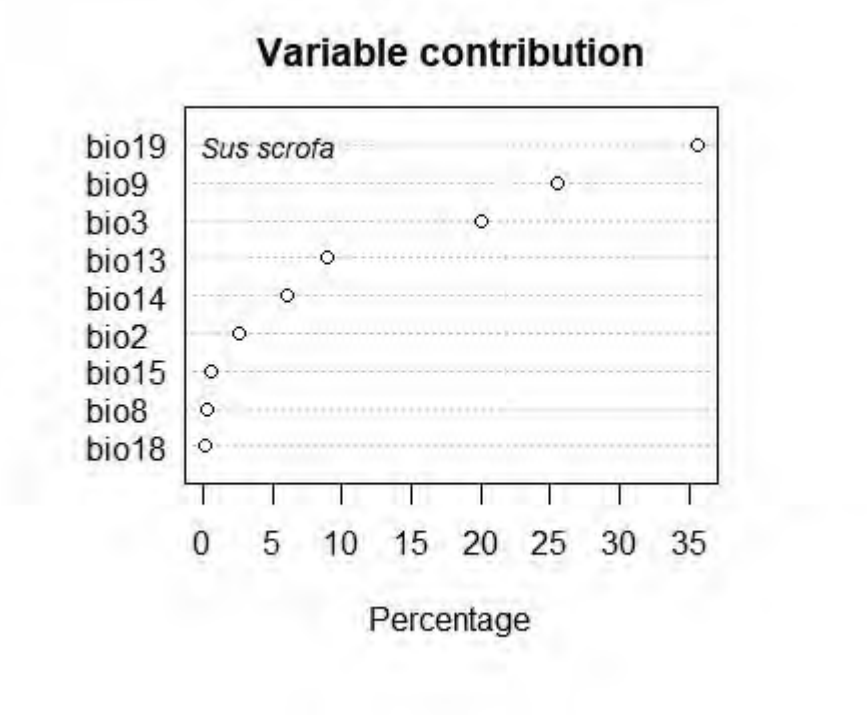
3.11 Supplementary information

Supplementary information Table S3.1: The online questionnaire used to get data on wild boar occurrence in KwaZulu-Natal Province using public participation.

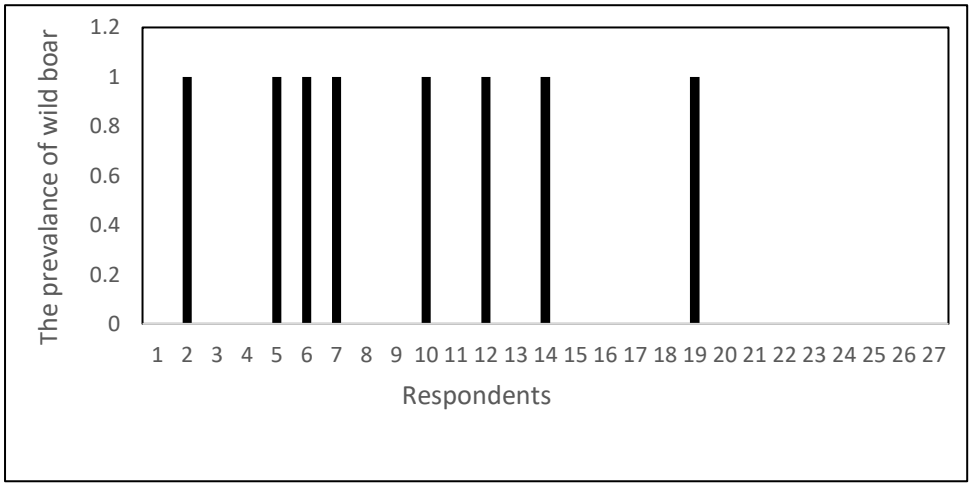
No.	Questions
1	Are you aware of any populations of Wild Boar in your area?
2	If yes, do you have the following information on such
3	Please can you provide such information (per property) in the box below: If you would prefer to email a map/Co-ordinates, please do so to: Claudette.James@kznwildlife.com
4	Are you aware of any human-wildlife conflict as a result of Wild Boar
5	If yes, have any of the following measures been instituted to address such
6	Are you aware of any hunting of wild boar taking place in the province
7	If yes, please can you provide locality details of such
8	Are you aware that Wild Boar are listed as a Category 1b listed invasive species in terms of the Alien and Invasive Species Regulations, promulgated in terms of the National Environmental Management: Biodiversity Act, 10 of 2004?
9	If no, would you like to be provided with more information?
10	Should you be willing to provide your contact details, please do so below (name, email address and phone number)?



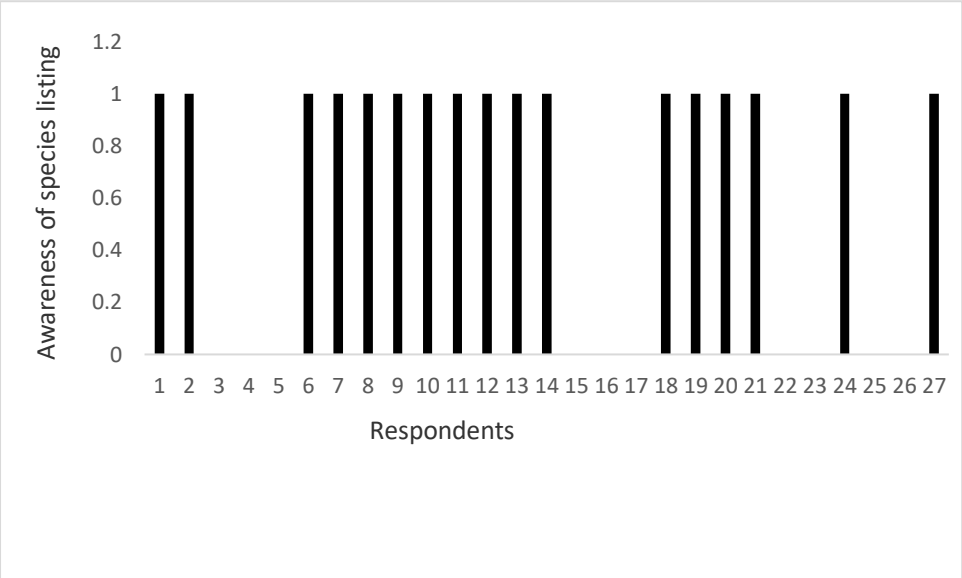
Supplementary Information Figure S3.1: Receiver Operation Curve showing the performance of the model in predicting the climatic suitability of invasive wild boar in the present study.



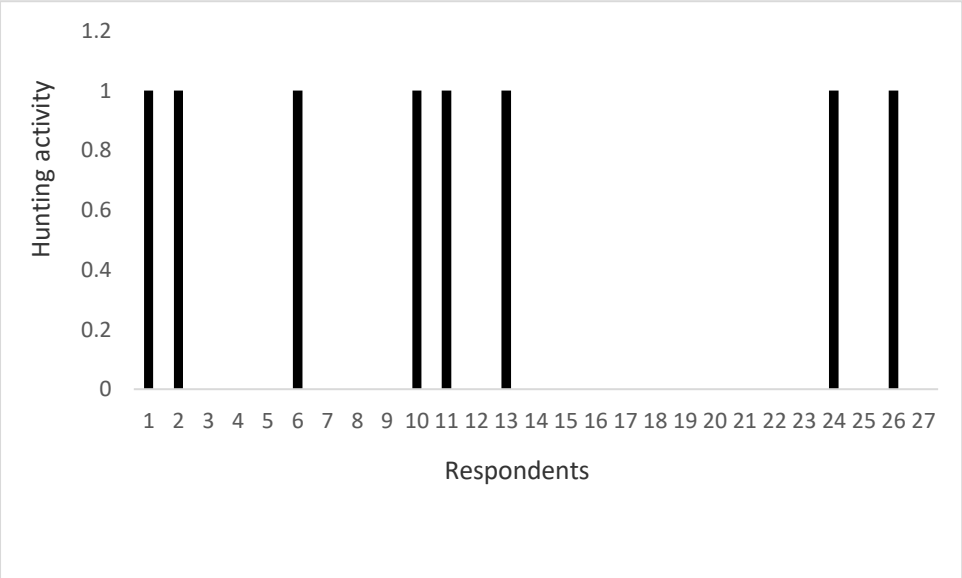
Supplementary Information Figure S3.2: Predictor variables that contributed the most in modelling the distribution of invasive wild boar (*Sus scrofa*)



Supplementary information Figure S3.3: The prevalence of wild boar in KwaZulu-Natal Province, South Africa, from the responses to the online survey conducted through the platform SurveyMonkey (https://www.surveymonkey.com). (A value of 1 on the y-axis indicated that the individual knew an area where wild boar are present, and a value of 0 indicated that the individual did not know of the presence of wild boar here). Only 29.6% of the stakeholders that participated in the survey knew of the prevalence of wild boar in KwaZulu-Natal.



Supplementary information Figure S3.4: Awareness of wild boar being listed as a category 1b species in KwaZulu-Natal Province, South Africa, from the responses to the online survey conducted through the platform SurveyMonkey (https://www.surveymonkey.com). (A value of 1 on the y-axis indicated that the individual was aware of the wild boar listing on the NEMBA Alien Invasive Species List, and a value of 0 indicated that the individual had no knowledge of the listing of wild boar on the NEM: BA Alien Invasive Species List). The majority, 62.9% of stakeholders that took part in the survey, knew of the Listing of wild boar on the National Alien and Invasive Species List.



Supplementary information Figure S3.5: The hunting of wild boar in KwaZulu-Natal Province, South Africa, from the responses to the online survey conducted through the platform SurveyMonkey (https://www.surveymonkey.com). **(**A value of 1 on the y-axis indicated that the individual knew of an area here where wild boar was being hunted, and a value of 0 indicated that the individual did not know of hunting wild boar here). Only 29.6% of stakeholders knew of hunting sites for wild boar in KwaZulu-Natal.

Supplementary information Figure S3.6: Human-wildlife conflict as a result of wild boar in KwaZulu-Natal Province, South Africa, from the responses to the online survey conducted through the platform SurveyMonkey (https://www.surveymonkey.com). (A value of 1 on the y-axis indicated that the individual had knowledge of the prevalence of human-wildlife conflict involving wild boar, and a value of 0 indicated that the individual had no knowledge of the prevalence of human-wildlife conflict involving wild boar). Only 25.9% of stakeholders knew of human-wildlife conflict involving wild boar.

Supplementary information Table S3.2: Localities where wild boar were present in KwaZulu-Natal Province, South Africa, from the responses to the online questionnaire conducted through the platform SurveyMonkey (https://www.surveymonkey.com).

Locations in KwaZulu-Natal	Wild boar presence
Molemane Eye Nature Reserve	Yes
Lot 7 Ekukhanyeni Farm, Pietermaritzburg	Yes
Throughout Newcastle District	Yes
Zingela Nature Reserve, Weenen	Yes
Goschen Farm, Drakensberg Gardens Road	Yes
Underberg District	Yes
Wartburg District (S 29 26 55.5 E 30 32 45.62)	Yes
Giba Gorge, Durban	Yes

Supplementary information Table S3.3: Hunting localities of wild boar in KwaZulu-Natal Province, South Africa, from the responses to the online questionnaire conducted through the platform SurveyMonkey (https://www.surveymonkey.com).

Locality	Wild boar hunting
Zingela Nature Reserve, Tugela Valley, Weenen	Yes
Sugarcane fields, Wartburg	Yes
Pietermaritzburg	Yes
Newcastle District	Yes
Crop growing areas mainly, location not specified	Yes
Adjoining farm, location not specified	Yes
Normandien (African Bush pig)	Yes

Supplementary information Table S3.4: Measures being employed to address human-wildlife conflict with wild boar in KwaZulu-Natal Province, South Africa, from the responses to the online questionnaire conducted through the platform SurveyMonkey (https://www.surveymonkey.com).

Control measures	**Wild boar (*Sus scrofa*)**
Hunting	Yes
Culling	Yes
Capture	Yes

CHAPTER 4

The occurrence of wild boar (*Sus scrofa*) in KwaZulu-Natal, South Africa

Claudette N. James[1,2], Brent Coverdale[1,2] and Colleen T. Downs*

[1]*Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg, 3209, South Africa*

[2]*Ezemvelo KZN Wildlife, Conservation Research & Assessment, 1 Peter Brown Drive, Montrose, Pietermaritzburg, 3201*

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* Corresponding author: Colleen T. Downs

Email: downs@ukzn.ac.za; ORCID: http://orcid.org/0000-0001-8334-1510

Other emails and ORCIDs:

C James Email: cnjames0204@gmail.com; ORCID: https://orcid.org/0000-0001-8970-6947

B Coverdale Email: Brent.Coverdale@kznwildlife.com

Running header: Prevalence of wild boar

4.1 Abstract

Wild boar (*Sus scrofa*), native to Europe, has established populations almost throughout the world because of their ability to adapt to new environments. The distribution of wild boar throughout the world is largely through anthropogenic activities, where the species has been introduced intentionally. The possibility of wild boars establishing feral populations from pig farms as the source of origin has been evident in other regions of the world and is a serious concern. Using camera trap surveys, we aimed to determine the prevalence of feral wild boar in KwaZulu-Natal Province, South Africa. The study areas were selected based on citizen science feedback through an online questionnaire to determine areas with evidence of wild boar. Thus, all the study areas we used in this research were known to have wild boar activity in the past. The results of the camera trap surveys showed no feral wild boar populations in KwaZulu-Natal presently, except at the one study area in the Thukela River Valley near Weenen, where the wild boar were given supplemental food, and 'farmed' for hunting. These findings were similar to those from our questionnaire on community perceptions of the prevalence of wild boar, where wild boar was listed as the least prevalent of the pig species in KwaZulu-Natal. However, with the prevalence of commercial pig farms in KwaZulu-Natal, especially the Midlands, there is a need for regular monitoring to ensure that escaped wild boar do not establish feral populations.

Keywords: *Sus scrofa*; pig farms; crop farms; wild boar farm; nocturnal species; prevalence of wild boar

4.2 Introduction

Wild boar (*Sus scrofa*), natively from Europe, has been able to establish populations almost throughout the world because of their ability to adapt to new environments (Massei et al., 2011; Barrios-Garcia and Ballari, 2012; Skewes and Jaksic, 2015; Johann et al., 2020; Sütő et al., 2020; Mihalik et al., 2020). The distribution of wild boar throughout the world is largely through anthropogenic activities, where the species has been introduced intentionally (Johann et al., 2020).

Wild boar are omnivores whose diet ranges from plant to animal species (Schley and Roper, 2003; Herrero et al., 2006; Sütő et al., 2020), thus allowing the species to be able to establish in many environments. However, wild boar population dynamics vary depending on the environment in which they persist (Geisser et al., 2005; Magnusson, 2010; Kopij and Panek, 2016). It has been determined that the growth rate of wild boar is also dependent on food availability and prevailing weather conditions, which in turn influences mating patterns and distribution (Massei et al., 1996; Baubet et al., 2004; Geisser et al., 2005; Magnusson, 2010; Sales et al., 2017; Mikulka et al., 2018; Bisi et al., 2018). The faster the growth rate, the more frequent matting occurs, thus faster-growing populations. Moreover, of all ungulates, wild boar have the highest reproductive rate (Fonseca et al., 2010; Keuling et al., 2013; Gamelon et al., 2014).

The wild boar's diet and behavioural patterns make them pests (Baubet et al., 2004; Greco et al., 2021). They can cause local extinctions of plant species, accelerate soil erosion by rooting on slopes, cause the loss of fertile topsoil, feed on the eggs and chicks of ground-nesting birds and alter the flow of energy in ecosystems (Sanders et al., 2020). Hence, wild boars are considered invasive in their new environments outside of their historical distribution range because of their behavioural patterns and impacts (Fernanda Cuevas et al., 2013; Brogi et al., 2019).

Wild boar can alter ecosystems through their habits like wallowing, rooting for food, and selective breeding (Ballari et al. 2015; Burrascano et al. 2015). Furthermore, wild boar can have an economic impact by destroying crops and transmitting diseases to cattle leading to major economic losses (Rutten et al. 2020). For example, in the USA, the US Department of Agriculture (USDA) is presently investing ~$75 million in projects to help agricultural producers and private landowners trap and control feral swine as part of the Feral Swine Eradication and Control Pilot Program (USDA 2023, "Feral Swine Eradication").

In South Africa, the NEMMBA Alien Invasive Species regulations (20 September 2020) have listed wild boar (*Sus scrofa*) as a category 1b alien invasive species. Thus, the prevalence of the species in the country must be monitored. The invasive range distribution of wild boar in South Africa is mainly along the eastern seaboard, including KwaZulu-Natal Province, and inland in the Gauteng Province mainly (Chapter 3, Fig. 4.1). Our study aimed to determine the prevalence of feral wild boar in the KwaZulu-Natal Province where it was reported. We predicted that their prevalence would be low in areas where reported, as farmers generally shoot them (Chapter 3), but we expected high numbers where they were farmed as wild stock and fed supplementary food.

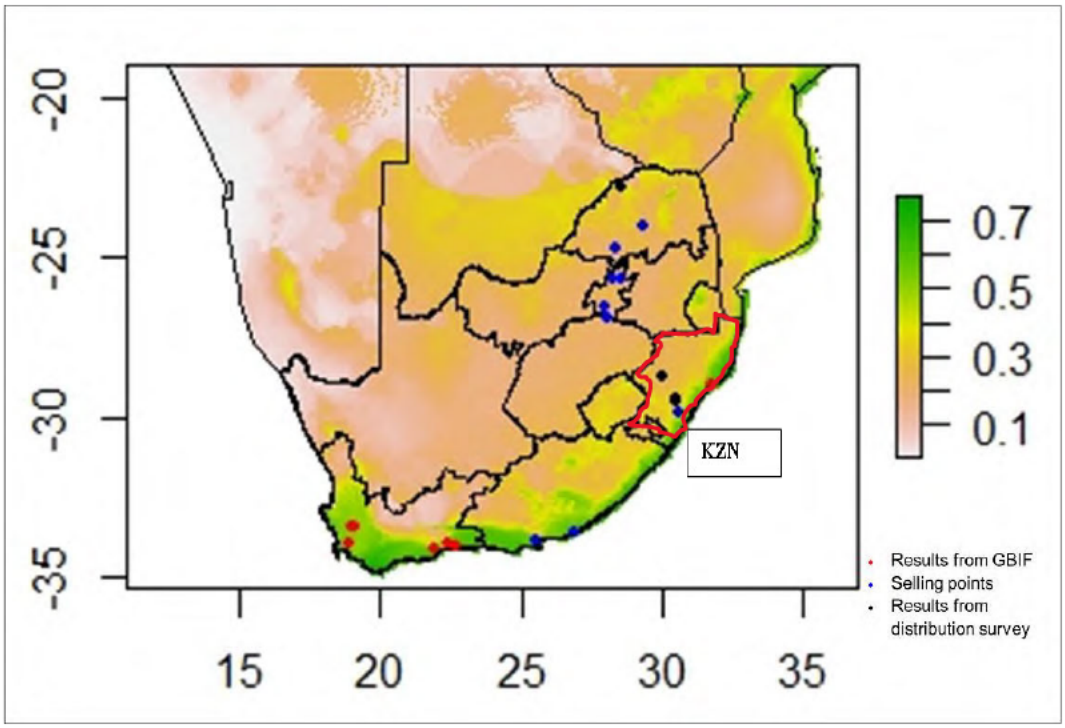


Figure 4.1: Map of wild boar distribution in South Africa (Source: Chapter 3). The points on the map represent wild boar locations in South Africa. This study focused on wild boar locations in KwaZulu-Natal (KZN) Province (outlined in red).

4.3 Methods

We used a questionnaire (Chapter 3, Supplementary information Table S3.1) to obtain citizen science feedback on where wild boar were present in KwaZulu-Natal for selecting study areas to conduct camera trap surveys to determine the prevalence of wild boar.

4.3.1 Study areas

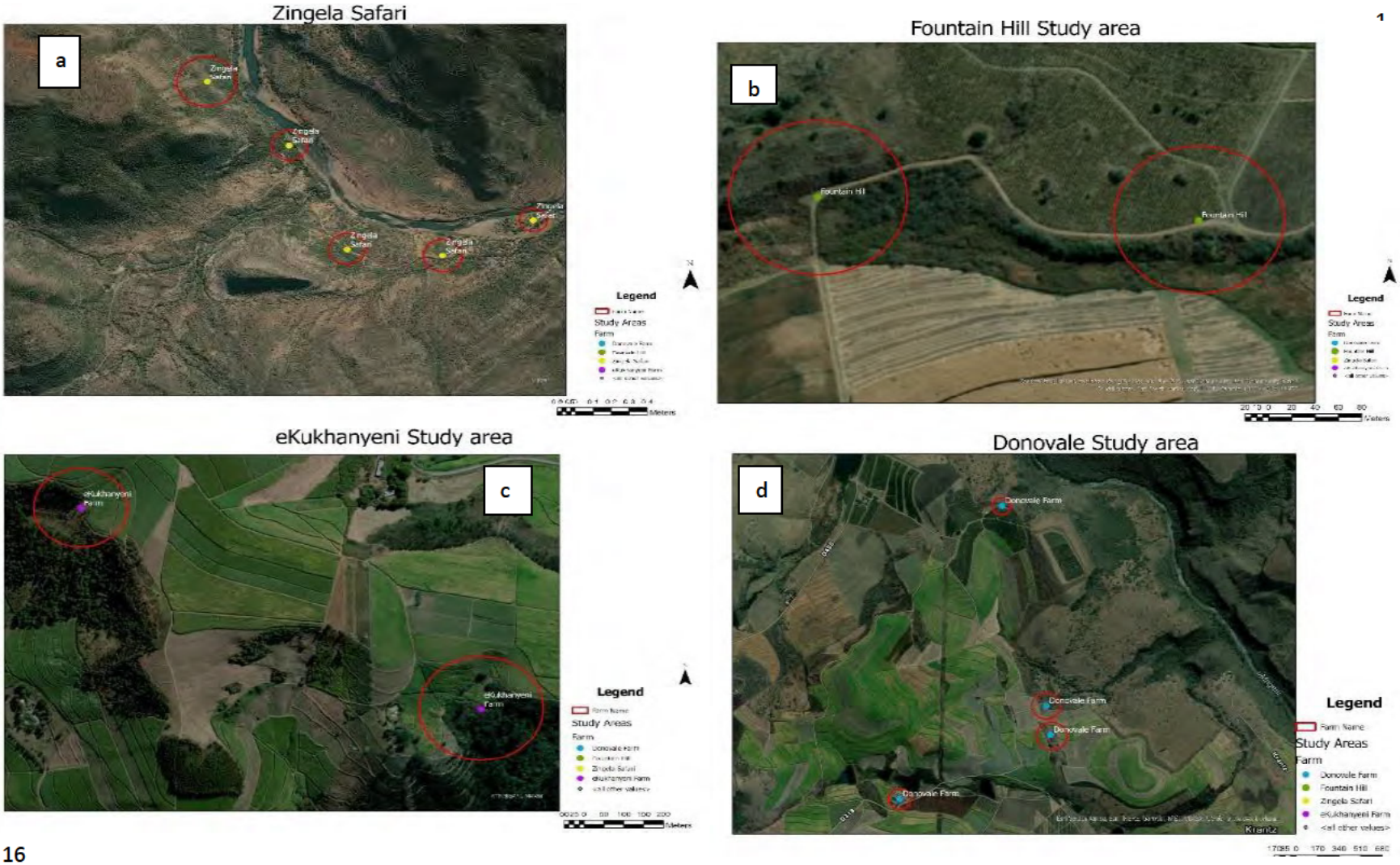
The study areas for this research were in the Midlands of the KwaZulu-Natal Province, South Africa. These study sites were selected based on the results from a parallel study investigating the prevalence of wild boar in South Africa (Fig. 4.2, Supplementary Fig. S4.1).

The first study area was Zingela Safari (hereafter Zingela), located in the Weenen area of KwaZulu-Natal (28º 43.035 S 30º 03.800 E, Fig. 4.2), which is ~1200 ha and is bordered by the uThukela River. It has some arid areas as well as areas dominated by the Thukela Valley Bushveld vegetation type. This vegetation type is dominated by *Vachellia* tree species which are *V. tortilis* and *V. robusta* together with evergreen tree species such as the shepherd's tree (*Boscia albitrunca*) (Ezemvelo KZN Wildlife 2013). The area also has high numbers of Aloe *marlothii*. The area is generally dominated by *Blepharis natalensis* undergrowth resulting from overgrazing in the past. Zingela is a private game reserve with a section of the farm used to breed wild boars. The wild boar at the farm are free-ranging and are supplementary fed (pers. comm., Supplementary Fig. S4.2).

The second study area was Fountain Hill Estate (29.4470 S, 30.5461 E, Fig. 4.2), located outside Wartburg, ~30 km from Pietermaritzburg. This comprises ~2200 ha, with a section maintained as a privately owned game reserve (~1600 ha) with wildlife (Grey-Ross et al., 2009). The remaining area is a commercial section with mainly sugar cane (*Saccharum officinarum*) and avocado (*Persea americana*) plantations, while further sugarcane plantations border the property. The dominant crops planted on this farm are sugarcane and maize (*Zea mays*) in rotation (10 years rotations). This study area had recorded previous encounters with escaped wild boar from a nearby pig farm (E. Gevers pers. comm.).

The other study areas were Donovale Farm (29°29′57″S, 030°29′44″E) and Ekukhanyeni Farm (29°33'40.4"S 30°28'33.7"E, Fig. 4.2), which were crop farms located in the Table Mountain area outside the city of Pietermaritzburg in KwaZulu-Natal. The dominant crops on these farms were sugarcane and maize in rotation.

Figure 4.2: Map of the selected study areas to determine wild boar prevalence in KwaZulu-Natal Province, South Africa.



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17 **Figure 4.3:** The study sites at the selected study areas where the camera traps were set up where a. Zingela Safari, b. Fountain Hill Estate c.
18 Donovale Farm and d. Ekukhanyeni Farm in KwaZulu-Natal.

4.3.2 Camera trapping

Our sampling technique used to determine the prevalence of wild boar in KwaZulu-Natal was using a camera trap survey (trail camera traps Moultrie and Browning brands, USA, with infrared flash). The settings we used on the camera traps were as follows: the photo mode was used with a 30 s delay between captures, the temperature was set to Degrees Celsius, the date and time were set to Central African Time, the picture size was set to 8 MP, the infrared flash was set to long range, the info strip was set ON, and the Secure Digital (SD) card management feature was set off, so images were not deleted from the memory card once it was full. We named the respective camera trap and inserted memory cards and batteries into the camera strap to take and store images. We retrieved the images captured and stored on the memory cards of each camera trap using a Universal Serial Bus (USB) memory card adaptor and saved the images digitally.

We placed the camera traps in a random systematic format at each of our study areas (where each camera trap site was referred to as a camera trap station). Zingela is known to have wild boars that were supplementary fed so we set camera traps at more sites there than in the other study areas to determine where the boar were predominately and what numbers there were. Generally, we set the camera traps at known feeding sites, along walking trails, at drinking points or where there was evidence of pig activity such as rooting. Each camera trap was attached to the trunk of a tree and mounted to face the point of interest (e.g. evidence of pig activity). We attached camera traps (Fig. 4.4) at the height of ~40 cm above the ground to ensure that piglets could also be captured. We used a global positioning system (GPS) to record the geographical location of each camera trap. We left the camera traps for a week to capture data and ensure that data were for a closed population. We conducted the camera trap

surveys in two seasons, austral summer (2021 – 2022) and winter (2022), with camera traps in the same sites, and then compared the results.

To increase the chances of capturing photographs of wild boar, we used a mix of whole yellow dry maize (Smith Aminal Feeds) and molasses (left over scrap from Ekukhenyeni Farm) (for scent) as bait to attract wild boar to the camera stations. The amount of bait used was standardised to ~2 kg of bait per camera trap station, and bait was only provided once at the beginning of the week of data collection. The setting up of the camera traps and the baiting technique were standard for both summer and winter surveys.

Figure 4.4: Each camera trap was attached to a tree trunk, and bait was placed to attract the species of interest, the wild boar.

4.3.3 Questionnaire

We prepared a questionnaire (Supplementary information Table S4.2) to get community perceptions on wild pigs and to determine the knowledge and perceptions of landowners/ farmers on the prevalence of wild pigs, especially wild boar, in the farming areas of KwaZulu-Natal. We had ethical clearance from the University of KwaZulu-Natal Humanities Ethics Committee (Reference no. HSSREC/00003263/2021) for the questionnaire. We used an

online survey platform, SurveyMonkey (https://www.surveymonkey.com), to host the questionnaire. The questionnaire's link (https://www.surveymonkey.com/r/6WSBW3C) was emailed to Conservation Conservancies, taxidermists, hunting groups, and private landowners to get respondents. The questionnaire was active for five months (November 2021 – March 2022).

4.3.3 Data analyses

The camera trap images were sorted according to a method described by (Sanderson and Harris, 2013). The images were renamed using the application ReNamer (version 7.4), and the images were renamed according to the date and time they were captured. Thereafter we sorted the images according to species and determined the frequencies of each. We produced graphs in Microsoft Excel© to display the trends in the species captured by the camera traps in each study area.

We used descriptive statistics to analyse our results from our questionnaire. We had a low response to the questionnaire, so we did not use non-parametric statistics to determine any significance.

4.4 Results

4.4.1 Camera trap vertebrate species- farmland sites

During summer, only two vertebrate species were captured using camera traps at Donovale Farm site 1 (common or grey duiker (*Sylvicapra grimmia*) and vervet monkey (*Chlorocebus pygerythrus*)) (Table 4.1). In comparison, during winter, a total of eight species were captured on camera at Donovale Farm site 1 and only one individual of each species (Table 4.1). Of the species photographed, only two species, Cape or South African large-spotted genet (*Genetta tigrina*) and Cape porcupine (*Hystrix africaeaustralis)*, were nocturnal. The most

prevalent species at this site was Cape porcupine, with over 20 incidences recorded. No wild boar or other nocturnal species were recorded at this site in both seasons. Five species were captured at Donovale Farm site 2 in summer (common duiker, quail spp., Cape genet, vervet monkey and common warthog (*Phacochoerus africanus*) (Table 4.1). Of the species recorded, only one species was nocturnal, the Cape genet. Vervet monkeys were the most prevalent, with up to two individuals recorded at a time in more than one incidence. During winter, five vertebrate species were captured on camera at Donovale farm site 2 (Table 4.1). The most prevalent species at this site were birds and vervet monkeys, with up to two individuals recorded and over 30 incidences recorded. There were no nocturnal species recorded at this site in winter. There were no wild boar recorded at this site in either season.

Nine vertebrate species were captured on camera at Ekukhanyeni Farm site 1 during summer (vervet monkey, bushbuck (*Tragelaphus scriptus*), bush pig (*Potamochoerus larvatus*), Cape porcupine, Cape genet, quail spp. and wild boar (Table 4.1). Four were nocturnal; bush pig, Cape porcupine, Cape genet, and one suspected juvenile wild boar (Fig. 4.5). Vervet monkeys were the most prevalent, with up to 12 individuals photographed in one instance. Cape porcupine and bush pig were the most prevalent nocturnal species, with incidences of one individual photographed more than five times for each species. Genet and wild boar were only recorded once at this site with one individual of each species, respectively. In repeat summer sampling, eight vertebrate species were captured on camera at this site (Table 4.1), with only two nocturnal species, Cape genet and Cape porcupine. The most prevalent at this site was vervet monkey, with over five individuals recorded in one instance.

Four species were recorded at Ekukhanyeni farm site 2 in summer (Table 4.1), and most were nocturnal; bush pig, genet, and Cape porcupine. Bush pig was the most prevalent species at this site, with incidences of more than one individual recorded more than five times.

During winter at Ekukhanyeni farm site 2, only three vertebrate species were recorded, antelope, bird and vervet monkey (Table 4.1). The most prevalent species at this site were vervet monkeys, with over six individuals recorded in one instance and over 190 incidences recorded. The least common species at this site were antelope and bird, with only one photographed for each, respectively. Wild boar was not recorded at site 2 in both seasons.

Figure 4.5: Image of suspected juvenile wild boar recorded in November 2021 at Ekukhanyeni Farm site 1. However, this was later refuted.

Ekukhanyeni Farm site 3 was overgrown with vegetation in the first summer (October 2021 – February 2022). No camera traps were set up, hence there were no records. In winter at Ekukhanyeni Farm site 3, a total of eight vertebrate species were photographed. Three species were nocturnal (bush pig, Cape genet, and Cape porcupine). The most prevalent species on this site was the vervet monkey, with over three individuals of the species recorded in one instance and 150 incidences overall, followed by birds with over 50 incidences. The least prevalent species was the bush pig, with only one individual recorded less than six times. There were no wild boar recorded at this site in both seasons.

During summer, only one vertebrate species was recorded at Fountain Hill Estate site 1, a mongoose spp., while seven were recorded at Fountain Hill Estate site 2 (Table 4.1). Of the species photographed, only three species were nocturnal, bush pig, genet, and Cape porcupine. No wild boar were recorded at this site. Cape porcupine was the most prevalent at this site, with up to 12 incidences of one individual photographed and one incidences of two individuals photographed. The second most active species at this site was the bush pig, with up to three individuals recorded at a time. In contrast in winter at Fountain Hill Estate site 1, six vertebrate species recorded (antelope spp., bird spp., giraffe (*Giraffa giraffa*), ostrich (*Struthio camelus*), warthog, vervet monkey and zebra (*Equus quagga*), Table 4.1). There were no wild boar recorded as well as no other nocturnal species. The most prevalent species at this site were birds with up to two individuals recorded in one instance and over 60 incidences overall. The second most prevalent species at this site were zebra with one individual recorded more than ten times.

A second summer sampling was conducted at Ekukhanyeni Farm to confirm the absence of wild boar in the study region. In summer (November 2022), nine vertebrate species (antelope spp., bird spp., bushbuck, bush pig, caracal, Cape genet, Cape porcupine, grey duiker, and vervet monkey) were recorded at Ekukhanyeni Farm site 1. Only two species were nocturnal, Cape genet and Cape porcupine. There were no wild boar recorded at this site. The most prevalent species at this site were vervet monkey, with over three individuals recorded in one instance and over 300 incidences recorded. Bird spp. were the second most prevalent at this site, with up to two individuals recorded in one instance and an overall of over 100 incidences recorded. The least prevalent species at this site was caracal, with only one individual recorded and only one encounter.

In summer, seven vertebrate species (antelope spp., bird spp., Cape genet, black-backed jackal, mongoose spp., vervet monkey and Cape porcupine) were recorded at

Ekukhanyeni Farm site 2. Only two species were nocturnal, Cape genet and Cape porcupine. There were no wild boar recorded at this site. The most prevalent species at this site were antelope spp. with over 25 incidences of one individual recorded. The least prevalent species were mongoose spp. and vervet monkey, with only one individual and one incident recorded, respectively.

In summer (November 2022), seven vertebrate species (antelope spp., bird spp., bush pig, caracal, Cape genet, Cape porcupine and vervet monkey) were captured using camera traps at Ekukhanyeni farm site 3. Three species were nocturnal, bush pig, Cape genet, and Cape porcupine. The most prevalent species at this site were vervet monkeys, with up to seven individuals recorded in one instance and an overall of more than 150 incidences recorded. The second most prevalent species at this site were antelope spp., with 195 encounters recorded. The least prevalent species at this site was caracal, with only one individual and five incidences recorded.

Table 4.1. Summary of vertebrate species captured using camera traps in the present study.

Study area		Donovale Site 1		Donovale Site 2		Ekukhanyeni Site 1		Ekukhanyeni Site 2		Ekukhanyeni Site 3		Fountain Hill Site 1		Fountain Hill Site 2		Zingela (wild boar farm)							
																Dump Site 1	Feeding Site 2	House Site 3	Laney Lane Site 4	Marula Bend Site 5	Riverbank Site 6	Roadside Site 7	Warthog Island Site 8
Species	Latin name	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	S	S	S	S	S	S	S
Common or grey duiker	*Sylvicapra grimmia*	Y		Y						Y													
Bushbuck	*Tragelaphus scriptus*					Y				Y													
Nyala	*Tragelaphus angasii*													Y									
Antelope spp.			Y		Y		Y		Y	Y	Y				Y		Y	Y	Y	Y	Y	Y	Y
Giraffe	*Giraffa giraffa*														Y							Y	
Zebra	*Equus quagga*														Y								
Donkey	*Equus a. asinus*															Y	Y	Y	Y		Y	Y	Y
Vervet monkey	*Chlorocebus pygerythrus*	Y	Y	Y	Y	Y	Y		Y	Y	Y			Y									
Chacma baboon	*Papio ursinus*																Y	Y		Y	Y	Y	Y
Aardvark	*Orycteropus afer*																				Y	Y	
Rock hyrax	*Procavia capensis*																				Y		
Bush pig	*Potamochoerus larvatus*					Y		Y		Y	Y			Y									
Common warthog	*Phacochoerus africanus*		Y	Y										Y				Y			Y	Y	Y
Wild boar	*Sus scrofa*					?										Y	Y	Y	Y		Y	Y	Y
Cape porcupine	*Hystrix africaeaustralis*		Y	Y		Y	Y	Y		Y	Y			Y							Y	Y	
Rodent spp.					Y			Y			Y					Y	Y						
Mongoose spp.			Y		Y	Y	Y				Y	Y		Y									
Large-spotted genet	*Genetta tigrina*		Y	Y		Y	Y	Y		Y	Y			Y				Y			Y		
Domestic dog	Canis lupus familiaris					Y	Y									Y		Y					
Black-backed jackal	*Lupulella mesomelas*		Y											Y									
Caracal	*Caracal caracal*						Y			Y													
Quail spp.				Y		Y																	
Bird spp.			Y		Y		Y		Y	Y	Y				Y		Y	Y	Y	Y	Y	Y	Y
Ostrich	*Struthio camelus*														Y							Y	
Owl spp.																		Y					
Helmeted guineafowl	*Numida meleagris*																						Y
Crow	*Corvus*															Y							
Wildebeest	*Connochaetes taurinus*																					Y	

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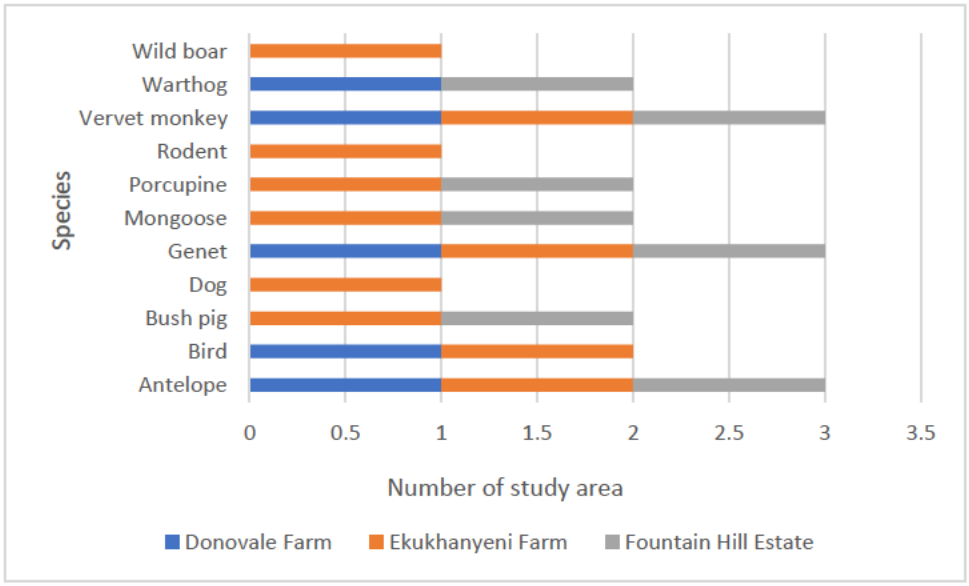

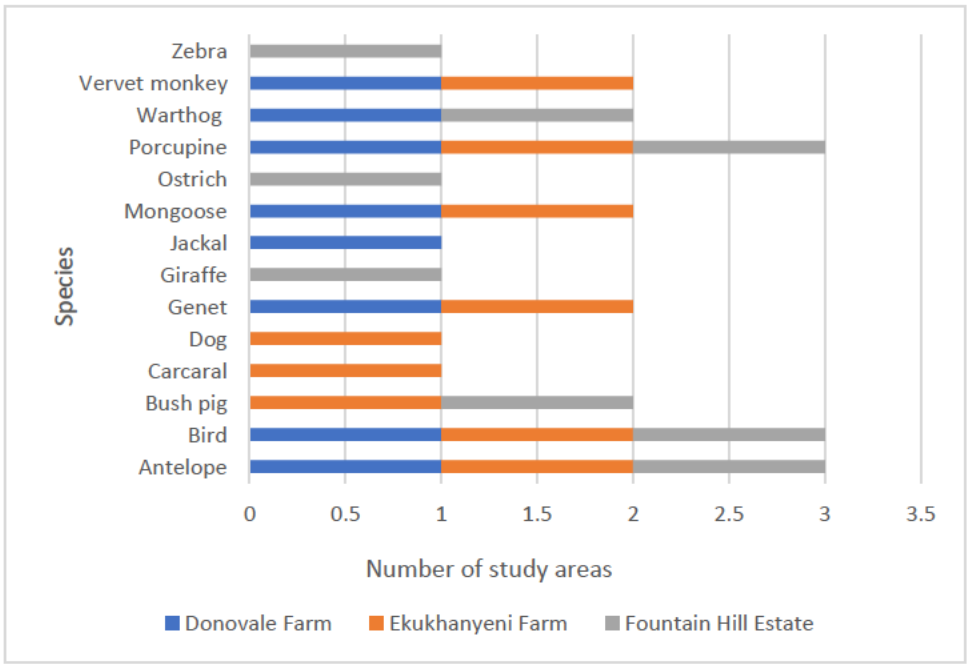

Figure 4.6: Summary of vertebrate species captured on camera at the selected study sites at the crop farms in a. summer (October 2021 – February 2022), and b. winter (July 2022) in the present study. Note the singular sighting of a wild boar was later refuted.

4.4.2 Summary of vertebrate species captured using camera traps on farm sites

In both summer and winter, Ekukhanyeni Farm selected study sites were the most diverse, with a greater variety of vertebrate species recorded by camera traps than Donovale Farm and Fountain Hill Estate study sites (Fig. 4.6, Table 4.1). In summer, a possible wild boar was only recorded in one study area, Ekukhanyeni Farm. This was later refuted. Warthog were only recorded in two study areas, Donovale Farm and Fountain Hill Estate, in both seasons. Bushpig, mongoose spp., and Cape porcupine were recorded on Ekukhanyeni Farm and Fountain Hill Estate in summer. Antelope spp., Cape genet, and vervet monkey were recorded in all three study areas in summer. Antelope and Cape porcupine were prevalent in all three study areas in winter. In winter, the black-backed jackal was only recorded in one study area, Donovale Farm, while a caracal (*Caracal caracal*) was only recorded at Ekukhanyeni Farm (Fig. 4.6).

Figure 4.7: Wild boar were farmed and regularly fed at one farm, Zingela Safari, near Weenen wild boar farm. (Photo credit: C James).

4.4.3 Zingela - free-ranging wild boar farm

The management of Zingela reported over 20 free-ranging wild boar (Supplementary Information Figure S4.1 -S4.) that were supplementary fed (Fig. 4.7). The wild boar were regularly fed dry maize, leftover food and scraps from the kitchen.

In the summer at Zingela, five vertebrate species (crow, donkey (*Equus a. asinus*), dog, rodent spp. and wild boar) were captured using camera traps at site 1, the dumping site (Table 4.1). The most prevalent species at this site were wild boar with up to 7 individuals recorded in one instance, with an overall of over 200 incidences recorded at this site. Adult wild boars were the most prevalent at this site, and the activity times ranged from late morning (around 11h30) and late afternoon (around 17h30). The second most prevalent were piglets, where the activity times were similar to that of adult wild boar. Juvenile wild boar were less prevalent at this site. The second most prevalent species at this site were donkeys, with up to three individuals recorded in one instance and an overall of over 29 incidences recorded. Birds were the second most prevalent species at this site, with up to two individuals recorded in one instance and an overall of more than 50 incidences recorded.

Six species (antelope spp., chacma baboon (*Papio ursinus*), bird spp., donkey, rodent spp., and wild boar) were recorded at site 2, the Feeding Site (Table 4.1). Only one species, wild boar, was nocturnal. They were the most prevalent at this site, with encounters of over 15 individuals in one instance and an overall of more than 69 incidences recorded. Piglets were the most prevalent at this site, followed by adults, then juveniles. The activity by wild boar at this site ranged from around 08h00 and was throughout the day and night.

Nine vertebrate species (antelope spp., chacma baboon, bird spp., donkey, dog, Cape genet, owl spp., warthog and wild boar) were recorded at Zingela site 3, the house on the hill (Table 4.1). Three were nocturnal (Cape genet, owl spp., and wild boar). The most prevalent species at this site were antelope, with up to nine individuals encountered at a time, followed by wild boar, with up to four individuals at a time encountered at this site and more than 79 encounters recorded. Adult wild boars were the most prevalent at this site, followed by piglets, then juveniles. The wild boar activity at this site ranged from around 07h00 and was throughout the day and night.

Five vertebrate species (antelope spp., chacma baboon, bird spp., donkey, and wild boar) were recorded at Zingela site 4, Laney Lane (Table 4.1). Only one, the wild boar, was nocturnal. The most prevalent species at this site was antelope spp., with up to ten individuals recorded in one instance and an overall of over 200 incidences recorded. The second most prevalent species at this site were wild boar, with up to six individuals and more than 25 incidences recorded. Wild boar piglets were the most prevalent at this site. The wild boar activity ranged from around 11h30 to ~16h00.

Three vertebrate species (antelope spp., chacma baboon, and bird spp.) were recorded at the Zingela site 5, Marula Bend (Table 4.1). Wild boar was not recorded at this site. The most prevalent species at this site was antelope spp. with up to six individuals recorded in one instance. The least prevalent species at this site was the baboon, with only one incidence of two individuals recorded.

Ten vertebrate species were recorded at Zingela site 6, Riverbank (Table 4.1). These were aardvark (*Orycteropus afer*), antelope spp., chacma baboon, bird spp., rock hyrax (dassie, *Procavia capensis*), donkey, genet, Cape porcupine, warthog, and wild boar. Three were nocturnal (Cape porcupine, genet and wild boar). The most prevalent species was antelope spp., with 70 incidences recorded, followed by wild boar, with 26 incidences recorded. The activity of wild boar at this site was relatively low, however, adults, juveniles, and piglets were recorded. Activity ranged from late morning (~ 11h00-13h00), early afternoon (13h00-14h00) and late afternoon (16h00-18h00). There was no late-night wild boar activity at this site.

Similarly, at Zingela site 7, Roadside, 11 vertebrate species were recorded by a camera trap (Table 4.1). These were aardvark, antelope spp., chacma baboon, bird spp., donkey, giraffe, ostrich, Cape porcupine, warthog, wildebeest, and wild boar. Only two were nocturnal, Cape porcupine and wild boar. The most prevalent species at this site were antelope, followed by wild boar, with recorded incidences of 137 and 96, respectively. Wild boar piglets were the

most prevalent, followed by juveniles. Wild boar activity mainly ranged from ~08h30-18h00. The least prevalent species at this site were ostrich and Cape porcupine.

The camera trap captured seven vertebrate species at Zingela site 8, Warthog Island. These were antelope spp., chacma baboon, donkey, rodent spp., ostrich, warthog, helmeted guineafowl (*Numida meleagris*) and wild boar (Table 4.1). Only the wild boar was nocturnal. Helmeted guineafowl was the most prevalent at this site, with over 16 individuals recorded in one instance, followed by wild boar, with up to four individuals recorded at a time. Piglets and juvenile wild boar were the most prevalent at this site, with activity ranging from ~11h30-17h00.

In summary, wild boar were present at all Zingela sites, except the Marula Bend site (Table 4.1, Fig. 4.8). Wild boars were the most prevalent at the feeding site (over 350 incidences of wild boar recorded), followed by the dumping site (over 300 incidences of wild boar recorded) and Warthog Island (over 250 incidences of wild boar recorded). The site with the least amount of wild boar activity was the riverbank study site which had less than 50 incidences of wild boar activity.

In addition, wild boar were recorded by camera trap with five different vertebrate species (human, donkey, crow, bird and wildebeest- ones in yellow not mentioned earlier). Wild boar were recorded with donkey more than 20 times, with bird spp. over 15 times and with crow spp. twice. There were eight incidences of wild boar and vehicles captured on camera.

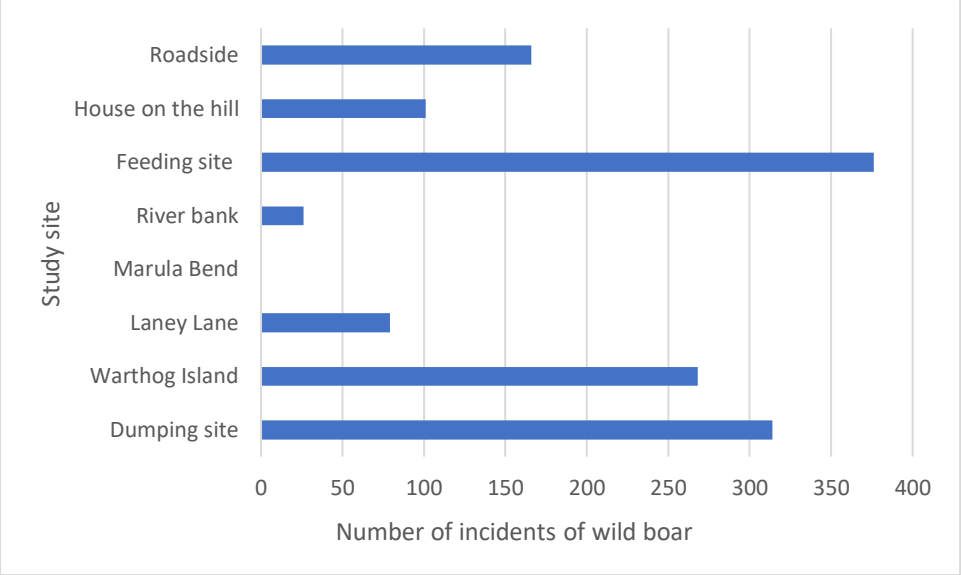

Figure 4.8: The number of incidences of wild boar at the different study sites at Zingela in the present study.

4.4.4 Questionnaire responses to wild pig

Despite sharing the questionnaire with a range of organisations and agricultural forums in KwaZulu-Natal, only ten people answered the questionnaire. The low response may represent that most farmers/ landowners have not seen wild pigs, especially wild boar, in KwaZulu-Natal. Of the age groups, most (40%) respondents were older than 50 years, while the age group of 42 -50 years old was the least represented with one (10%) participant. Most (90%) respondents were males, and there was only one (10%) female respondent. The majority, six (60%) respondents, were employed. There were no unemployed individuals that answered the questionnaire. The other (30%) of respondents were self-employed, and one (10%) was retired. The majority, nine (90%) of respondents, had a tertiary level of education, and only one (10%) of the participants had a secondary school highest level of education.

The majority, nine (90%) respondents, listed land and water as resources in their community. The second most listed resource was forest which was listed by six (60%) respondents. Other resources listed were livestock and crops which were listed by four (40%)

respondents each, respectively. Only one (10%) respondent listed valley thicket as a natural resource.

The majority, six (60%) respondents, responded yes to having seen wild pigs in the last 12 months (between 2021 and 2022). The other four (40%) respondents had not seen wild pigs on their farm/ land in the past 12 months (between 2021 and 2022). In terms of frequency of seeing wild pigs, there were only nine (99.9%) responses and several, four (44.4%) respondents, saw wild pigs very often, 33.3% responded to rarely seeing pigs, and 22.2% responded that they seldom see wild pigs. In terms of the time of day when wild pigs were observed, the majority, seven (70%) respondents, generally saw wild pigs during the morning, while three (30%) respondents saw them during the night.

The majority, six (60%) respondents, selected warthog as the wild pig species they often see, while five (50%) respondents chose bush pig as the pig species they see often. A few respondents, two (20%), selected wild boar and domestic pigs as species they often see. The prevalence of the different wild pig species varied throughout the year, according to the respondents in their farm communities. The majority, six (60%) respondents, selected warthog as a species whose prevalence is the same throughout the year. Only one (10%) of the respondents selected mostly in summer and the option winter for the prevalence of wild boar, respectively. All pig species were reportedly observed in groups, generally between 0-3 individuals. Two species, bush pig and warthog, were also seen in groups of between 4-7 individuals. Wild boar and warthog were also reported to be in groups of more than seven individuals.

The majority, five (50%) respondents, reported no changes in observed bush pig populations over the past five years. One (10%) respondent had observed changes in wild boar and domestic pig populations over the past five years, respectively. The majority, four (40%) respondents, reported having no negative experiences involving warthog, while three (30%)

had negative experiences involving bush pig and warthog, respectively. Only two (20%) respondents had negative experiences with wild boar and domestic pigs, respectively. The majority of the respondents, five (50%), responded yes to warthog being an important pig species in their farm community, and five (50%) respondents responded no to domestic pigs as being an important pig species in their community. Only one (10%) responded yes to wild boar being an important pig species in their farm community. Half (50%) of the respondents responded that the vegetation coverage in their farm communities had been more diverse over the years, and only one (10%) respondent responded that the vegetation cover had stayed the same over the years. The other respondents (40%) responded that the vegetative cover has been less diverse over the years.

The farms with the most resources had five listed, and bush pigs and warthogs were the pig species that lived there. Three different types of pigs were present, domestic pig, wild boar, bush pig. The lowest amount of resources reported was one. Few wild pigs were observed in the farmlands of the five respondents who identified the most resources. In contrast, individuals who listed three resources either observed wild pigs in their farmlands occasionally or frequently. In their farmland, the three respondents who listed the most resources reported seeing warthogs and bush pigs all year round. The respondents who listed the fewest resources (n = 1) had seen warthog and domestic pigs all year round.

The online questionnaire respondents listed three localities in KwaZulu-Natal Province as wild boar hunting areas, namely crop growing areas, the Pietermaritzburg area and Zingela Safari near Weenen. The majority (57.1%) of the respondents listed crop-growing areas as wild boar hunting sites, followed by Zingela Safari (listed by 28.6%), and only 14.3% of respondents listed Pietermaritzburg as a wild boar hunting area. An incident of escaped wild boars from a nearby pig farm and later trapped at the Fountain Hill Estate crop farm was reported (Fig. 4.9).

Figure 4.9: Photograph of escaped wild boar trapped at Fountain Hill Estate study area before the present study. (Photo credit: D. Johnson).

4.5 Discussion

The study areas in the KwaZulu-Natal Province were selected based on citizen science feedback which was conducted through an online questionnaire to determine sites with wild boar prevalence (Chapter 3). Thus, all the study areas used in the present study were known to have wild boar activity in the past. The selected study areas were also near commercial pig farms, and the concern was that there might be feral wild boar populations on the crop farms if they escaped (various pers. comm.). The possibility of wild boars establishing feral populations from pig farms as the source of origin has been evident in other regions of the world (Lemel et al., 2003; Johann et al., 2020) and was a concern.

From the camera trap survey performed in the summer (October 2021 - February 2022) at the crop farm study areas, it was evident that there were no feral wild boar populations at these sites. This was suggested based on the lack of wild boar activity captured on camera at the study sites. The image (Fig. 4.3) captured at Ekukhanyeni Farm study area, which was suspected to be wild boar based on the morphology of the head (large head, narrow snout and small ears) as described by (Genov and Massei, 2004) was more likely not wild boar. This

suggestion was made as there was no further evidence of wild boar activity in this study area. The species captured on camera was most probably a juvenile bush pig. As predicted, the prevalence of wild boar was zero to low in areas where reported, as farmers generally shoot them (Chapter 3). As expected, we found relatively high numbers of wild boar on one farm in KwaZulu-Natal, where they were farmed as wild stock and fed supplementary food.

The camera trap survey conducted in the winter season at the crop farm study areas was to determine if there were any seasonal variations in the prevalence of wild boar in our study areas. Again, the results of our camera trap survey suggested that no feral wild boars were present, as camera traps at our selected crop farm study sites recorded no wild boars. The nocturnal species that were prevalent in the summer (October 2021 – February 2022), which included bush pigs, Cape genet and Cape porcupine, were also present in the winter at our crop farm study areas. However, Cape genets were not recorded at Fountain Hill Estate study sites in the winter. However, the study sites at this farm did show a variation in the species recorded seasonally. Larger animals (giraffe, zebra, ostrich) were recorded at Fountain Hill Estate in the winter and not summer. The prevalence of large animals may have been perceived as high risk for predation by Cape genet. The prevalence of Cape genet can be influenced by predation risk (Zungu et al. 2020).

The nocturnal vertebrate species that dominated our study areas were the bush pig, Cape genet, and Cape porcupine. The prevalence of these nocturnal species suggested that the crop farms did provide suitable habitats in terms of available food for the establishment of feral wild boar. Moreover, wild boars are known to show behavioural plasticity and persist in new environments, especially crop farms (Rutten et al., 2019; Aschim and Brook, 2019; Kramer, 2021). Furthermore, the omnivore diet of wild boar is also a contributing factor for wild boar successfully colonising new environments (Armstrong et al., 2009; Ballari and Barrios-García, 2014).

The activity periods for wild boar are generally from sunset to the early morning hours (Lemel et al., 2003). From this, we can deduce that feral wild boar were not present at our study sites as there was no wild boar activity recorded at our cropland study areas even at the ideal activity times. However, indigenous bush pigs were prevalent at our study sites. The prevalence of feral wild boar would have brought about competition for resources with the indigenous pig species. Furthermore, the crop farms would have experienced greater crop damage because of the prevalence of feral wild boar. This can be inferred based on a study conducted by (Hafeez et al., 2012), where the main diet of wild boar was determined to be cultivated crops, where sugarcane was listed as part of the cultivated crop diet.

The Zingela study area, which had free-ranging wild boar that are 'farmed', was used as a point of reference for wild boar behaviour and interaction with other species. The activity of wild boar at this study site revealed that wild boar that are fed supplementary tend to show a decrease in foraging activity. This was evident in the distribution of wild boar at the various study sites, where wild boar were most prevalent at the feeding site and the dump site. Thus, suggesting a decrease in foraging activity. Generally, anthropogenic altering of the landscape, such as the establishment of crop farms, does influence animal behaviour (Kuka et al., 2022). Concerning our study, the changed behaviour of wild boar would be dwelling where there was easy access to food (feeding site and dumping site). The incidences we recorded of wild boar and humans being active at the same time and in the same place suggest a change in the behaviour of the free-ranging wild boar, where fear for humans and vehicles were lost.

For the questionnaire section of this study, the majority of the farm community members that took part in the study were males. The questionnaire was aimed at individuals who had some knowledge of the prevalence of wild pigs on farmlands. The questionnaire was distributed to farm staff and stakeholders of wild boar. Generally, farming is a male-dominated industry (Shisler and Sbicca, 2019).

The questionnaire responses obtained correlated with those of our camera trap surveys. Both showed that the most prevalent pig species in KwaZulu-Natal farmlands were bush pig and warthog, with relatively rare sightings of wild boar except on a farm where they were 'farmed'. We found no correlation between available resources and the pig species present, as the prevalence of pigs was listed in a diverse range of resources.

4.5.1 Conclusions

We found no evidence of feral wild boar activity in our selected crop farm study areas in KwaZulu-Natal. The exception was a non-cropland farm where wild boar were actively fed and bred for hunting. The use of camera trap surveys to determine the prevalence of wild boar was a suitable method as this method has been used in similar studies and was considered viable (Engeman et al., 2013). With the prevalence of commercial pig farms in KwaZulu-Natal, especially the Midlands, there is a need for regular monitoring to ensure that escaped wild boar do not establish feral populations. The establishment of feral wild boar populations would be detrimental to the agriculture industry in this region, causing major economic losses, as wild boar are known to be very successful crop invaders (Frederick, 1998; McKee et al., 2020). In addition, the wild boar also carries diseases that can be transmitted to livestock and humans (Broadhurst and Hoffmann, 2016; Luskin et al., 2021; Eschen et al., 2021). The prevalence of feral wild boar would also have a negative impact on biodiversity conservation. The wild boar has been listed as part of the top 100 most invasive alien species (GIS, 2023) and contributes to biodiversity loss. Thus, monitoring the prevalence of wild boar in KwaZulu-Natal is important for maintaining a successful and profitable agriculture industry and sustaining the biodiversity in the region.

4.6 Acknowledgements

We are grateful to the University of KwaZulu-Natal (ZA), and the National Research Foundation (ZA, Grant 98404) for funding. We thank Ezemvelo KZN Wildlife for vehicle support and fieldwork resources. We thank the various landowners for permission to conduct camera trap surveys on their properties.

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4.8 Supplementary information

Supplementary information Table S4.1. The questionnaire used to get data on wild boar occurrence in KwaZulu-Natal Province using public participation (See Chapter 3).

No.	Questions
1	Are you aware of any populations of Wild Boar in your area?
2	If yes, do you have the following information on such
3	Please can you provide such information (per property) in the box below: If you would prefer to email a map/Co-ordinates, please do so to: Claudette.James@kznwildlife.com
4	Are you aware of any human-wildlife conflict as a result of Wild Boar
5	If yes, have any of the following measures been instituted to address such
6	Are you aware of any hunting of wild boar taking place in the province
7	If yes, please can you provide locality details of such
8	Are you aware that Wild Boar are listed as a Category 1b listed invasive species in terms of the Alien and Invasive Species Regulations, promulgated in terms of the National Environmental Management: Biodiversity Act, 10 of 2004?
9	If no, would you like to be provided with more information?
10	Should you be willing to provide your contact details, please do so below (name, email address and phone number)?

Supplementary information Table S4.2. The questionnaire used to get information on knowledge and perceptions on wild pig occurrence in KwaZulu-Natal Province using public participation.

1. Demographic and socio-economic information

1.1. Age

a. 18-25	b. 26-33	c. 34-41	d. 42-50	e. >50

1.2. Gender

a. Male	b. Female

1.3. Level of education

a. None	b. Primary	c. Secondary	d. Tertiary

1.4. Occupation (Free listing)

1.5. Livelihood (free listing)

1.6. What resources does this community have?

a. Land	b. Livestock	c. Crops	d. Water source	e. None

1.7 Do you benefit from the resources in this community? (Please explain)

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2. Knowledge about wild pigs

2.1. Have you seen wild pigs in this area over the last 12 months?

a. Yes	b. No

2.2. How often do you see them?

a. Very often	b. Often	c. Seldom	d. Rarely

2.3. When do you see them?

a. In the morning	b. During the day	c. In the afternoon	d. At night

2.4. Where do you see them?

2.5. Which species do you often see?

a. Bush pig	b. Wild boar	c. Warthog	d. Domestic pig
			

2.6. How frequently do you see each species?

Frequency		**Species**		
	Bush pig	Wild boar	Warthog	Domestic pig
a. Very often				
b. Often				
c. Rarely				
d. Never				

2.7 What do you see them doing?

Activity		**Species**		
	Bush pig	Wild boar	Warthog	Domestic pig
a. Feeding				
b. Lying down				
c. Moving about				
d. Other (Please state)				

2.9. If feeding, what do they eat in the communal/ farmland?

2.10. Do you see them in groups?

Number of individuals		**Species**		
	Bush pig	Wild boar	Warthog	Domestic pig
a. 0-3				
b. 4-7				
c. >7				

2.11. What are problem causing animals in this area? (List animals)

2.12. How do you or other community members' deal with problem causing animals?

2.13. Can you give me reasons why a person would kill a wild pig? (Free listing)

2.14. Have you noticed any changes in wild pig populations over the past 5 years?

Population changes		**Species**		
	Bush pig	Wild boar	Warthog	Domestic pig
Yes/No				

2.14.1. If yes, what kind of change have you noticed and what could be causing this?

Bush pig:

Wild boar:

Warthog:

Domestic pig:

2.15. According to your knowledge, how long have the wild pigs been around in this area?

Species		**Years**		
	0-5	**5-10**	**5-15**	**>15**
Bush pig				
Wild Boar				
Warthog				
Domestic pig				

2.16. How would you describe the vegetation in this area over the years?

a. Increased	b. Decreased	c. The same

2.16.1 If any change, please explain

3. Perceptions about wild pigs

3.1 Have you experienced any loses because of any of the pig species in this area?

Loss		**Species**		
	Bush pig	Wild boar	Warthog	Domestic pig
Yes/No				

3.1.1 If yes, please explain what kind of loss you experienced?

Bush pig:

Wild boar:

Warthog:

Domestic pig:

3.2. Are any of these species of any importance in this community? Please explain

Species	**Importance**
Bush pig	
Wild boar	
Warthog	
Domestic pig	

3.3. Do you think any of these species should be protected?

		Species		
	Bush pig	Wild boar	Warthog	Domestic pig
Yes/No				

3.3.1 If yes/no, why?

Bush pig:

Wild boar:

Warthog:

Domestic pig:

3.3. At which time of the year are you most likely to see any of the pig species?

Time of your		**Species**		
	Bush pig	Wild boar	Warthog	Domestic pigs
Summer				
Mostly in Summer				

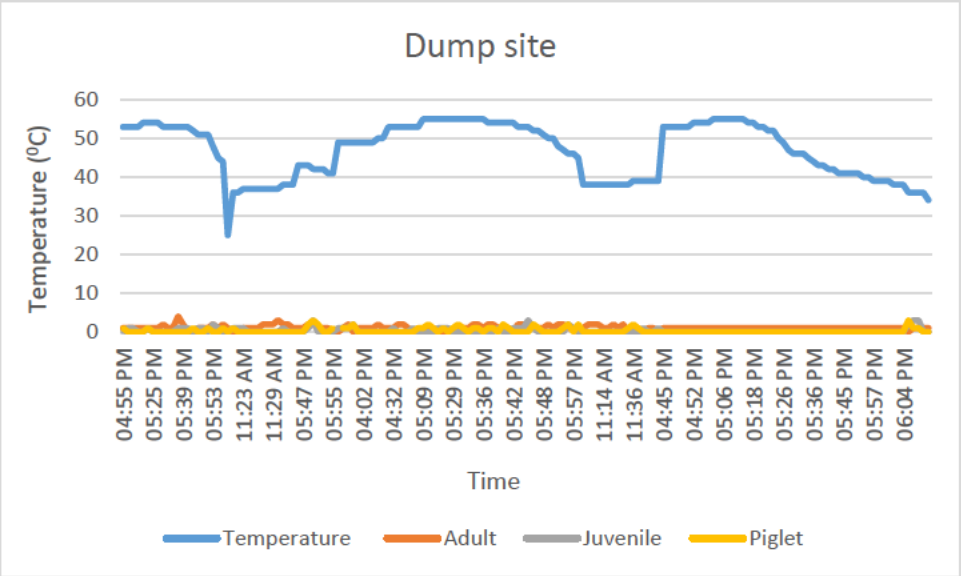
Winter				
Mostly in winter				
Prevalence is the same throughout the year				

3.4. Do you think any of these species have a negative impact in the community? Please explain

Species	**Negative impact, Yes/No**	**Explain**
Bush pig		
Wild boar		
Warthog		
Domestic pig		

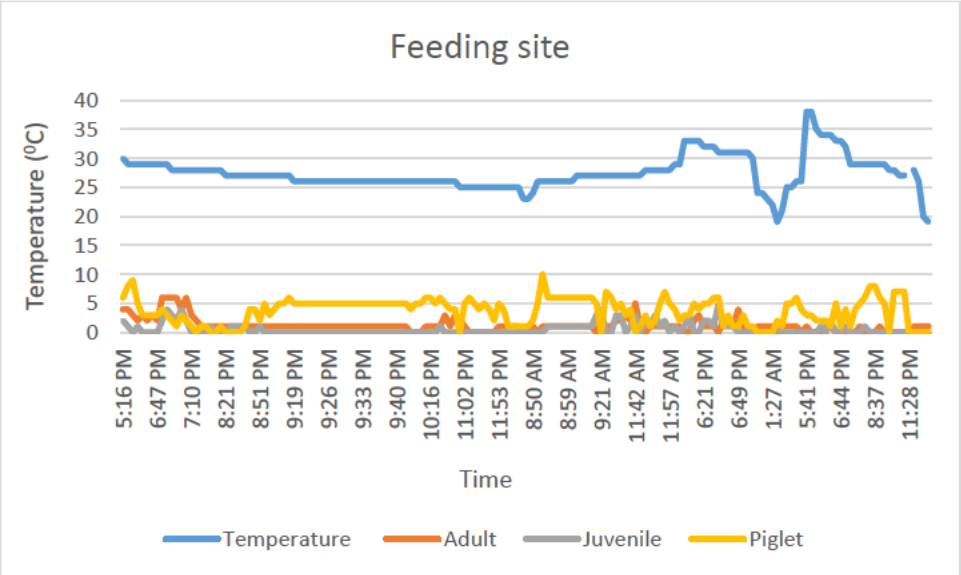
3.5. Will you be willing to participate in future wild pig intervention initiatives?

Thank you for your time



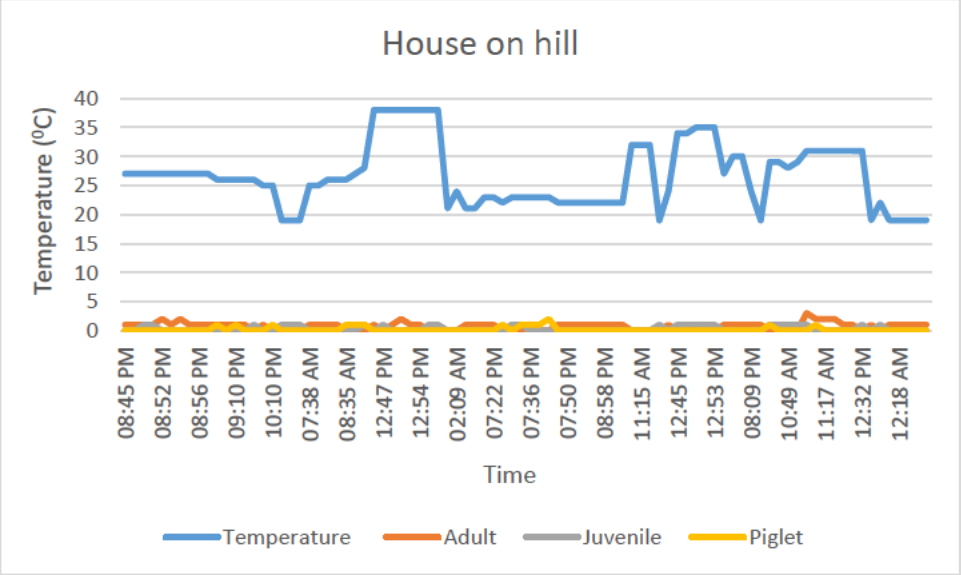
Supplementary Information Figure S4.1: Times of activity of wild boar captured on camera at the dumping site

Adult wild boar were the most prevalent at this site and the activity times ranged from late morning (around 11:30 am) and late afternoon (around 5:30 pm). The second most prevalent were piglets, where the activity times where similar to that of adult wild boar. Juvenile wild boar were less prevalent at this site. Most of the wild boar activity at this site took place while the sun was still shining at temperatures between 250C and 530C.



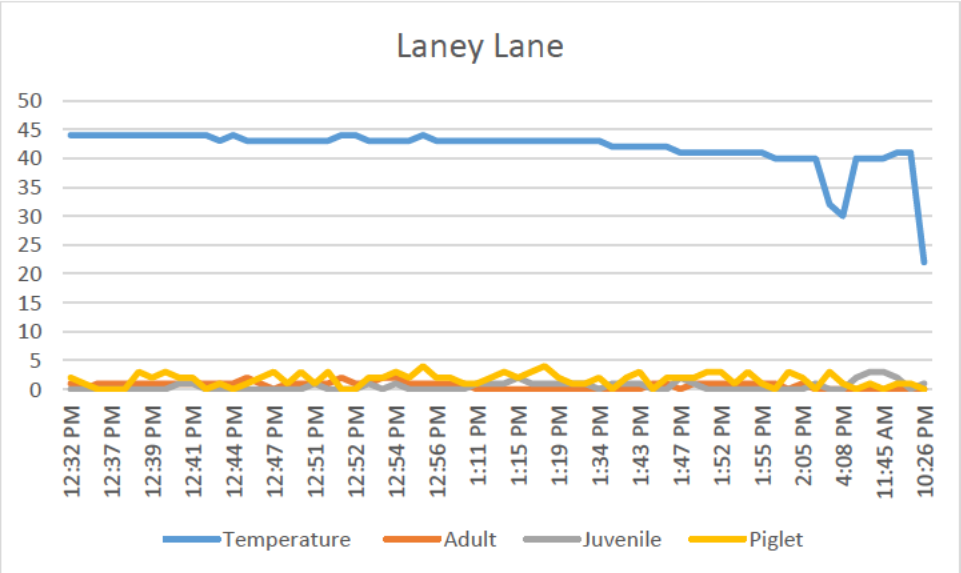
Supplementary Information Figure S4.2: Times of activity of wild boar captured on camera at the feeding site

Piglets were the most prevalent at this site, followed by adults then juveniles. The activity by wild boar at this site ranged from around 08:00 am and was throughout the day and night. Most of the activity at this site took place at temperatures between 190C and 380C.



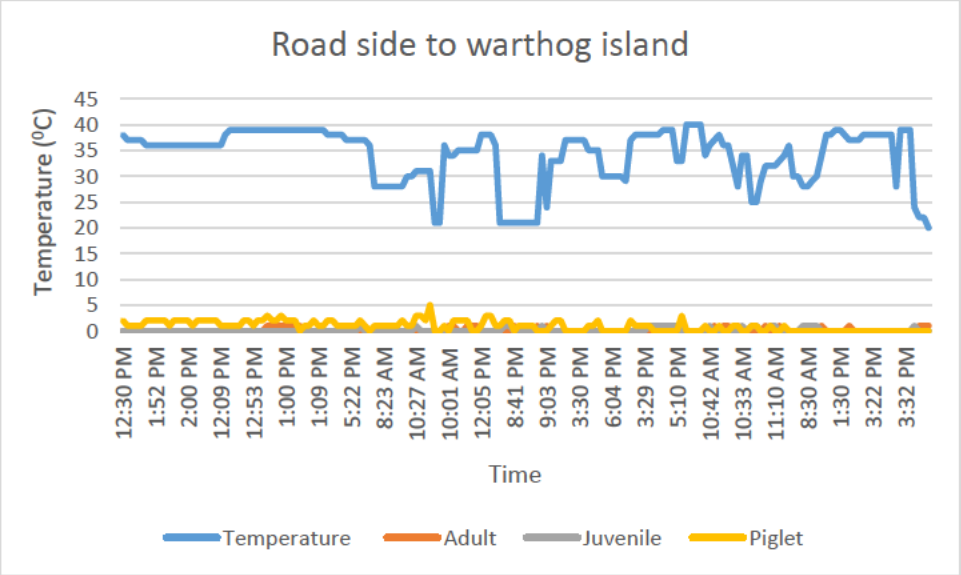
Supplementary Information Figure S4.3: Times of activity of wild boar captured on camera at the house on the hill study site

Adult wild boar were the most prevalent at this site, followed by piglets then juveniles. The activity at this site ranged from around 07:00 am and was throughout the day and night, at temperatures between 19^{0}C and 38^{0}C.



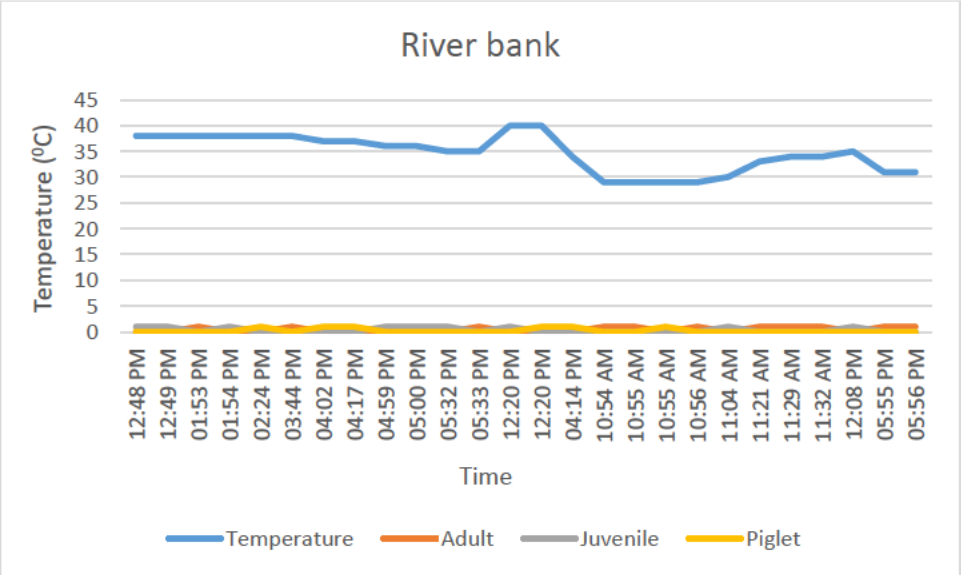
Supplementary Information Figure S4.4: The time of activity of wild boar captured on camera at the Laney Lane study site

Piglets were the most prevalent at this site. The activity ranged from around 11:30 am to about 04:00 pm at temperatures between 30^{0}C and 44^{0}C.



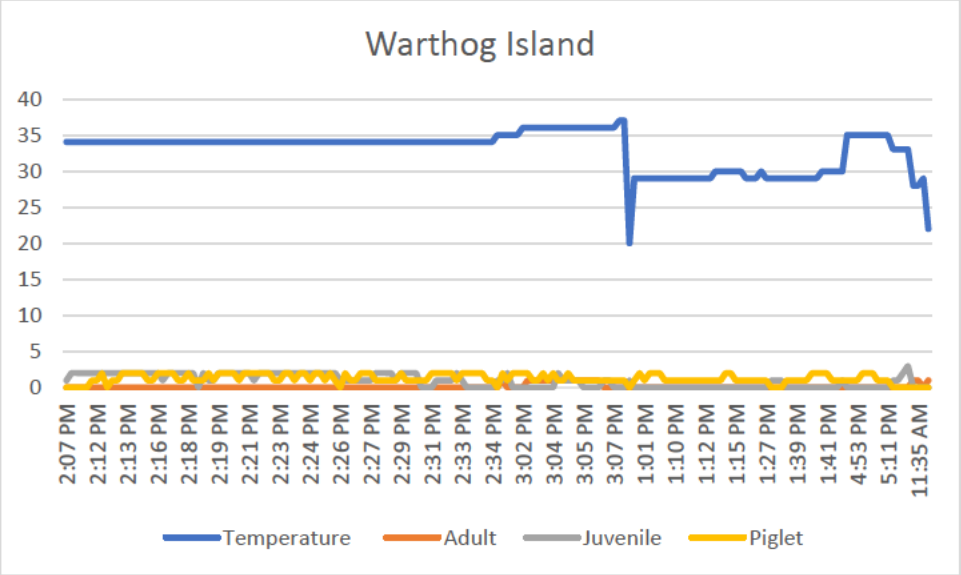
Supplementary Information Figure S4.5: Times of activity of wild boar captured on camera at the roadside study side

Piglets were the most prevalent at the roadside study site with activity ranging from around 08:30 am to around 06:00 pm. The second most prevalent was juvenile wild boar. The activity of wild boar at this site took place been the temperatures of 20^{0}C to 40^{0}C.



Supplementary Information Figure S4.6: Times of activity of wild boar captured on camera at the riverbank study site

The activity of wild boar at this site was low, however adults, juveniles, and piglets were captured on camera at this site. The times of activity at this site ranged from late morning (around 11: 00 am – 1:00 pm), midday (around 1:00 pm – 2:00 pm) and afternoon (around 4:00 pm – 6:00 pm). The activity at this site ranged between the temperatures of 29^{0}C and 40^{0}C. There was no late night wild boar activity at this site.



Supplementary Information Figure S4.7: Times of activity of wild boar captured on camera at the warthog Island study site

Piglets and juvenile wild boar were the most prevalent at the Warthog Island study site with activity ranging from around 11: 30 am to around 05:00 pm. Adult wild boar were the least prevalent at this site. The activity at this site took place at temperatures between 20^{0}C and 37^{0}C.

CHAPTER 5

Conclusions and recommendations

5.1 Background

The introduction of species by humans into regions where they do not naturally occur has had disastrous effects on the environment and the economy (Salamin et al., 2006; Pyšek et al., 2020; Tedeschi et al., 2021). The effects of invasive alien species, especially invasive mammals with an emphasis on feral pigs, are well documented (Chew et al., 2006; Gentili et al., 2021; Chapter 1). Invasive alien species also have socioeconomic effects since they impact the elements that make up human well-being (Bacher et al., 2018; Evans et al., 2020; Duboscq-Carra et al., 2021). Food security, health, and interpersonal, spiritual, and cultural relationships are a few of these considerations (Chhangani and Mohnot, 2004; Bacher et al., 2018; Kull et al., 2019; Sena and Ebi, 2020). Through predation, browsing, and competition, invasive mammal species directly impact biodiversity (Bradley et al., 2019; Kelt et al., 2019; Silveira de Oliveira et al., 2020). Additionally, they alter the trophic cascades and nutrient flow patterns (Clout and Russell, 2008). Rooting and wallowing for food significantly influence ecosystems because of resulting soil erosion, reduced earthworm activity, hindered plant succession, and transmission of diseases (Muthoka, 2021). According to the South African NEMBA Alien Invasive Species List (25 September 2020), the European wild boar (*Sus scrofa*) is listed as a category 1b alien invasive species (NEMBA Alien and Invasive Species List). Thus, its persistence in South Africa must be controlled, hence the focus of this research.

5.2 Summary of results

From wild boar (*Sus scrofa*) research conducted worldwide, there appears to be a lack of research conducted on wild boar in Africa (Chapter 2). The leading continents on wild boar research the past two decades were Europe, followed by Asia, South America, North America and then Australia (Chapter 2). The countries conducting most of the research on wild boar during this period were Spain, Italy, Germany, and Japan, in descending order (Chapter 2). The research on wild boar mainly focused on epidemiological studies followed by ecological, genetics, and biochemistry studies (Chapter 2). Other research areas identified within the review parameters were microbiology, toxicology, archaeology, osteology, and palaeontology (Chapter 2). The European wild boar is a highly successful alien and invasive species (IUCN, GISB). Thus, it has the potential to be invasive in most environments where it has been introduced. Moreover, the invasive success of wild boar poses a major threat to biodiversity conservation and poses health risks to livestock and wildlife by its ability to transmit diseases (Podgórski et al., 2018). Furthermore, the ecological behaviour of wild boar, such as its diet preferences for high-energy foods such as fruits and vegetables, poses a threat to the agriculture industry and, consequently, the economy (Chapter 2). However, wild boar is a conflict species in South Africa as wild boar farmers generate revenue from their farms by selling wild boar meat and offering wild boar hunting at a fee (Chapters 2-4). For the control of wild boar in South Africa, we recommend the legislation regulating the prevalence of the species in the country should be revised and enforced.

The occurrence of alien and invasive species in South Africa is governed by the National Environmental Management: Biodiversity Act (Act 10 of 2004): Alien and Invasive Species, 2014. The guidelines for regulatory adherence to the Biodiversity Act (Act 10 of 2004): Alien and Invasive Species are housed in the Biodiversity Act (Act 10 of 2004): Alien and Invasive Species List and the Biodiversity Act (Act 10 of 2004): Alien and Invasive

Species Regulations documents. Wild boar occurrence in South Africa must adhere to the regulations stipulated by the NEMBA (Act 10 of 2004): Alien and Invasive Species List and the Alien and Invasive Regulations. An update to the Alien and Invasive Species List in September of 2020 had wild boar listed as a category 1b alien and invasive species. Thus, the prevalence of wild boar in South Africa must be monitored and controlled, otherwise, its impacts will be severe, as documented in Chapter 2.

Chapter 3 was aimed at determining the climatic suitability for wild boar in South Africa. From the outcomes of this study, it was determined that South Africa has a climatically suitable environment for wild boar and was determined to be the coastal areas of South Africa (Chapter 3). The Western Cape, Eastern Cape and KwaZulu-Natal Provinces were part of the climatically suitable areas for wild boar in South Africa (Chapter 3). From this study, we also determined that wild boar does prevail in these provinces, thus, indicating the need for monitoring and controlling the prevalence of wild boar in these provinces, as there is a great chance of wild successfully establishing feral populations in these regions (Chapter 3).

KwaZulu-Natal Province was used as the main study area to determine the prevalence of feral wild boar populations in South Africa (Chapter 4). The selection of the study areas in KwaZulu-Natal was determined by citizen science feedback, especially through a questionnaire distributed to wild boar stakeholders. The selected study sites were sites where wild boar persisted or where there were previous encounters with wild boar. The chosen study sites included crop farms and a wild boar farm. To determine the prevalence of feral wild boar populations, camera trap surveys were conducted (Chapter 4). The wild boar farm was used to reference farmed wild boars' behaviour. The outcome of this study showed that there was no evidence of feral wild boar populations in our study areas, except the wild boar farm; thus, it was deduced that there were no feral wild boar populations in the Midlands of KwaZulu-Natal presently (Chapter 4). At the wild boar farm, from the outcome of our camera trap survey, it

was revealed that wild boar fed supplementary tend to spend more time at sites where food is readily available and less time foraging (Chapter 4). This suggests that wild boars, which are supplementary fed, tend to wander around where there are easily available food sources. This leads to the conclusion that escaped wild boars entering crop farms are more likely to settle within the crop areas because of easily available food sources. Thus, this emphasises the need to monitor and control this species to reduce the possibility of wild boars establishing feral populations on crop farms.

5.3 Recommendations and possible interventions for regulating wild boar in South Africa

According to the South African NEM:BA Alien and Invasive Species List (25 September 2020), the European wild boar is listed as a category 1b Alien and Invasive Species (AIS). Thus, its prevalence in South Africa must be controlled, as stipulated by the NEM:BA: Alien and Invasive Species Regulations, 2014. However, the regulations only apply to the feral state of the species. Here management and control options for the prevalence of wild boar in South Africa are provided.

It is recommended that there should be clearly defined conditions for the captive state of wild boar that pig farmers must adhere to and so prevent escapes, environmental degradation, and economic losses. For instance, fencing specifications, population quotas per hectare and buffer zones from the nearest crop farm. A clear definition for captive wild boar will ensure that the incidence of escapes is minimised and that the species' potential environmental degradation and economic losses are also reduced. The selling of wild boar in relation to the present legislation on wild boar in South Africa (NEM:BA Alien and Invasive Species List) is illegal. Thus, the selling of wild boar is a contributing factor to the spread of the species in the country which was determined in this study. It is recommended that the sale

of wild boar should be monitored in South Africa by conservation authorities and the animals confiscated from the offenders and euthanised to prevent the further uncontrolled spread of the species. Moreover, the revised legislation could require all wild boar farms to register with conservation authorities to allow regular monitoring for compliance with captive state regulations and population quotas.

5.4 Conclusions

The European wild boar (*S. scrofa*), prevalent almost worldwide, is one of the most successful invasive species. Research has been conducted on the species across the globe. However, there appears to be a lack of research on the species in Africa. The prevalence of wild boar in South Africa is a cause of concern, considering the lack of research on the species on the African continent. Consequently, there is a need for ongoing monitoring and controlling of the prevalence of wild boar in South Africa to prevent the development of feral populations. More research on the species in South Africa in terms of disease transmission is encouraged as the species has been recorded interacting with indigenous wildlife.

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