MITIGATION OF CROP-RAIDING WILD BOARS IN SELECTED COUNTIES IN SWEDEN: ASSESSING FEASIBILITY OF ELECTRIC FENCES AND SUPPLEMENTARY FEEDING

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DECLARATION

This thesis is my original work and has not been presented elsewhere for a degree or any other award.

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DEDICATION

I dedicate this thesis work to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. I also dedicate this thesis to my family. My late father Mr. Gregory Muthoka, who unfortunately, didn't live long to witness my academic accomplishments and my lovely mum, Mrs. Catherine Muthoka, whose prayers and words of encouragement saw me through this journey.

Special gratitude to my brothers, and sisters for their consent source of support and great inspiration during research work. I sincerely dedicate and give thanks to my spouse Kennedy Musyoka who greatly encouraged me to pursue my dreams.

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May the almighty God bless you abundantly!

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	3 - Dimensional
ANOVA	Analysis of Variance
cm	Centimeter
EU	European Union
GLMM	General Linear Mixed Model
GPS	Global Positioning System
GSM	Global Systems of Mobile Communications
GmbH	Gesellschaft mit beschränkter Haftung
GM	Gross Margin
GWRA	Grimsö Wildlife Research Area
J	Joule
NP	Net Profit
RCBD	Randomized Complete Block Design
SEBA	Swedish Board of Agriculture
SEK	Swedish Krona
SEPA	Swedish Environmental Protection Agency
SLU	Sveriges Lantbruks Universitet
SMS	Short Message Services
TR	Total Revenue
VHF	Very High Frequency

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ABSTRACT

Wild boar (*Sus scrofa*) is a wild Suidae native in Europe, North West Africa and Asia. The population of wild boar has drastically increased during the last threedecades in Southern and Central Sweden. This increase in population density has caused severe damages to agricultural fields thus affecting the agricultural economy.There has been a significant loss of wheat, worth over 60 - 70 million Euros between1990 - 2016 due to crop damage by wild boar. This study sought to investigate the effectiveness of electric fencing and supplementary feeding as mitigation measures to crop-raiding of wheat fields by wild boar in South-Central Sweden. The study was carried out in five study sites in Sweden; Koberg, Boo, Bornsjön, Mörkö, and Grimsö. To achieveobjectives one and two, a total of eleven adult wild boar were marked with GPS/GSM-collars in 4 study sites (Koberg, Boo, Mörkö, and Grimsö), and monitoring of crop and habitat selection was performed using GPS units. Data fromthe marked animals was logged in every one hour and then transmitted through the GSM network every seventh hour by SMS to a computer server. Further, a total of 131 feeding stations were used to determine the effectiveness of supplementary food.Objective three, had Boo, Bornsjön, and Mörkö sites experimental wheat fields, i.e., 12 fields with electric fences, and 12 without fences. The fences were constructed by wooden poles in all corners of the field and with small plastic poles in between, and ringed with three metal wires at 20cm, 40cm, and 60 cm high from the ground and supplied with a 12-volt battery. GLMM models in R software (version 3.6.2) and Q GIS (version 3.10.2) were used for the data analysis. Results indicated that wild boar had a high preference for clear-cuts, agricultural fields, anddeciduous forests. The marked animals showed a high preference for crop fields withoat, spring wheat, and mixed crops. A binary logistic model revealed a significant influence of distance to feeding stations on the selection of different habitats and crop fields with both positive and negative effects. Generally, feeding stations influenced the selection of different habitats and crops negatively i.e., the closer a habitat or crop field is to a feeding station, the higher the likelihood of its selection. Besides, distance to main roads significantly influenced the selection of habitats and crop fields with both positive and negative effects. The paired t-test analysis was conducted in R-studio to compare mean harvest yield, pre-harvest damage (< 1 month) and, growing season damage (from sowing period to < 1-month pre-harvest)between electrically fenced fields and unfenced fields. Significant differences in thepre-harvest damaged area were found between the electric fenced and unfenced wheat fields in two of the three study sites. Further, there was an inverse relation between damage size and mean yield in the fenced fields. The gross margin results found that supplementary feeding was effective in preventing wild boar from farmlands. In conclusion, distance to feeding station and main road influenced wild boar selection of different habitat and crop fields differently. Also, the electric fences installed were effective in reducing wild boar damages on the wheat fields. The study recommends farmers and landowners to use electric fences as a way of reducing wild boar damages to their agricultural fields.

CHAPTER ONE
INTRODUCTION

1.1 Background information

The wild boar species is a wild Suidae native in Europe, North-West Africa, and Asia. (Olofsson, 2015; Engelman and Lagerkvist, 2016). In Europe, wild boar has recently recolonized Sweden, Estonia, and Finland (Massei *et al*., 2011). In Sweden, the population was extinct at the beginning of the 1700s; but in the 1970s, the wild boar returned through escapes from enclosures and the population increased rapidly (Massei *et al*., 2015; Cozzi *et al*., 2019). Stokke *et al*., (2017) found that the population of wild boar in Sweden is estimated to be 200,0000 – 300,000 and increaseby 25% – 30 % yearly, before hunting. Their drastic increment in population size has ledto intensified farm raids and sometimes habitat destruction, leading to losses in the agricultural sector and natural ecosystems through their wallowing, rooting and foraging behavior (Thurfjell *et al*., 2009).

Wild boar can adapt to varying climatic conditions, and as such occupies an extremely wide range of habitats from semi-arid environments to alpine grasslands (Massei *et al*., 2011). They survive in bushy areas and in forest edges near agricultural farms to avoid predators. They also extend their habitats to areas such as mixed forests that include deciduous species, scots pine, and oak (Olofsson, 2015). In terms of their diet, wild boars are omnivores with a high preference for crops like corn (*Zea mays*), potatoes (*Solanum tuberosum*), beans (*Phaseolus spp*.), peas (*Pisum spp*.), and sugar beets (*Beta spp*.) (Ballari and Barrios-Garcia 2014; Oja, 2017). Besides, they also feed on earthworms, rodents, moles, and scavenge on dead animals (Ballari, 2012). In Sweden, it has been established that wild boar majorly feed on crops such as wheat (*Triticum aevistum*), barley (*Hordeum vulgare*), corn (*Zea mays*), and oats (*Avena sativa*) (Gentle *et al*., 2015).

The total land area in Sweden is 450,000 kilometers squared (km^2) and 7 percent (%) of this is arable land. The country has four agro-ecological zones namely: Mountain/Alpine zones in the Northern part, Boreal zone in the central, Hemi- boreal zone in the south-central part, and Nemoral zone in the southern part (Östlund *et al*., 2006). These zones form various habitats which include coniferous forests, broad-leaved deciduous forests, agricultural lands, open lands, clear cuts, lakes, and streams.

Cropping systems in Sweden are categorized into organic farming mainly fodders crops and pastures for livestock and conventional systems for commercial and consumption purposes (Kirchmann *et al*., 2016). Ley and forage are important for livestock and comprise eight kinds of grasses and four legumes. Cereals grown include barley, mainly spring barley which is grown in the largest part of Sweden (St-martin *et al*., 2017). Wheat is a predominant crop grown in Southern and Central Sweden. Other cereals include oat and maize. Potatoes, legumes, fruits, and vegetables are also grown in mostparts of Sweden (Henryson *et al*., 2019).

Wild boar causes an extensive loss in the agricultural sector and affect natural ecosystems (Linkie *et al*., 2007). Risk assessment of crop damage has shown that wild boar are a major threat to the agricultural sector due to crops and forest damage (Schley *et al*., 2008). For instance, the damage cost in the agricultural sector in Sweden due to wild boar has been estimated to be 60 - 70 million dollars per year (Anderson and Gren, 2017). The extent of grassland damage by wild boar is far more numerous and intense than destruction to yearly crops (Thinley *et al*., 2017). Natural ecosystems have also been affected by the dramatic increase of wild boar as they feed on whole plants or vegetative parts such as fruits, bulbs, and tubers thus affecting the local plant communities and possibly diversity (Oja *et al*., 2014). Measures to mitigate such damages are important to farmers, landowners, and the government to reduce the damage they cause in the agricultural sector and natural ecosystems.

Mitigation measures have been carried out to reduce the high economic cost due to the increasing wild boar population in agricultural farmlands in Sweden (Kubasiewicz *et al*., 2016; Felton e*t al*., 2017). One of these measures is hunting, but this solves the problem temporarily of an increasing wild boar population (Thurfjell *et al*., 2013). Hunting is recommended for some ungulates species like moose (*Alces Alces*) and roe-deer (*Capreolus capreolus*) whereby, hunters are given hunting licenses by the Swedish Environmental Protection Agency (SEPA, 2015; Engelman *et al*., 2016).

Artificial feeding mainly supplementary feeding and diversionary feeding are used by hunters and farmers either to divert animals from sensitive crops and or to attract them closer to a hunting blind for easier and safer hunting. Supplementary feeding, particularly of wild boar is a common practice throughout Sweden. This practice has been suggested to have positive effects to maintain high densities of animals for hunting through improved reproductive potentials (Cellina, 2008). However, very little scientific evidence exists on the impact of supplementary feeding on reducing wild boar damageon agriculture as they have not been adequately tested.

Electric fence is another common mitigation measure to keep wild boar off from agricultural farms. Farmers previously used conventional non-electric wire fences to refrain wildlife while maintaining farm animals within grazing fields (Massei *et al*., 2011). The non-electric fences were ineffective since they were not durable and wildlife species still caused damage to the agricultural farms. More recently, electric fences have been used as a crop damage prevention measure (Vidrih and Trdan, 2008). These fences have helped in the management of human-wildlife conflicts in some parts of Sweden (Sapkota *et al*., 2014), but little information exists on the cost-effectiveness of their performance and their capacity to deter farm raiding by wild animals. Therefore, this study sought to assess the mitigating effect and feasibility of electric fences and supplementary feeding in reducing crop-raiding by wild boar in selected counties in Sweden.

1.2 Statement of the problem

The population of ungulates particularly, wild boar, red deer (*Cervus elaphus*), and fallow deer (*Dama dama*) has been increasing over the last three decades in Sweden, these animals have several impacts on the ecosystem contributing to species diversity. However, they are a major threat to the agricultural fields specifically wheat and oat fields in which they cause huge damages through their feeding behaviour. Wild boar population has been adaptive to different environmental conditions and has significantly impacted on intensifying farm raiding and associated agricultural losses. Wheat is a predominant crop in Sweden and is widely destroyed by wild boar. For instance, studies have estimated wheat losses resulting from wild boar and found that there has been significant wheat loss worth 60-70 million USD from 1996 to 2016. Different mitigation measures have been developed to reduce wild boars' invasions to croplands. However, a paucity of knowledge exists on the effectiveness of the different wild boar mitigation measures on crop-raiding. Besides, little is known about the influence of landscape factors on crop and habitat selection by wild boar. Further, there is limited research based information on the feasibility of electric fences and supplementary feeding as mitigation measures to crop-raiding. Therefore, this study sought to investigate the effectiveness of electric fences and supplementary feeding as mitigation measures in reducing crop-raids by wild boar in wheat fields in Sweden.

1.3 Justification

The dramatic increase of the Swedish wild boar population over the past three decades has resulted in conflicts with the agriculture sector and natural ecosystems. This is due to their foraging behavior and ability to survive in adverse climate conditions thus, their higher reproductive rate. There is need for research on efficient management methods where the effectiveness of wild boar mitigation measures such as the use of supplementary feeding and electric fences on the prevention of crop damage needs to be evaluated and implemented. Therefore, if properly implemented, these mitigation measures can deter wild boar from destroying wheat crop fields. This can improve wheat productivity and increase income for farmers. Feasibility analysis of these mitigation measures is essential as farmers need to be informed on the economically viable methods to improve their productivity of wheat.

1.4 Objectives

1.4.1 General objective

To investigate the effectiveness of electric fences and supplementary feeding as a mitigation measure to crop-raiding of wheat fields by wild boar in Sweden

1.4.2 Specific objectives

1. To evaluate possible landscape factors affecting the wild boar selection of habitat andcrop fields in different ecological settings by wild boar
2. To determine the mitigating effects of supplementary feeding in the prevention of crops damage by wild boar
3. To determine possible differences in the wild boar damages between electrically fenced and unfenced wheat fields
4. To determine the economic feasibility of artificial feeding and the use of electric fences in wild boar management

1.5 Research questions

1. Do landscape factors affect the feeding on different crops by wild boar and their choice of habitats in different ecological settings?
2. What is the mitigating effect of supplementary feeding in the prevention of crops damage by wild boar?
3. What is the difference in wild boar damages between electrically fenced and unfenced wheat fields?
4. Are either supplementary feeding and electric fences economically feasible?

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview of the effects of wild animals on crops

Wild animals have been reported to contribute to crop damages in many countries (Burbaite and Csányi, 2009). Ungulates, in particular, the wild boar (*Sus scrofa*), have been associated with such major crop damages (Amici *et al*., 2012). Other ungulates such as fallow deer have also been reported to raid oat and wheat fields in Sweden (Menichetti *et al*., 2019). Also, the Andean bears (*Tremarctos arnauts*) cause major damage to corn in Bolivia, South America (Herrero *et al*., 2006). In Slovenia (Europe), red deer (*Cervus elaphus*) has also been reported to damage the farmers' grasslands (Bleier *et al*., 2017).

Wild boar is among the largest ungulate species in Europe and it extends over the entire continent (Geisser and Reyer, 2005; Tack, 2018). This species has been recently recolonizing Sweden after escapes from enclosures (Massei *et al*., 2015) and thus its population size has been increasing over the past 30 years (Amici *et al*., 2012; Viccaro and Romano, 2019). This drastic increase in the wild boar population size has caused a huge economic loss in the agricultural sector and natural ecosystems through its foraging behavior (Linkie *et al*., 2007; Lindblom, 2010). The risk assessment of crop damage has shown that wild boar is a major threat to the agricultural industry due to crops and forest damage (Schley *et al*., 2008; Sarwar, 2019)). For instance, the cost due to wild boar damage to crops in Sweden has been estimated to be 60 - 70 million USD per year (Anderson and Gren, 2017). Further, the extent of grassland damage by wild boar is far more numerous and intense than destruction to yearly crops (Thinley *et al*., 2017). Wild boar is perceived as an important nuisance to the agricultural sector and researchers and managers are searching for preventative methods to reduce the extent of their damages on crops (Samiappan *et al*., 2017).

2.1 Landscape factors influencing habitat and crop selection by wild boar

2.1.1 Habitat selection

The Swedish zonal vegetation pattern includes mountain/ alpine zones in the Northern part, boreal zone in the central, hemi- boreal zone in the south-central part, and nemoral zone in the southern part (Östlund, *et al*., 2006; Hedenås *et al*., 2016). The alpine zone is further divided into the lower, middle, and high alpine zone depending on altitude (Laitinen *et al*., 2017). This zone is also known to have the richest flora because of many mountain plants (Egelkraut *et al*., 2018). The boreal zone is commonly known as northern coniferous forests. It includes all the vast areas up to forest limits in the mountains and covers lowlands and river valleys. The hemi-boreal zone is also called the boreal-nemoral or southern coniferous forest region. This zone comprises mainly Scotch pine (*Pinus sylvestris*) and Norwegian spruce (*Picea abies*) and also some deciduous species like oak, birch, willows (*Salix alba*), and aspen (*Populus tremuloides*) (Hansson *et al*., 2018). The last zone is the Nemoral zone also called the southern deciduous forest region. In this region, conifers have been recently planted or reproduced naturally and some Scotch pine and oak. These different zones form different habitat which includes coniferous forests, broad-leaved deciduous forests, agricultural lands, other open lands, clear cuts and lakes, and streams.

Landscape factors influence habitat use including agricultural activities by wild boar. Besides geographical and seasonal variation which may be the main determinant for habitat use (Schley *et al*., 2008; Amici *et al*., 2012), disturbance from roads has both direct and indirect influences on habitat selection (Lee *et al*., 2018). Water sources are also essential, particularly during summer droughts and also for wallowing to get rid of ectoparasites. Thus marshlands, bogs, and wetlands are preferred habitats during certain conditions and may have positive effects on wild boar population growth (Paolini *et al*., 2018).

Forest is an important habitat for shelter and resting sites during daytime and as hideouts from hunters (Morelle and Lejeune, 2015; Bobek *et al*., 2017). Dense forests seem to sustain high wild boar population densities (Borowik *et al*., 2013). Other studies showed that agricultural fields are the most preferred habitat during summer as they offer a large amount of high-quality food whereas coniferous forests and open areas are avoided during summer and preferred during winter (Schley and Roper, 2003;

Cellina, 2008; Thurfjell *et al*., 2009). This shift is most likely connected to food availability and cover (Keuling *et al*., 2009). Wild boar also have preferences for certain landscape elements such as hedges, ditches, stone walls, rows of trees or bushes,streams, and forest edges near agricultural farms (Thurfjell *et al*., 2009; Mikulka *et al*.,2018). They prefer large forest fragments especially near mountains and riparian areas(Ball, *et al*., 2000). Studies show that such topological factors may influence habitat selections by wild boar in Sweden (Thinley *et al*., 2017). However, it is not clear how these factors influence habitat selection, and previous literature has been limited to the factors influencing habitat selection and crop selection (Toger *et al*., 2018).

2.1 2. Crop selection

Wild boar are generalists, opportunistic omnivores that consume a wide variety of food (Felton *et al*., 2017). They have a high preference for crops (Herrero *et al*., 2006). In Europe, they have been reported to be feeding on crops such as corn (*Zea mays*), wheat (*Triticum aevistum*), barley (*Hordeum vulgare*), rye (*Secale cereale*), oat (*Aneva sativa*), rice (Oryza sativa), sorghum (*Sorghum bicolor*) and potato (*Solanum tuberosum*) (Schley and Roper, 2009). Wild boar diets from plants have been categorized into four main types: mast, roots, green plants, and crops (Schley and Roper, 2003). Crop selection by wild boar is largely influenced by seasonal patterns and geographical locations (Timmons *et al*., 2010).

Seasonal patterns determine the cultivation of dominant crops in Europe which in turn influences crop selection by wild boar (Thinley *et al*., 2017). For instance, they prefer maize in most parts of the year while they also feed on wheat and barley mainly during the summer periods (Gentle *et al*., 2015). In the northern parts of Europe, harsh winter conditions affect wild boar foraging activities (Schley *et al*., 2008). In the Mediterranean during is the dry summer periods limiting, because of less food (Oja *et al*., 2014).

The seasonal variation, other geographical factors associated with wild boar crop selection include topographical factors which are major determinants of wildlife habitat use (including agricultural activities) (Lee *et al*., 20018). This is because there can be environmental variability and strong local gradients of insulation which depends on topography such as elevation and surface orientation.

Wild boar is defined as a nuisance animal in the agro-ecosystems as it can survive in human-dominated landscapes (Paolini *et al*., 2018). The rooting behavior of wild boar has a positive effect of enhancing biodiversity and richness of natural systems as many plants require "disturbed soil" for germination. Nevertheless, increased rooting on agricultural fields has a direct negative effect as crop production is affected (Ballari, *et al*., 2014).

2.2 Effects of supplementary feeding on habitat selection

Supplementary feeding was introduced in Europe and the USA to prevent damage to commercial and native forests (Putman and Staines, 2004; Felton *et al.*, 2017). These feeds include maize, wheat, barley, sugar beet, potatoes, and industrial food pellets (Milner *et al*., 2014; Oja *et al*., 2014). Farmers and landowners offer supplementary food to ungulates to keep them away from agricultural farms and forest plantations (Schley *et al*., 2008). Supplementary feeding has been found to have a direct effect on habitat use by wild animals as many ungulates continue browsing in forests plantations besides consuming the feeds (Thurfjell *et al*., 2009; Ballari *et al*., 2012). Previous studies have also established that aggregations of wild animals around such feeding stations are also a challenge, this is because they trample on the soil thus affecting ground cover and reduction in vegetation growth (Scott and Palmer, 2000; Selva *et al*., 2014). For instance, in Scandinavia, extensive damage occurs in areas surrounding feeding stations and larger landscape scales (Felton *et al*., 2017).

Feeding stations along with agricultural fields and near forest edges likely influences habitat use (Ficetola *et al*., 2014). Feeding stations are either for diversionary feeding, which is used to divert or distract animals from agricultural fields or supplementary feeding which is the provision of additional food for the wild boar or used in baiting traps to facilitate trapping or shooting of wild boar by hunters (Calenge *et al*., 2004; Geisser and Reyer, 2004; Massei *et al*., 2011). The density and location of feeding stations seem to be important factors affecting the efficiency of artificial feeding. Studies have shown artificial feeding to be controversial as it has been suggested to have unintended impacts on wild boar such as infer high reproductive rates and increased survival rates which may be associated with increased damages (Geisser and Reyer, 2004; Novosel *et al*., 2012).

2.2.1 Mitigating effects of supplementary feeding on wild boar crop-raiding

Supplementary feeding reduces wild boar's impacts on agricultural farms by shifting their distribution across the landscapes (Milner *et al*., 2014). Besides reducing crop damage by wild boar, it has also been shown that winter supplementary feeding, especially in Europe and North America, enhances an animal's winter survival and reproductive success (Ballari *et al*., 2012). Supplementary foods have also been used to maintain high densities of animals for hunting (Burbaite and Csányi, 2009) and also to divert animals away from roads (Lindblom, 2010). However, limited information exists on the impacts of supplemental feeding as a method of reducing crop damage (Anderson, 2017). Although some studies have been conducted on the mitigating effects of supplementary feeding, understanding of the ecological effects and practices that reduce crop damage is yet to be explored fully (Selva *et al*., 2014).

2.3 Effectiveness of electric fencing on deterring crop-raiding by wild boar

Further, another common mitigation measure is the use of electric fences to restrict wild boar from agricultural farms. Farmers previously used conventional non-electric wire fences to refrain wildlife animals and maintain farm animals within grazing fields (Massei *et al*., 2011). The non-electric fences were ineffective since they were not durable and wildlife still caused damage to the agricultural farms. The electric fences have been used as a crop damage prevention measure (Vidrih and Trdan, 2008).

Designs of simple or electrified fences have been used in different countries to prevent damage to valuable crops by wildlife. For example, a fence consisting of 2 to 3 strands of electric wires spaced 15 - 30 cm apart or woven wire mesh with strands of barbed wire strung along the top, bottom, and above the woven wire mesh. In Australia, for example, different fence designs have been tested to protect crops and lambing paddocks. Also, in France, steel-wire electric fencing was used extensively to prevent damage to valuable crops over relatively small areas, although Geisser and Reyer, (2004) noted that it may cause a shift in damage to adjacent, non-fenced fields (Reidy *et al*., 2008).

In Africa, electric fences are being used as a measure for reducing crop damage by large mammals, especially elephants and rhinos. It has been successfully used in countries such as South Africa and Namibia to deter elephants from agricultural fields and thus increase harvest yields. It has been demonstrated to have a long-term deterrent of elephants and hence reducing human-elephant conflict. However, electric fences, in general, are not species-specific, the effectiveness and efficiency of electric fences depend mainly on many factors such as topography, type, and design of the fence and the species it is designed to combat as small predators and wild pigs can squeeze through the wires or dig underneath the fences. A study by Lindblom, (2010) concluded that wild boar can jump up to 1.5 meters in height thus these fences need to be high and strong enough to restrict their movement effectively. Also, the use of electric fences requires a lot of capital (both purchasing and maintenance, clearing vegetation regularly) and therefore causes hindrance to farmers with limited resources in terms of capital and human resource. However, it is not fully effective in controlling small mammals and ungulates

In Europe, electric fencing can restrict wild boar movement, depending on the type of used fencing system. Electric fences have been used to prevent wild boar from entering into agricultural fields only if properly installed and maintained (Reidy *et al*., 2008; Bruland et *al*., 2010; Honda *et al*., 2011; Lavelle *et al*., 2011; Saito *et al*., 2011). A study done in Slovenia to determine the most effective designs of a temporary electric fence showed that the distance from the ground to the first wire matters as some ungulates can dig and pass underground. The study also recommended the need to upgrade three strands of temporary electric fences (Vidrih and Trdan, 2008). Despite their ability to reduce damage in arable lands, temporal electric fences have additional damages to the adjacent areas or the less protected areas and the ecosystem as the wild animals will shift and cause damages to the unprotected areas (Geisser and Reyer, 2005; Thinley *et al*., 2017).

In Sweden, electric fencing has helped in the management of human-wildlife conflict and controlling wild pests (Sapkota *et al*., 2014), but little information exists on the effectiveness of their performance and their capacity to deter farm raiding by wild boar. The study hypothesized that there is a difference in crop damages in electric-fenced and unfenced wheat fields.

2.4 Economic feasibility of the supplementary feeding and electric fences

Supplementary feeding has been used as a mechanism for preventing farm raids (Kaplan *et al*., 2011; Kubasiewicz *et al*., 2016). However, its effectiveness in deterring crop damage has been shown to have unintended effects like increasing reproductive success (Milner *et al*., 2014). Little knowledge exists on their effectiveness in preventing farm raids (Massei *et al*., 2011). A study done in Canton Thurgau, Switzerland showed that supplementary feeding did not successfully reduce farm raiding by boar (Geisser and Reyer, 2005). This is because feeding stations were randomly selected in the forests and feeding mode was not effectively monitored. Other factors like the variation of seasons, mode of distribution of supplementary feeds, the number of feeding stations per study site, and density of the wild boar also do influence the cost-effectiveness of the supplementary feeding method (Kubasiewicz *et al*., 2016).

A study in Nepal to evaluate the economic viability of using electric fences as a means of preventing damage by wildlife found it to be cost-effective (Sapkota *et al*., 2014). However, this evaluation was based on the cost-benefit analysis to measure the effects and placed emphasis only on the data obtained from a household survey which was insufficient to determine the viability of the electric fences (Schley *et al*., 2008). On the other hand, a study in Sweden on damages by fallow deer estimated a net positive economic effect of constructing permanent perimeter fences made from woven wires around fields (Menichetti *et al*., 2019). Other studies recommended that the economic feasibility of electric fences should put the following factors into consideration: the life span of the fences, voltage requirements, charge and fence configuration, and the perimeter of the fence (Honda *et al*., 2015; Sapkota *et al*., 2014).

The study sought to incorporate the peculiarities in the studies above. So far, only a few studies have been done on the cost-effectiveness of both supplementary feeding and electric fencing. Besides, there is limited information that compares the economic viability of electric fences and supplementary feeding methods. The study intended to recommend the most economically viable measure that farmers can use to reduce farm raiding by the wild boar.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of study sites

The study was conducted in five different sites in three Counties of Sweden; Koberg (58°02'13.42" N 12°48'32.65" E) in Västergötland county; Mörkö (65°42’96 N 16°06’90” E) island and Bornsjön (59°14'25.7"N 17°45'09.8"E) in Stockholm county; Boo (59°16 '26.83" N15°12'23.76" E) and Grimsö wildlife research area (GWRA) (59°43'45.0"N 15°28'20.6"E) in Örebro county (Fig. 3.1).

Koberg estate cover approximately 100 km^2 receives an average annual precipitation of 682 mm and has an average annual temperature of approximately 8.2°C. The landscape is mostly made up of farmland and forests consisting mainly of spruce and pine with some mixed deciduous stands between the farmlands, urban structures, and small lakes.

Mörkö island is approximately 59 km^2 and receives an average annual precipitation of about 500 mm and has an annual temperature of between 5-6 °C. The period of vegetative growth - days with an average temperature above 5°C is about 200 days. The undulating landscape consists of approximately 25% of agricultural land, and 60% is covered by coniferous forest, consisting mainly of spruce and pine. Bornsjön receive average annual precipitation of 500 mm and have an annual temperature between 5-6°C. They are a nature reserve and water protection area with only organic farming.

Boo castle site receives annual average precipitation of about 555 mm and has an annual average temperature of between 5 - 6°C. The main economic activities include active forestry and farming, as well as hunting and fishing. The forests cover approximately 116 km^2 of productive woodland and the arable land consists of about 7 km^2.

The GWRA is about 130 km^2 and receives an average precipitation of about 555 mm and has an annual average temperature of between 5-6°C. The area is covered mainly by mixed coniferous forests (74%) and, bogs and mires (18%). About 85% of the area is managed by conventional forest practices. Farmland constitutes 3%, while lakes and rivers constitute 5% of the area. The landscape is relatively flat.

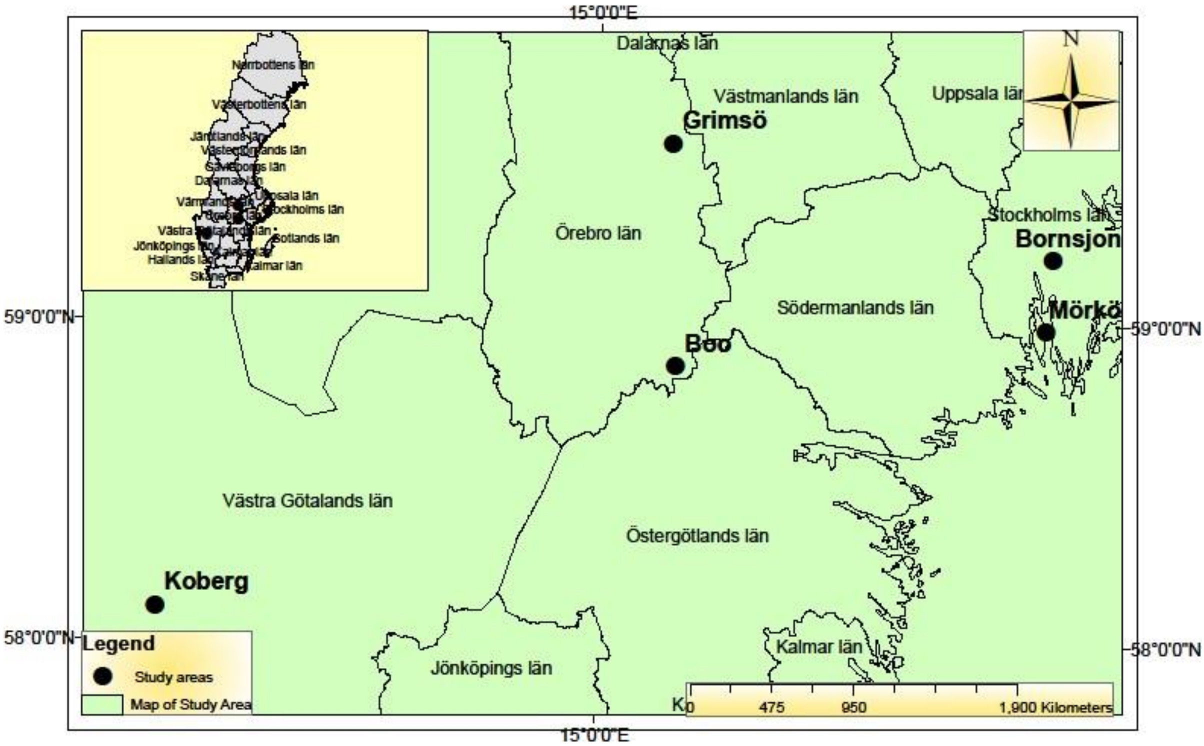

Figure 3. 1: Map of the five study areas in Sweden

3.2 Data collection

3.2.1 Habitat and crop selection by wild boar and the mitigating effect of supplementary feeding on reducing crops damage

Data collection on habitat and crop selection by wild boar and the mitigating effect of supplementary feeding on reducing crops damage was carried out from May to August 2019. A total of 11 wild boar including 8 sows and 3 males variously from four study sites were marked with Global positioning systems/Global systems of mobile communications (GPS/GSM) collars. Marking was achieved by first immobilizing the animal with a tranquilizer dart gun from a four-wheeled vehicle or on foot during the night from stands with a feeding station or in traps. After immobilization, the boars were aged, weighed, measured, earmarked, and equipped with GPS/GSM plus 3-D collars from Vectronic Aerospace GmbH, administered with antidotes, and released. The collars were programmed to acquire position after every one hour and accumulated positions were transmitted to a server at Grimsö. The positions with the dilution of precision (DOP) of less than 5 and 3D positions were calculated and at least four satellites were used in the analysis.

Detailed maps on habitat types and main roads were obtained from the Swedish Environmental Protection Agency, (*Nationella marktäckedata basskikt*, *2018*) where 6 different habitats were identified. and classified them into 6 habitat types; (1) "open wetlands" (open water for a large part of the year), (2) "agricultural fields" (arable land for cultivation), (3) "other open lands" (vegetated and non-vegetated open lands, areas with artificial surfaces around buildings, roads, and railways as parks and lawns), (4) "mixed coniferous forests" (forests consisting > 70% spruce or pine > 5 m high); (5) "mixed deciduous forests", (forests consisting >50% broadleaved deciduous forest - mainly birch (*Betula pendula, B. pubescens*), aspen (*Populus tremula*) oak (*Quercus robur*), beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*), linden (*Tilia cordata*) and maple (*Acer platanoides*) with trees > 5 m high), and (6) "clear-cuts" (open and re-growing clear-felled, storm-felled or burnt areas with trees < 5 m high. The study focused on all the sixhabitat types as they are suggested by prevailing literature to be the main habitattypes preferred by wild boar (Thurfjell *et al*, 2009; Eom *et al*, 2019). However, there islimited information on the level of wild boar selection and how feeding stations influence the extent of selection.

Agricultural fields were of special interest since the study aimed to investigate the wild boarlevel of selection on crop fields during vegetative seasons. Data was obtained on crop type from the Swedish Board of Agriculture, (2019). Crop fields were reclassified into6 main crop types; "spring barley", "winter wheat", "spring wheat", "oats", "mixed crops" (spring rapeseed, winter triticale, other cereals), and "grasslands".

To determine the influence of feeding stations and main roads on wild boar habitat selection, data on 132 feeding stations was collected from farmers and hunters. The farmers provided the stations with unused foodstuffs which included cereals, fruits, and vegetables twice or four times a day depending on the density of wild boars. GPS coordinates for the feeding stations were recorded and coded in Quantum Geographic Information System (Q GIS) for analysis. Determining the influence of roads, detailed maps on main roads which paved highways with one (1) lane in each direction of traffic, witha posted speed limit of 80 km/h and average daily traffic were obtained from the Swedish Environmental Protection Agency (SEPA).

3.2.2 Wild boar damage in electrically fenced and unfenced wheat fields

To collect the data on wild boar damage in electrically fenced and unfenced wheat fields, A Randomized complete block design (RCBD) was used with each treatment (electricfence) in the 4 study sites (Boo, Ökna/Nynäs, Bornsjön, and Mörkö) and replicated 3 times. Spring wheat and winter wheat were used during the study. The electric fences were installed from late June to September of 2019 during the cultivation of wheat. The fences were temporary and both wooden poles (in corners) and small plastic poles were used.They were ringed with three lines of iron wire located at 20cm, 40cm, and 60 cm above the ground. In total 12 fences were used in the 3 study sites thus each study site had 4 fences. Each fence was powered by a mobile 12 V battery unit, charged with a solar panel, generating a maximum charge of 11,800 V or 3.1 J. Among all the 3 sites, Bornsjön practiced organic farming but the rest was conventionally managed. A total of 24 fields were used for the study, 12 fields with electric fences, and 12 unfenced. Two fields were harvested earlier as silage and thus not included in the analysis. All the harvest was done during august and in kg/ha and a total of 22 fields were used for analysis (11 fenced and 11 unfenced).

To determine the damage inventory, a total of 24 fields were monitored during the study, 12 fenced fields, and 12 unfencedfields. In this study, only 22 fields were used in the analysis. The damage was monitored from May to August for both fenced and unfenced fields. The monitoring method was done by using 10-m wide line transects along tractor tracks which were made during the sawing period. All the fields were monitored 6 times. The information recorded includes; damaged area, damage type (presence of animals, lying straws, rooting signs, paths, scats, and tracks). Also, the height of wheat was recorded and thecoordinates in which damage was found. More focus was put on the damage caused bywild boar less than 1 month to harvesting time since it is then when crops start to ripe and reach the milky stage and are more damaged by wild boar.

3.2.3 Determination of economic feasibility between the two measures

To collect the data on economic feasibility between the two measures (electric fencing and supplementary feeding), the harvest yields in kg/ha obtained from objectives 2 and 3 were used. The total cost of anaverage electric fence was determined by calculating the cost incurred during the installation of the fence, maintenance costs, labor costs, and the cost of purchasing the fences. The cost of supplementary feeding was determined from the labor involved in the distribution of the feeds to the different sites, the cost of purchasing the supplemental foodstuff, and the cost of the feeding station. The benefits were achieved from total revenues after wheat grains harvest for both fields with feeding stations and electric fences and were expressed in monetary terms at the market price of the harvesting season that year. The independent variables which were measured were categorical and include costs, time, and laborwhile the dependent variable was the harvest data. Through analysis of the variables, the measure which had higher benefits than the costs were recommended useful to farmers.

3.3 Data analysis

3.3.1 Habitat and crop selection by wild boar and the mitigating effect of supplementary feeding on reducing crops damage

For the data analysis on habitat and crop selection by wild boar and the mitigating effect of supplementary feeding on reducing crops damage, Quantum GIS version 3.10.0 (QGIS Development Team2015), and R studio (3.6.2) was used. Transmitter data from the four study areas were uploadedinto Microsoft Excel. Positions with a dilution of precision (DOP) of 5 and a3D position provided by 4 satellites were used in this study. Wild boar movements were mapped and georeferenced with the Q GIS software (3.10.0).

The first analysis aimed at investigating general habitat selection where agricultural land was considered as one among many habitats and in the second step, possible additive effects of the distance to feeding stations and main roads was investigated. In the 6 habitats, a total of 26, 911 (mean per individual = 2711, Min-Max = 1374 – 2912) locations from the 11 wild boar were used to create minimum convex polygons (MCP) in Q GIS to estimate home ranges and to generate an equal number of random points in relation to the actual wild boar locations, i.e., the ratio of 1:1 within the individual home range (Fig.3.2).

Thus, the wild boar locations were defined as to which habitat the individual boar used compared to what was available (random points) in the home range. The use of MCP ensured all the random points were created from the area available for each wild boar. To analyze the selection of crop types, subset of 3,904 actual wild boar locations in agricultural fields and generated equal random locations in agricultural fields was used. The random and actual wild boar locations (1 location per hour) were used to analyze the probability of wild boar selection of different habitats and crop fields as theactual number of locations indicated the time wild boar spent in that habitat. Thus, if the number of actual wild boar locations is higher than the number of random locationsin that habitat, then it was interpreted that wild boar preferred that habitat.

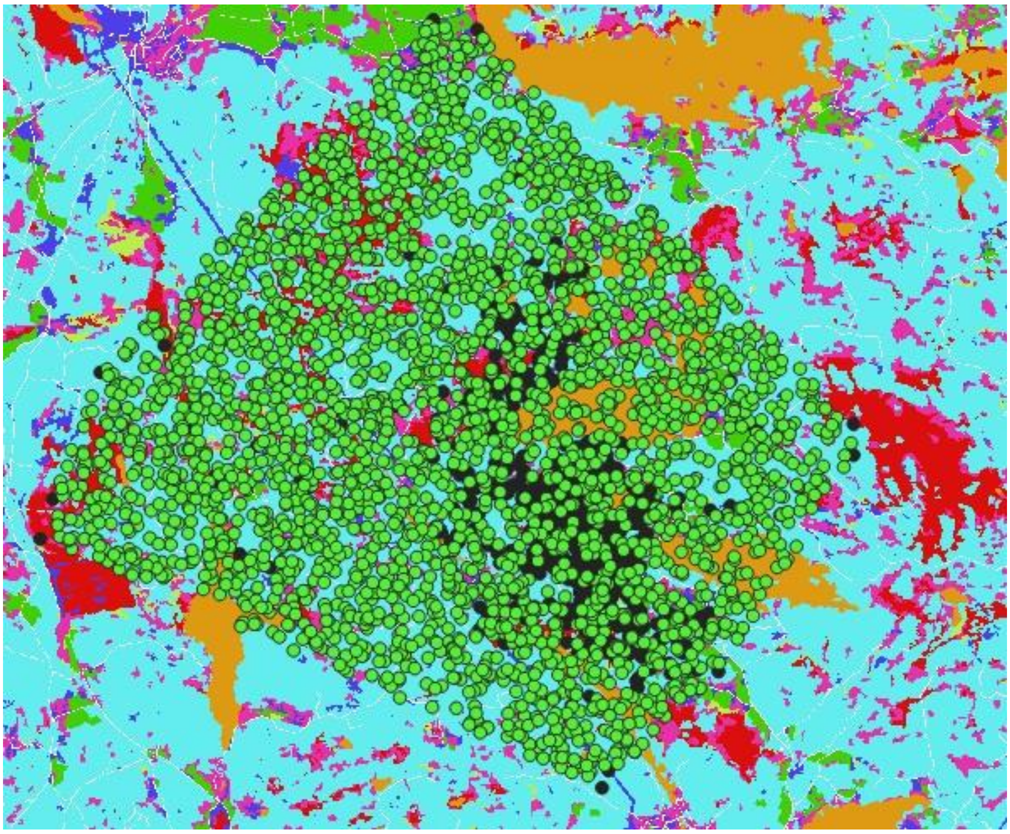

Figure 3.2: An example of the distribution of random locations (green dots) in the home range by a female wild boar (WB02) in Boo study site and her actual locations (black dots) in the ratio of 1:1 formed by concave hull (alpha shapes) (in QGIS version 3.10.0). The random location show where the female could have been apart from where was.

To evaluate the effect of distance to feeding stations on wild boar habitat and crop selection, generalized linear mixed models (GLMM) were used to implement a binary logistic regression where the modelling of the probability of selection was done in R software (ver. 3.6.2). The response variables were the location types (actual wild boar locations and random wild boar locations) and were binomial, where "0" was set for random locations in the available area, where the wild boar could be and "1" was set for the actual wild boar locations. The fixed explanatory variables were: "Different types of habitat" (6 habitat categories), "Distance to main roads (log_{10}-transformed)" and "Distance to feeding stations (log_{10}-transformed)" for habitat selection and the crop selection, the explanatory variables were "Distance to feeding stations (log_{10}-transformed)", "Distance to main roads (log_{10}-transformed)" and "Crop types" (6 crop types). Individual animals were treated as random factors. The within habitat effects were calculated as the coefficient for the reference habitat plus the habitat coefficient that was relative to the reference. The same method was used to estimate the effect of distance to feeding station in different habitat categories; i.e. the slope of the reference habitat plus the habitat slope relative to the reference. The selection for habitat categories and crop type was tested in the logistic regression. At neutral selection and with an equal number of true and random locations, there is a 1:1 probability of true versus random locations. This corresponds to a log(odds) of 0 in logistic regression. Thus, a coefficient significantly higher than 0 indicates selection for that habitat category.

The model selection was based on the Akaike information criterion (AIC) and was compared with the null model. The pseudo R^2 is the proportion variation explained by the fixed factor. The model with low AIC (ΔAIC) was termed the best model to explain the influence of landscape factors on habitat selection. In the first and second models, interactions (distance to the feeding station and distance to roads) were added respectively.

3.3.2 Wild boar damage in electrically fenced and unfenced wheat fields

Data analysis on wild boar damage in electrically fenced and unfenced wheat fields on all the fields were analyzed using Microsoft Excel andR studio. Paired t-test was used to compare the possible difference in the mean of harvest and damage in both fenced and unfenced fields. Mean differences of the damage caused by wild boar during growing seasons (3months) and less than 1 monthto harvest period was determined. Correlation tests were run to test the relationship between harvest yield (kg/ha) and the proportion of damage caused by wild boar in lessthan 1 month to harvesting period in the fenced wheat fields.

3.3.3 Determination of economic feasibility between the two measures

To determine the economic feasibility between the electrically fenced and supplementary feeding, gross margins and net profit analyses wereapplied in comparing the profitability. Gross margin (GM) has been specified as a proxy used in the analyses of profitability (Mukherjee, Sarkar, and Sarkar, 2018). Despite this ability, gross margin only includesvariable costs and dismisses fixed and capital costs. This necessitated the need to combine GM analyses with net profit (NP) which accounts for the fixed and capital costs while computing profitability. Gross margin was computed as the difference between total revenue and total variable costs (Jagelavicius, 2013).

$$GM = TR - TVC$$

Where GM is the Gross Margin; TR is the Total Revenue; TVC is the Total Variable Costs. In addition, Net profit was computed as total revenue less than the total costs (Husna and Desiyanti, 2016).

$$\Pi = TR - TC$$

Where TR is Total Revenue; TC is the Total Costs of production and Π is the net profit. Total revenue was computed as the product of price and the quantity of output, that is, total revenue was quantified from the quantity of wheat marketed and the prevailing prices in the season under review.

Total costs were obtained by summing up the total variable costs and the total fixed costs. Total variable costs were the sum of all costs of variable inputs, labour cost, and maintenance and transportation. Variable costs included in this study were the cost of inputs and costs of labor. In addition, the initial cost of investment, interest on total variable costs, and depreciation formed the fixed costs. The initial cost of investment (capital cost) was spread across the useful life of investments in wheat production.

Interest was achieved by charging a simple savings interest rate of 2 percent which was the average annual saving deposit interest rate for the Swedish Central Bank in Sweden (SCB, 2019). In addition, the economic life of 10 years was used as the average period within which farmers and land owners were expected to use acquired assets assuming a standard usage and preventive maintenance (Jadhav and Rosentrater, 2017). While calculating depreciation, a 10 percent scrap value was taken from the purchase price of the equipment as indicated by Wachira *et al*. (2014). The depreciable expense of assets was assumed to be fixed during the useful life hence the straight-line method of depreciation was appropriate in determining the portion of the decrease in value (Mccoy and Rubin, 2008). The method is simple and frequently applied as it replaces the time function with the utilization function (Mert and Demir, 2016) and is expressed as shown;

$$\text{Depreciation} = \frac{\text{Asset Price Value} - \text{Scrap Value}}{\text{Expected economic life}}$$

To compare the economic feasibility of electric fences and supplementary feeding in reducing crop damages, gross margin and net profits were computed per unit of the farm under wheat cultivation in hectares (ha).

CHAPTER FOUR

RESULTS

4.0 Overview

This chapter provides data analysis results both descriptive and inferential results from binary logistic models for objectives 1 and 2. It also provide results of paired t-test analysis for possible differences in wild boar differences between electrically fenced and unfenced wheat fields and the economically viable measure between the provision of supplemental foodstuffs and electric fencing on reducing wild boar crop damages.

4.1 Evaluating landscape factors on habitat and crop selection

4.1.1 Descriptive results on habitat selection

“Clear-cuts” was the most selected among all habitats with a selection value of 0.74. Other selected habitats included “agricultural field” (0.63), “deciduous forest” (0.58), and “other open lands” (0.53). “Open wetland” (0.44) and “coniferous forest” (0.30) were avoided (Fig.4.1).

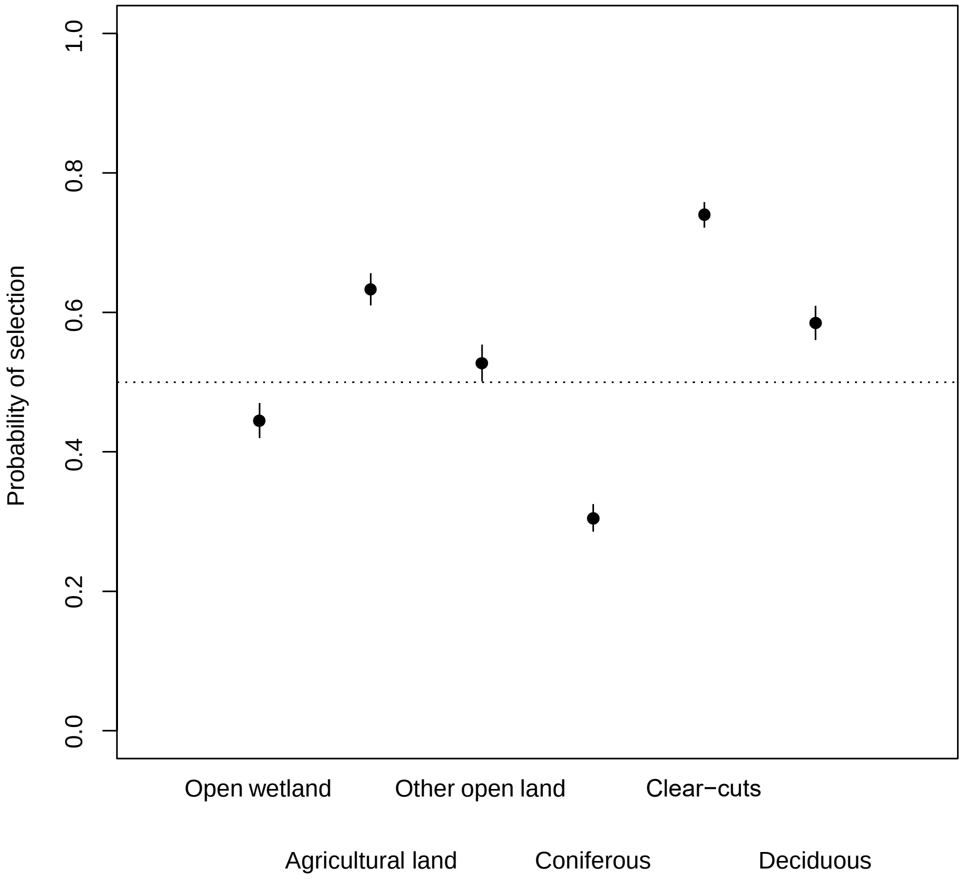

Figure 4.1: Wild boar habitat selection retrieved from 11 marked wild boar (one location per hour) in six different habitat classes, in the four study areas in southern Sweden, 2019. A probability above 0.5 indicate a selection for that habitat and below 0.5 indicates avoidance of that habitat.

Approximately 42.5% of all wild boar locations were found in “clear cuts” while only6.6% of the random locations were found in that habitat (Fig.4.2). Only 24.6% of the wild boar locations were found in “coniferous forests”, compared to 58.0% of the random locations (Fig.4.2).

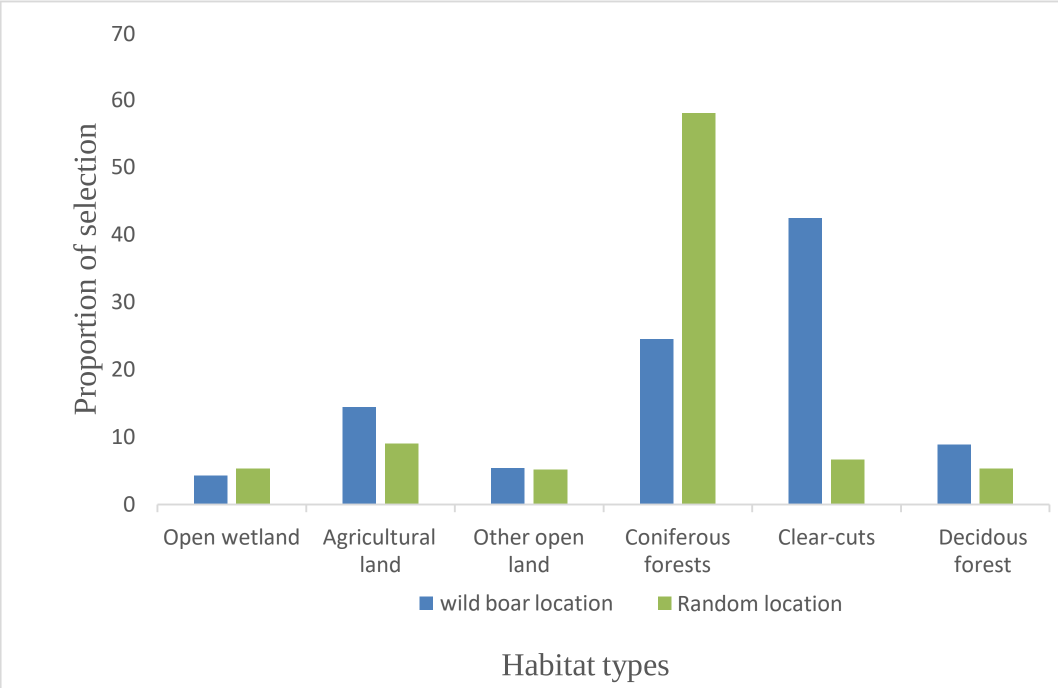

Figure 4.2: The proportion of wild boar locations in all habitats retrieved from 11 marked wild boar (one location per hour) and the proportion of random locations in six different habitat classes, in the four study areas in Southern Sweden, 2019.

4.1.2 Binary logistic regression model results on habitat selection

Clear cuts were the most significantly preferred habitat. Agricultural lands, deciduous forests, and other open lands are also preferred. Open wetlands and coniferous forests were significantly avoided during summer (Table. 4.1, Fig.4. 1 and Fig.4. 2).

Table 4.1: A binary logistic regression model with location types (actual wild boar and random locations) as dependent variable and habitat as the explanatory variable, animal ID as a random factor, and open wetlands as the intercept

Fixed factor	Coefficient ± SE	P-value	Within habitat effect Coefficient ±SE	P-value
Open wetlands (intercept)	-0.22± 0.05	0.0001	-0.22±0.05	0.0001
Agricultural lands	0.77±0.05	<0.0001	0.55±0.05[a]	<0.0001
Other open land	0.33±0.06	<0.0001	0.11±0.05	0.034
Coniferous forests	-0.60±0.04	<0.0001	-0.83±0.05	<0.0001
Clear-cuts	1.27±0.05	<0.0001	1.05±0.05	<0.0001
Deciduous forests	0.57±0.05	<0.0001	0.34±0.05	<0.0001

[a] The habitat differences were estimate as “reference coefficient” + “habitat coefficient”

For example, for Agricultural land;

coefficient 0.55 = -0.22 + 0.77, SE = 0.05 = sqrt ((0.052^2+0.050^2)/2)

The most parsimonious model included; “habitat type”, “distance to feeding station”, “distance to roads” and the interaction “habitat type” and “distance to feeding stations” (Model 1; Table 4. 2).

Table 4. 2: GLMM, binary logistic regressions models on the influence of distance to the feeding station and distance to main roads on habitat selection by wild boars

Models	AIC	ΔAIC	Pseudo R2
Model 1[1]	64003.2	0.0	19%
Model 2[2]	64109.7	106.6	19%
Model 3[3]	64304.2	194.4	18%
Model 4[4]	64855.3	551.2	17%
Null model[5]	72341.8	7486.5	0%

[1]Model 1 = habitat + dist. feed + dist. roads+ habitat*dist. feed + (ID random factor)

[2]Model 2= habitat + dist. feed + dist. roads+ habitat type*dist. roads+ (ID random factor)

[3]Model 3 = habitat+ dist. feed +dist. roads+ (ID random factor)

[4]Model 4 =habitat + (ID random factor)

[5]Null model = 1 + (ID random factor)

4.1 3 Influence of distance to feeding station on habitat selection by wild boar

There was a negative significant influence of "distance to feeding station" in the habitat types "agricultural land", "coniferous forest", and "other open land", whereas the relationship was positively significant in "open wetland" and not significant in "clear-cut" and "mixed deciduous forests" (Table 4.3 and Fig 4.3).

Table 4.3: Binary logistic regression models on the influence of distance to feeding stations on habitat selection by wild boar

Fixed factor	Coefficient ±SE	p-value	Within habitat effects Coefficient ±SE	p-value
Open wetland (intercept)	-1.85±0.39	<0.001	-	-
Agricultural land	5.47±0.43	<0.001	3.62±0.41[a]	<0.001
Other open land	5.18±0.42	<0.001	3.33±0.41	<0.001
Mixed coniferous forest	3.34±0.42	<0.001	1.49±0.41	<0.001
Clear cuts	3.67±0.39	<0.001	1.82±0.39	<0.001
Mixed deciduous forest	3.18±0.42	<0.001	1.33±0.41	0.001
Log_{10}dist. Feed (reference; Open wetland)	0.57±0.11	<0.001	-	-
Log_{10}dist. Feed: Agricultural land	-1.43±0.13	<0.001	-0.86±0.12	<0.001
Log_{10}dist. Feed: Other open land	-1.57±0.13	<0.001	-1.00±0.12	<0.001
Log_{10}dist. Feed: Mixed coniferous forests	-1.23±0.11	<0.001	-0.66±0.11	<0.001
Log_{10}dist. Feed: Clear cuts	-0.71±0.12	<0.001	-0.14±0.11	0.23
Log_{10}dist. Feed: Mixed deciduous forests	-0.77±0.13	<0.001	-0.20±0.12	0.10
Log_{10}dist. Road	-0.115 ±0.030	<0.001	-	-

[a] The within habitat effects were estimate as "reference coefficient" + "habitat coefficient" For example, for Agricultural land;

coefficient 3.62 = -1.85 + 5.47, SE = 0.41 = sqrt ((0.39^2+0.43^2)/2)

The predictions are at a mean distance to roads. The dots are based on binning the true wild boar locations /random locations (1 and 0) data into groups of 100 samples and estimating the proportion of true wild boar locations and the mean distance to feeding stations in the binned group. The analyses were done using log10(x+1)-the transformation of distance to feeding stations and roads. The figures show the results back-transformed. The jitter along the upper and lower axes represents the sample of true wild boar locations and random locations, respectively (Fig.4.3).

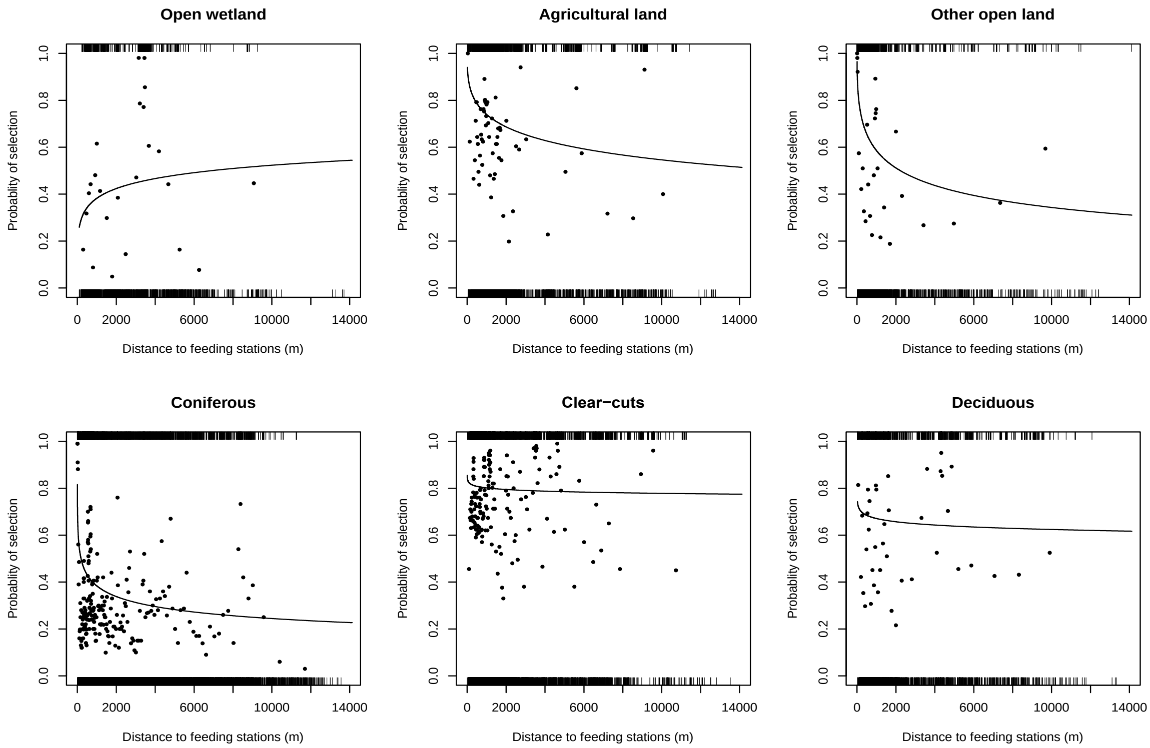

Figure 4.3: Model predictions of the probability of selection in the six habitat types in relation to the distance to feeding stations.

4.1.4 Influence of distance to main roads on habitat selection by wild boar

Distance to main roads significantly influenced wild boar selection of habitat types (Table 4.4). More specifically, distance to main roads had a negative effect on the selection in "other open land" as well as on the selection for "clear cuts", whereas "distance to main roads" positively influenced wild boar selection in "mixed deciduous forests" (Table 4.4).

Table 4.4: GLMM, binary logistic regression models on the influence of distance to main roads on habitat selection by wild boar.

			Within habitat effects	
Fixed factor	Coefficient ± SE	p-value	Coefficient ± SE	p-value
Open wetland (intercept)	0.91±0.37	0.014	-	-
Agricultural land	1.20±0.41	0.002	2.15±0.39 [a]	<0.001
Other open land	1.77±0.45	<0.001	2.6 ±0.41	<0.001
Mixed coniferous forest	-0.05±0.37	0.891	0.86±0.37	<0.001
Clear cuts	3.55±0.37	<0.001	4.46±0.37	<0.001
Mixed deciduous forest	-0.78±0.44	0.072	0.13±0.40	0.685
Log_{10}dist. Roads (reference; Open wetland)	0.21±0.12	0.078		
Log_{10}dist. Roads: Agricultural land	-0.12±0.14	0.394	0.09±0.13	0.487
Log_{10}dist. Roads: Other open land	-0.53±0.15	0.001	-0.32±0.14	0.018
Log_{10}dist. Roads: Mixed coniferous forests	-0.2±0.12	0.967	0.00±0.12	0.973
Log_{10}dist. Roads: Clear cuts	-0.79±0.13	<0.001	-0.58±0.12	<0.001
Log_{10}dist. Roads: Mixed deciduous forests	0.50±0.15	0.001	0.71±0.13	<0.001
Log_{10}dist. Feed	-0.56±0.03	<0.001	-	-

[a] The within habitat effects were estimate as “reference coefficient” + “habitat coefficient” For example, for Agricultural land;
coefficient 2.15 = 0.91 + 1.2, SE = 0.39 = sqrt ((0.37^2+0.41^2)/2)

4.1.5 Crop selection

Wild boar selection for “agricultural land”; the selection value was 0.63 (see above and Figure 4.1). This means that the selection estimate of 0.63 is used as the reference value for a neutral selection of crop types within the habitat type “agricultural land”. A coefficient corresponding to a neutral selection of 0.63 in the logistic regression is the log-odds of 0.63 = log (0.63/ (1-0.63)) = 0.53. Mixed crop fields (other cereals, rapeseed fields, and triticale fields) (0.89) were the most selected crop by wild boar in comparison to the other crops in this study followed by oat fields (0.88), spring wheat (0.88), spring barley (0.69) (Fig. 4.4). On the other hand, winter wheat fields (0.56) and grasslands (0.51) were avoided by wild boars during summer (Fig.4.4)

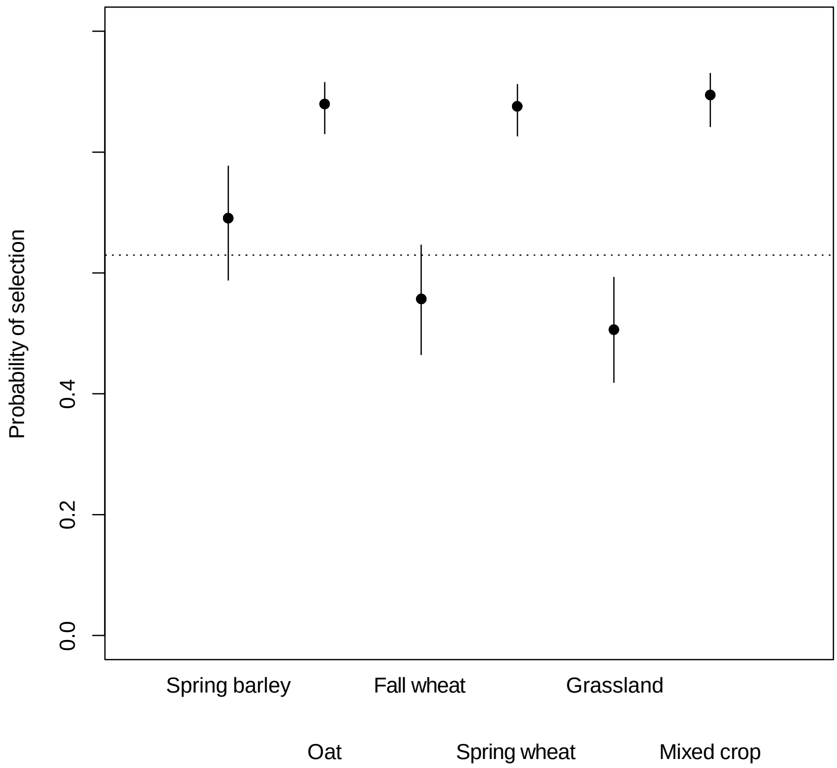

Figure 4.4: Wild boar selection for and against six different crop classes (spring barley, oat, winter wheat, spring wheat, grasslands, and mixed crops) from 1st May - 31st August 2019 in four study areas (Koberg, Mörkö, Boo, and Grimsö) in southern Sweden. Agricultural land has a threshold of 0.63 (Figure 4. 2). Thus, a value above 0.63 shows a selection for that crop type, and below 0.63 shows avoidance.

The total number of GPS locations for both actual wild boar locations and random locations is different for each crop field. Oat fields have the highest proportion of wild boar locations 16.8 % compared to the random locations (4.3%) which imply that wild boar spent most of their time in that crop field (four times more time than expected). However, grassland fields have a higher number of random locations (79.7%) compared to actual wild boar locations (60.3%). This indicates wild boar spend a lot of time, but less than expected in grassland fields during this time of the year (Fig.4.5).

Figure 4. 5: The proportion of wild boar locations retrieved from 11 marked wild boar (one location per hour) and the proportion of random locations in six different crop fields, in the four study areas in southern Sweden, 2019.

Table 4.5: GLMM, a binary logistic model for crop selection by wild boars. Crop fields were the explanatory variable while the dependent variable was the location types (wild boar locations and random locations) and animal ID was the random effect.

Fixed factor	Coefficient ±SE	P-value	Within habitat effects Coefficient ± SE	z-value	P-value
Spring barley (intercept)	0.80±0.23	0.001	0.80±0.23	1.19 [a]	0.23
Oat	1.19±0.18	<0.001	1.99±0.21 [b]	7.10	<0.001
Winter wheat	-0.57±0.14	<0.001	0.23±0.19	1.57	0.12
Spring wheat	1.15±0.17	<0.001	1.95±0.20	7.07	<0.001
Grasslands	-0.79± 0.11	<0.001	0.02±0.18	2.80	0.005
Mixed crop	1.33±0.25	<0.001	2.14±0.24	6.75	<0.001

[a] The new threshold is 0.63; i.e. a coefficient log-odds = log (0.63/1-0.63)) = 0.53, thus to test the difference to a "neutral selection" of 0.53; z = (coefficient – 0.53) / SE

For example, for Spring barley; z = 1.19 = (0.80 – 0.53)/0.23

[b] The within habitat effects were estimate as "reference coefficient" + "habitat coefficient"

For example, for Oat;

coefficient 1.99 = 0.80 + 1.19, SE = 0.21 =sqrt ((0.23^2+0.18^2)/2)

4.1.6 Influence of distance to feeding station on crop selection by wilboar

Wild boar selection for different crop fields was significantly influenced by “distance to the feeding station”. The closer to a feeding station the stronger selection for “spring wheat” and “grasslands”, while the opposite effect was found for “mixed crops”. Thus, a decreased distance to feeding stations decreased the use of “mixed crops” (Table 4.6). For “spring barley”, “oats” and “winter wheat” there was no significant effect of distance to the feeding station (Table 4.6).

Table 4. 6: Binary logistic model of the effect of log10 distance to feeding station on crop selection by wild boar. Model = crop field + dist. feeds+ crop fields*dist. feeds+ (ID random factor).

			Within habitat effects	
Fixed factor	Coefficient ±SE	p-value	Coefficient ±SE	p-value
Spring barley (intercept)	1.19±0.26	<0.001	-	-
Oats	0.51±0.20	0.010	1.70±0.23 [a]	<0.001
Winter wheat	- 0.18 ±0.20	0.370	1.01±0.25	0.001
Spring wheat	1.35±0.19	<0.001	2.54±0.30	<0.001
Grassland	-1.07±0.13	<0.001	0.12±0.21	0.603
Mixed crops	-1.48±0.47	0.002	-0.29±0.38	0.562
Log_{10}. dist. Feeds: Spring barley (references)	-0.22±0.22	0.308	-	-
Log_{10}. dist. Feeds: Oats	0.61±0.28	0.030	0.39±0.25	0.117
Log_{10}. dist. Feeds: Winter wheat	-0.26±0.34	0.435	0.48±0.28	0.087
Log_{10}. dist. Feeds: spring wheat	-0.36±0.39	0.324	-0.58±0.30	0.054
Log_{10}. dist. Feeds: Grasslands	-0.86±0.21	<0.001	-1.08±0.22	<0.001
Log_{10}. dist. Feeds: Mixed crops	1.64±0.340	<0.001	1.42±0.29	<0.001

[a] The within habitat effects were estimate as “reference coefficient” + “habitatcoefficient”
For example, for Oat;
coefficient 1.70 = 1.19 + 0.51 SE = 0.23 = sqrt((0.26^2+0.20^2)/2)

Figure 4.6 shows model predictions of the probability of selection (odds from logistic regression) in the six crop types in relation to the distance to feeding stations (Table 4.6). The dots are based on binning the actual wild boar locations /random locations (1 and 0) data into groups of 20 samples and estimating the proportion of actual wild boar locations and the mean distance to feeding stations in the binned group. The analyses were done using log10(x+1)-transformation of distance to feeding stations. The figures show the results back-transformed. The jitter along the upper and lower axes represents the sample of actual wild boar locations and random locations, respectively.

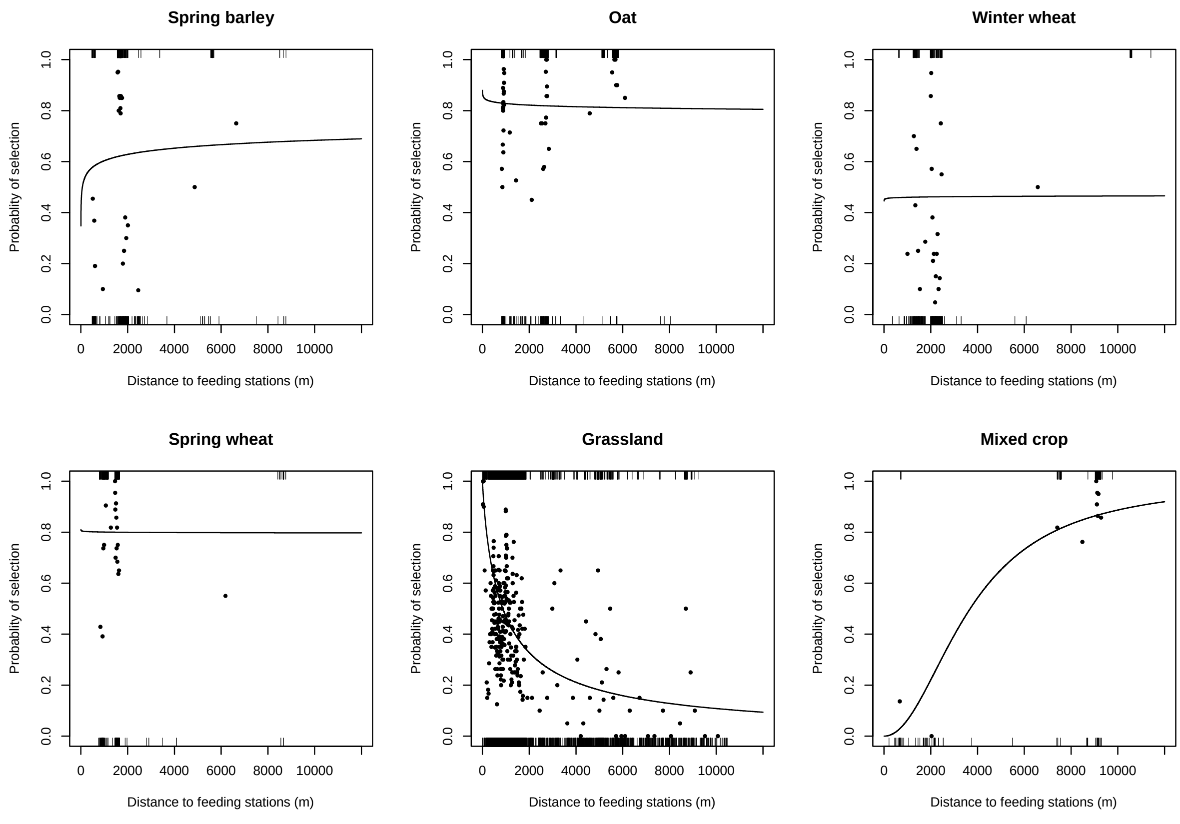

Figure 4.6 Model predictions of the probability of selection (odds from logistic regression) in the six habitat types in relation to the distance to feeding stations (Table 4.6).

4.1.7 Influence of distance to main roads on crop selection by wild boar

"Distance to main roads" significantly influenced wild boar selection of different crops (Table 4.7). The closer distance to main roads the less time is spent on "spring wheat" and "mixed crops" while it is the opposite in "winter wheat" and "spring barley". For "oats" and "grassland" there was no significant effect of distance to main roads. (Table.4.7).

Table 4.7: Binary logistic model of the effect of log_{10} distance to main roads on crop selection by wild boar. Model = crop field + dist. roads+ crop fields*dist. roads+ (ID random factor)

Fixed factor	Coefficient ±SE	p-value	Within habitat effects Coefficient ±SE	p-value
Spring barley (intercept)	1.06 ±0.27	<0.001	-	-
Oats	0.84 ±0.21	<0.001	1.90±0.26 [a]	<0.001
Winter wheat	-0.75 ±0.19	<0.001	0.31±0.26	0.236
Spring wheat	1.92 ±0.32	<0.001	3.00±0.37	<0.001
Grassland	-1.09 ±0.15	<0.001	-0.03±0.26	0.894
Mixed crops	0.89 ±0.27	0.001	1.96±0.31	<0.001
Log_{10}. dist. Roads: Spring barley (references)	-1.01±0.26	<0.001	-	-
Log_{10}. dist. Roads: Oats	1.39±0.27	<0.001	0.38±0.27	0.149
Log_{10}. dist. Roads: winter wheat	0.31±0.36	0.380	-0. 70±0.31	0.024
Log_{10}. dist. Roads: spring wheat	2.73±0.42	<0.001	1.72±0.35	<0.001
Log_{10}. dist. Roads: Grasslands	1.22±0.26	<0.001	0.21±0.26	0.409
Log_{10}. dist. Roads: Mixed crops	2.13±0.35	<0.001	0.12±0.31	0.000

[a] The within habitat effects were estimate as "reference coefficient" + "habitat coefficient"

For example, for Oat;

coefficient 1.90 = 1.06 + 0.84, SE = 0.26 = sqrt ((0.27^2+0.21^2)/2)

4.2 Wild boar damages between electrically fenced and unfenced wheat fields

4.2.1 Descriptive statistics

The descriptive statistics for the mean wheat harvest yield for the 3 study sites show that there were possible differences in the yield between the control sites (unfenced) and fenced wheat fields. The highest wheat mean yield was 5574.04 kg/ha in the control field in Mörkö while the lowest mean yield was 4489.18kg/ha in Bornsjön in fenced wheat fences (Fig.4.7)

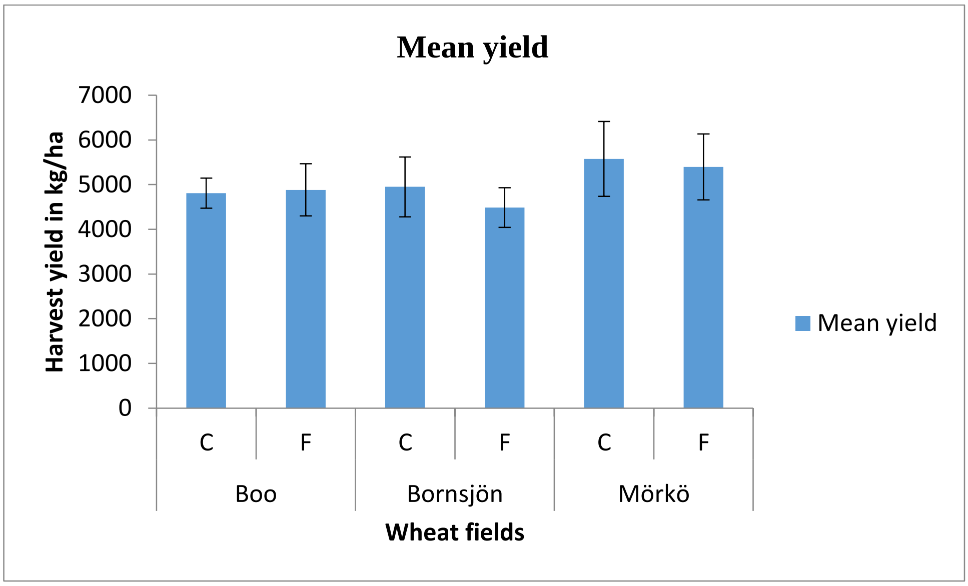

Figure 4.7: The bar plot of harvest yields (kg/ha) for 22 wheat fields, 11 fenced and 11 unfenced in the three study areas (Boo, Mörkö, and Bornsjön). The C means unfenced and the F means fenced wheat fields.

The mean damage area (m^2) monitored in less than 1 month to harvest in all the study areas showed that there were larger damaged areas in control fields compared to fenced wheat fields. Boo site had the largest damage compared to the other sites (Fig.4.8)

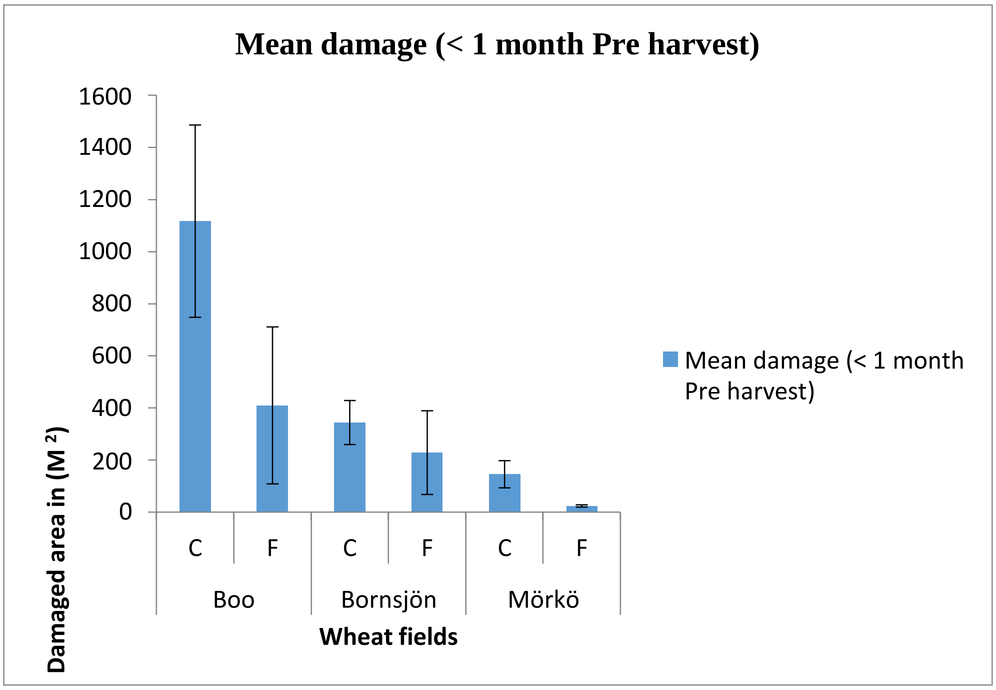

Figure 4.8: The mean damaged area (< 1-month pre-harvest) for both C (control) and F (fenced) wheat fields in the 3 study sites.

The relationship between mean wheat harvest yield and pre- harvest damage showed that fields with large damages had lower yields compared to fields with small damages which in turn had a higher yield. The trend-line for the mean damage and mean yield showed that a decrease in damage area increases harvest yield (Fig.4. 9)

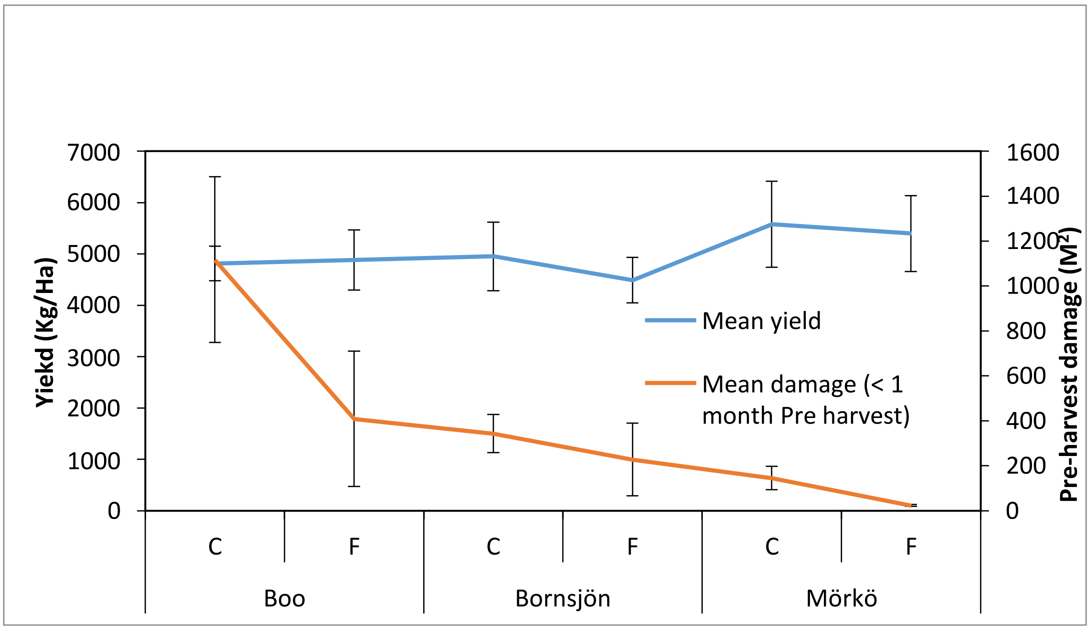

Figure 4. 9: Trend lines to show the relationship between the mean yield and mean damage in the control and fenced wheat fields for the three study sites.

The results on mean damage differences for the < 1-month pre-harvest and growing season (sowing to < 1-month pre-harvest damage, 3 months) show that control fields had larger damages compared to fenced fields. Further, despite monitoring damages for 3 months and comparing it with less than 1-month pre-harvest, there were slight differences in all the mean damages and thus most damages occur during the pre-harvesting period (Fig.4.10)

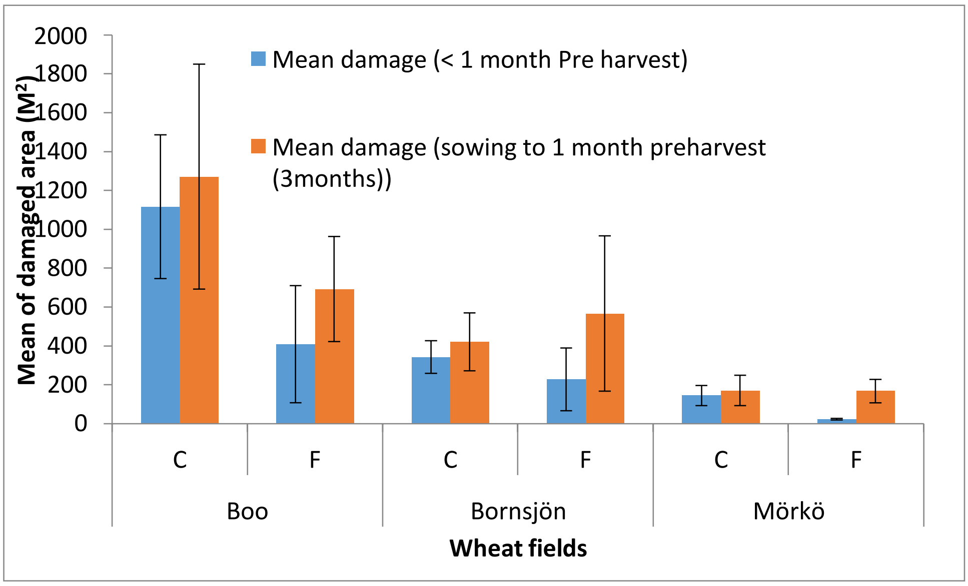

Figure 4. 10: A bar plot of the mean damaged area <1 month to harvest and earlier in the growing season (sowing to < 1-month pre-harvest).

The linear regression analysis showed that there was an inverse relationship between harvest yields and the damage caused by wild boar in less than one month to harvest period in the fenced wheat fields. This imply that a decrease in wild boar damages increased wheat harvest yields and an increase in damages reduced the harvest yields (Fig. 4.11).

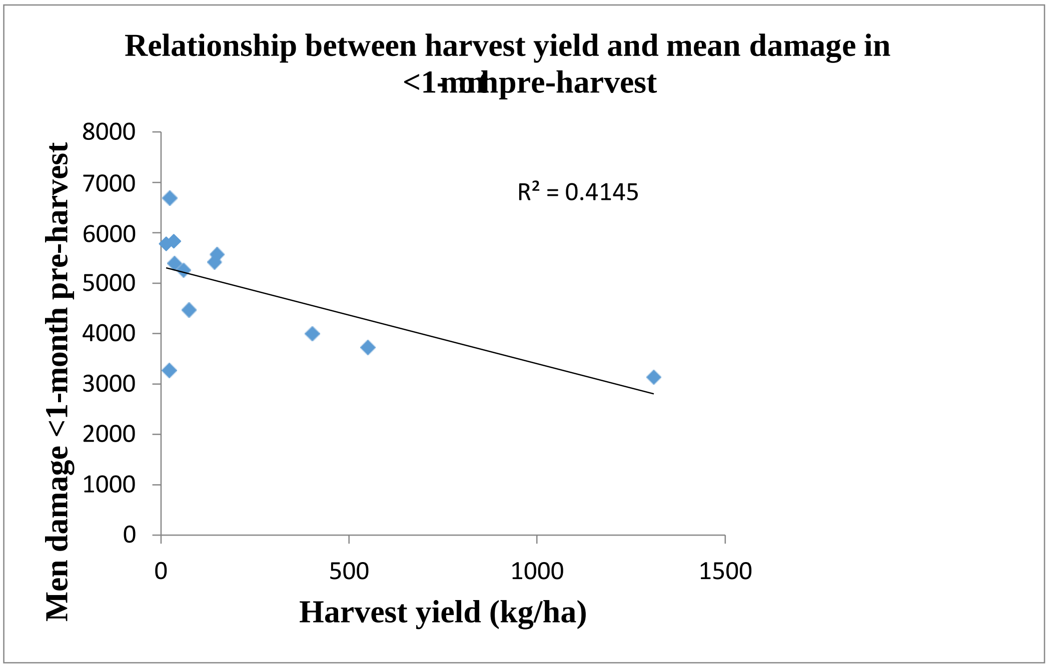

Figure 4. 11: Linear regression analysis for the wild boar damages in both the fenced and unfenced wheat fields.

4.2.2 Comparison between the fenced and unfenced wheat fields

The results of the paired t-test on the comparison between the fenced and unfenced wheat fields showed that there were significant differences in the Pre-harvest damage (<1-month pre-harvest) between electrically fenced and unfenced wheat fields in the Booand Mörkö study sites (Table 4.8).

Table 4. 8: The comparison between the possible differences in damage for the fenced and unfenced wheat fields

Study sites	Variables	Fenced wheat fields		Unfenced wheat fields		
		Pooled mean	St. Error	Pooled Mean	St. Error	P-value
Boo	Harvest yield (Kg/ha)	4881.75	584.12	4811.79	336.66	0.9207
	Pre harvest damage(<1 month harvest) (M2)	409.50	301.37	1117.13	368.80	0.0439**
	Growing season damage (Sowing to 1 month pre harvest) (M^2)	692.60	270.78	1271.25	577.94	0.3995
Bornsjön	Harvest yield (Kg/ha)	4481.18	442.80	4951.16	669.32	0.5957
	Pre harvest damage(<1 month harvest) (M2)	228.17	160.97	343.75	84.26	0.5593
	Growing season damage (Sowing to 1 month pre harvest) (M^2)	567.46	399.28	422.19	148.93	0.7503
Mörkö	Harvest yield (Kg/ha)	5394.45	738.41	5574.04	837.70	0.8775
	Pre harvest damage(<1 month harvest) (M2)	23.28	4.15	145.38	52.15	0.0292**
	Growing season damage (Sowing to 1 month pre harvest) (M^2)	169.03	60.05	171.41	78.49	0.9816

(***, ** and *show significant variable at 1%, 5% and 10% levels of significance respectively)

4.3 Economic feasibility

To determine the economic feasibility of electric fences and supplementary feeds in reducing wild boar damage on wheat fields, data from 2 study sites (Boo, Mörkö) in which each study site had four electrically fences fields of 4ha each was used. To measure the effectiveness of provisions of supplemental foodstuffs in each study site, data from approximately 5 feeding stations in which the farmers provided foodstuffs to the wild boar was used.

In comparing the economic feasibility between fencing and supplementary feeding in reducing wild boar damages, gross margins and net profit analyses were applied. Gross margin (GM) has been specified as a proxy used in the analyses of profitability (Ahmad *et al*., 2005; Roelofse, 2013). The gross margin only includes the variable cost and dismisses the fixed and the capital cost. This necessitated the need to conduct the gross margin analysis with Net Profit (NP) which accounts for the fixed and capital cost while computing the profitability. The gross margin for each mitigation measure (Supplementary feeding and fencing) was computed as the difference between the Total Revenue (TR) and the total cost (TC).

The total costs were categorized as variable costs and fixed costs. The cost of labor maintenance directly employed in the installation of electric fences and automatic feeding machines were incorporated as variable costs. Variable costs were computed by multiplying the quantities of each input by the factor prices. Annual initial costs, depreciation of the structures and tools, and interest on total variable costs (working capital) comprised the fixed costs. The straight-line method was applied to estimate the depreciation of assets. A 10 percent salvage value was calculated on the purchase worth as explained by Wachira et al. (2014). The total depreciable cost was divided by the useful life of the assets to obtain the annual depreciation expenditure. Interests on total variable costs were calculated by charging a simple interest rate of 1.5 percent which was the average annual saving deposit interest rate for the Swedish Central Bank (SCB, 2018). All the fixed costs were computed as shown in chapter three of the thesis.

The total revenue was computed as the product price and the quantity of output, that is, total revenue was quantified from the quantity of wheat marketed and the prevailing market prices in the wheat harvesting season under review. The total revenue obtained fromfencing was calculated as the total output/harvest yield (5138.10 kg/ha) multiplied by the current market price at that harvesting season (USD 0.17) bringing out a gross income of USD 873.48 (Table 4.9)

The total variable cost for fencing was obtained from the summation of the total installation cost which included (labour cost + maintenance cost per 4ha field). The total variable cost amounted to USD 960 per 4ha. The total fixed costs amounted to USD 149.22. Thus, to obtain the total cost of fencing, the summation of the total variable cost and the total fixed cost was done amounting to USD 1,109.22. This was based on the fact that the experiment was carried out in 2 study sites (Boo, Mörkö). The size of each field was estimated to be 4ha and thus in total 8 fields were fenced (Table 4.9).

The total revenue for supplementary feeding was obtained as the average harvest yield per farm (5192.91 kg/ ha) multiplied by the market price (USD 0.17). Therefore, the gross income or total revenue obtained from the supplementary feeding was USD 882.79).

The total variable cost (supplementary feeding) was obtained from the summation of the total cost of labour (USD 144) and maintenance cost (USD 48) per one feeding station in which cost was computed per hour for USD 200. This resulted in total variable costs amounting to USD 192. The artificial feeding sites (barrel and spreader) were set to give approximately 5kg per day of the foodstuff. The common feeds provided by farmers and landowners at the feeding stations were cereals especially maize and wheat which costs approximately USD 0.35/kg. Each feeding station was active throughout the year but data used in this study was from May 2019 to August 2019 that is from the sowing to harvesting period of spring wheat. This was to ensure that wild boarand other ungulates are diverted to the feeding stations and minimizing the damages they cause to the farmlands. The total fixed cost of feeds was estimated to be USD 191.19 and the total cost obtained was 383. 16 per feeding station per 4 months

Table 4.9: Cost analysis of preventive measures to crop damages. Costs per 4ha farm and 1 feeding station in electric fences and supplemental feedings respectively. (1SEK = USD 0.12 at 14th July 2021)

Items	**Electric fencing**			**Supplementary feeding**		
	Unit prices	**Quantity**	**Total USD**	**Unit price**	**Quantity**	**Total USD**
Total revenue			**873.48**			**882.79**
Variable costs						
Labour (man day/hr)	200	32	768	200	6	144
Maintenance costs	200	8	192	200	2	48
Total variable costs			**960**			**192**
Fixed costs						
Capital cost interest			19.26			27
Depreciation costs			115.56			162
Variable costs interests			14.4			2.16
Total fixed costs			**149.22**			**191.16**
Total cost			**1,109.22**			**383.16**
Net profit (USD)			**-235.74**			**499.63**

The results implied that a farmer who provided supplementary feeding as a way of reducing crop damages incurred an economic profit of USD 499.63 while a farmer who installed electric fences incurs an economic loss of USD 235. 74. Therefore, the use of supplementary feeding was more economical than the use of fences in reducing wild boar damages.

CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter provides a discussion on the results of data analysis for the mitigating effect and feasibility of supplementary feeding and electric fences in reducing crop-raiding by wild boar. It presents landscape factors influencings habitat and crop selection by wild boar. The possible difference in crop damages between electrically fenced fields and unfenced wheat fields and the economic feasibility of electric fencing and supplementary feeding will be discussed.

5.1 Landscape factors influencing habitat and crop selection by wild boar

5.1.1 Habitat selection

Descriptive statistics results indicated that specific habitats were preferred by wild boar while others were avoided. Clear-cuts seemed to be the most preferred habitat by wild boar during summer with a 74% probability of selection (Table 4.1, Fig.4.3, and 4.4). A plausible explanation for this is that clear cuts are open re-growing and clear-felled where regeneration has been gradually ongoing for the last 1-5 years with abundant shrubs and dens sprouts providing good shelter. Potentially, clear cuts could also provide some food in terms of invertebrates and rodents. Wild boar being generalist omnivores are thus attracted to these sites. The re-growing vegetation usually has fresh grass that might be attractive to wild boar during some seasons. Similarly, Eom *et al*. (2019) found that there was a positive coefficient of habitat use for clear-cuts by wild boar. This was due to an abundance of understory on the clear-cuts.

Deciduous forests had a positive significant influence on wild boar preference, during the summer season. This could be explained by the fact that fruits from some deciduous trees such as beech or oak constitute the most important natural food resource for wild boars in many areas. Furthermore, these tree species intermittently produce disproportionately high amounts of fruits (full mast). These results concur with Rho, (2015) findings that wild boar concentrate in mixed oak forests and croplands due to the availability of corns, masts, and crops, and also they preferred dense green forest areas as they protect them from predators and human disturbances. Similarly, Fonesca, (2008) found that the preference for deciduous forests by wild boar was due to its abundance of feeds in the forest floor in which the species structure comprised of herbs and grasses. Besides, the soil of these forests comprise of several insects and rodent species.

Agricultural lands had a significant influence on wild boar habitat selection, during the summer season. This is because during this time most cereals (barley, oats, wheat, and maize) ripen and thus become more attractive (Cellina, 2008). These results concur with Thurfjell *et al*. (2009) findings that agricultural lands are majorly selected by wild boar during summer than during other seasons. Herrero *et al*. (2006) also found that the stomach content in killed wild boar comprised 90% of crops during summer.

Other open lands were less preferred by wild boar than clear-cuts, deciduous forests, and agricultural lands. A credible possible explanation for this is that other open lands have small patches of trees and shrubs, and consist of some pastureland and areas and non-vegetated areas like those used for the construction of buildings and roads. The vegetated areas provide good cover for wild boar with plenty of feeding opportunities. During summer, with the abundance of crops in the farmlands, this habitat becomes less attractive to wild boar, and it is less preferred compared to agricultural lands and deciduous forests which have an abundance of food resources. Likewise, other studies have found that open areas were the most preferred habitat by wild boar during other seasons except summer (Fonesca *et al*., 2008; Schley *et al*., 2008; Keuling *et al*., 2009; Thurfjell *et al*., 2009).

Open wetlands had a negative influence on habitat selection by wild boar as there are abundant crops in the farmlands which are more attractive. These results are corroborated by Morelle and Lejeune, (2015) and Lee *et al*. (2018) argued that open wetlands had no significant effect on damages by wild boar. Likewise, Paolini*et al*. (2018) found that wetlands were consistently selected for each season but less strongly in the early growing season which coincided with increased resource availability. On the contrary, a study by Ficetola *et al*. (2014) in Southern Italy found that water was essential for drinking and also for wallowing to remove ectoparasites thus, bogs and marshy areas had high densities of wild boars in those areas.

Coniferous forests had a negative influence on wild boar selection during summer season. This is because it is less productive and lack the abundance of food and shelter the other habitats provided (deciduous forests, clear-cuts, and agricultural lands). Deciduous forests provide bed sites for wild boar as well as hiding areas from predators and hunters due to their dense cover, unlike coniferous forests that generally are not as dense. Similarly, a study by Massei and Genov, (2004) to evaluate the environmental impacts of wild boar found that they do more rooting in deciduous forests than in coniferous forests. Other studies by (Thurfjell *et al*., 2009; Zeman *et al*., 2016) also found that coniferous forests were avoided by wild boar during summer in comparison to other forest types.

5.1.1.1 Effect of distance from the feeding station and roads on habitat selection

Topographical factors are major determinants of wildlife habitat use (Lee *et al*., 20018). This is because there can be environmental variability and strong local gradients of insulation which depends on topography such as elevation and surface orientation. Human activities also affect wild boar habitat use either directly or indirectly. Human influence like the provision of supplemental feeds in the feeding stations attracts wild boar to that habitat more than those without the feeding stations. With more wild boar roaming in such an area the probability of feeding in that habitat increases. Thus close distances to feeding stations increase the probability of wild boar feeding in that site (Kubasiewicz *et al*., 2016).

There were significant negative effects of the distance to feeding stations for wild boar selection of agricultural lands, coniferous forests, and other open lands. The negative coefficients of these habitats implies that a decrease in distance to feeding stations increases the proportion of wild boar selection of these habitats respectively. This is explained by the fact that feeding stations are constructed mainly on the forest edges and further away from agricultural fields to attract wild boar to those sites. Similarly, other studies on moose and red deer found extensive damage in the Scandinavian forests occurs within a distance of 1 kilometer from the feeding stations. High levels of damage were explained by the increased number of feeding stations in the forest stands (Gundersen *et al*., 2004; Beest *et al*., 2010; Milner *et al*., 2014).

There were significant positive effects for open wetlands which show increaseddistance to the feeding station increases the proportion of wild boar selection for that habitat. A plausible explanation is that feeding sites are systematically located alongside forests and not on wetlands. Also, wild boar tends to avoid wetlands, especially during summer when there are abundant feeds in the farmlands. In contrast,results by Kubasiewicz *et al*. (2016) found that diversionary feeding was a mitigative measure to reduce habitat damages thus ungulates concentrated on feeding stations rather than on the natural forage the specific habitats provided.

Human activities along roads resulting in noise and pollution emitted by vehicles negatively influence wild boar preferences for different habitats. Thus, wild boar tends to avoid habitats that are close to main roads and prefer those further away. Perhaps because of a more limited chance to discover potential predators in the environment close to roads. In line with that, there were also significant positive effects of distance to roads on wild boar selection of deciduous forests. This implied that increased distance to roads increases the proportion of selection of this habitat. This is in agreement with Rho, (2015) results which showed that wild boar preferred areas that haveminimal human activities thus use areas with > 310 meters from paved areas.

On the other hand, other open lands and clear-cuts showed a negative correlation on the distance to roads as the increased distance to main roads decreased wild boar selection of these habitats (Table.4.4 and Fig. 4 6). Clear-cuts and other open lands were mainly alongside roads thus negative relationships with distance to roads. A study by Lee *et al*. (2018) on the maxent model, to predict wild boar damages on farmland, concluded that distance to roads was contributing very little to the model and thus could not give a clear implication of the significance of the roads on predicting damage of wild boar. The results in this study showed that distance to main roads affected wild boar selection of different habitats differently.

5.1.2 Crop fields selection

Results showed significant preferences of different crop fields by wild boar. Cereals especially oat, spring wheat, and mixed crops are highly preferred, especially during the milky stage as they contain high energy content (Schley *et al*., 2008; Frackowiak *et* *al*., 2013; Ballari, *et al*., 2014; Bobek *et al*., 2017). The high preference for these cereals was supported by Clarin and Karlsson (2010) on the Swedish Board of Agriculture (SEBA) report on cropland damages in Sweden, which showed a preference for oat, wheat, and barley. Mixed crops, oat, and spring wheat were more preferred relative to grasslands. The results indicated a significant positive selection for spring wheat fields by wild boar while spring barley and winter wheat fields were less preferred. These results are in line with the findings of Herrero *et al*. (2006) that wheat fields were more damaged by wild boars compared to barley fields. The difference in selection between spring and winter wheat is interesting and is probably explained by the difference in exposure time to damages. Since the winter wheat normally matures quicker and is harvested 2 - 4 weeks earlier than the spring sawed wheat, the boar simply has a shorter time to visit mature winter wheat as they have to visit spring wheat fields.

Furthermore, grasslands were less preferred by wild boar during summer. Grasslands (pastures and leys) are grown throughout the year and thus they provide food for wild boar in most of the seasons but less so during summer. The results concurred with Schley *et al*., (2008) and Amici *et al*., (2011) findings that grasslands were selected throughout the year but mostly during winter whereas cereals were selected mostly during summer when they are in their milky stage. Additionally, Caruso *et al*. (2018) found that wild boar used fewer grasslands when other habitats were available during summer.

5.1.2.1 Effect of the distance from feeding station and roads on crop fields selection

There was a significant effect of distance to the feeding station on crop selection by wild boar. The negative coefficient of spring wheat and grasslands implied that a decreased of distance to the feeding station increases the proportion of wild boar selection of spring wheat and grasslands. Wild boar is more attracted to feeding stations and thus tends to accumulate and roam around the sites thus when there are limited feeds in the stations they tend to shift to the nearby feeding zones. Thus having feeding stations close to the crop fields increased the chances of wild boar selecting those fields (Table 4 6). These results are in agreement with Geisser and Reyer, (2005) finding that the shorter the distance of a crop from the feeding stations the higher the likelihood of damage to the crops. Also, Schley and Roper, (2003) found that supplementary feeding increased the rooting activity in grasslands.

Positive coefficients of mixed crop fields imply that an increase in distance to feeding stations increases the proportion of wild boar selection of those fields (Table 4. 6). On the other hand, other studies have found that feeding stations concentrate wild boars to those sites and reduces their feeding extent on the nearby agricultural fields (Calenge *et al*., 2004; Cellina *et al*., 2008; Tryjanowski *et al*., 2017) while in another study, the effect of wild boar on agriculture fields was not clear (Pascual-rico *et al*., 2018).

Distance to main roads significantly influenced the selection of different crop fields. Spring wheat and mixed crop fields had positive coefficients which implied an increase of distance to roads increased the proportion of wild boar selection on those fields. However, spring barley and winter wheat had negative coefficients implying that a decrease in distance to the main road increased the proportion of wild boar selection to those fields (Table 4. 7). Similarly, Caruso *et al*. (2018) and Hellkvist (2019) reported a positive correlation on the distance to roads with damages that wild boar cause to selected crop fields that are further from roads due to disturbances.

5.2 Wild boar damage in electrically fenced and unfenced wheat fields

The second objective was to determine the possible differences in wild boar damage in both electrically fenced and unfenced wheat fields. The key observed differences were in terms of wheat harvest yields in both fenced and unfenced wheat fields. The results for the damage inventories in both fenced and adjacent unfenced wheat fields established different types of damage, mainly chewed seeds, scats, tracks, paths, rooting, straws for wild boar, and few damages for roe deer and fallow deer. The pre-harvest damagedarea results showed that the damage which was caused in the control site was higher compared to the damage which was caused by wild boar in the electrically fenced wheatfields in all three study sites.

Two study sites (Boo and Morko) showed significant differences in the damage caused by wild boar between the fenced and unfenced fields. Thus, electric fences installed were effective in reducing wild boar damages in farmlands. Also studies on appropriate techniques to prevent other ungulates (red deer and elk) from crop fields established that only poly rope electric fences prevented deer from entering into fields (Johnson *et al*., 2014). Other studies by (Reidy *et al*., 2008; Vidrih and Trdan, 2008; Honda *et al*., 2009, Saito *et al*., 2011) reported that electric fences were the most effective counter measure. However, vegetation can cause current leakage, and wild boar can pass beneath the wire if it is set too high (Hone and Atkinson, 1983). In contrast, a study by Honda, (2015) found that the three different electric fences were ineffective in reducing crop damages for small mammals and ungulates.

Damage data were separated into growing season data (from sowing period to < 1month pre-harvest, approximately, 3 month's period) and Pre harvesting data (< 1- month pre-harvest) during analysis to establish when damage occurred most. The resultsclearly showed that there were possible differences between the damage caused by wild boar during growing seasons and pre-harvest season in both controls and fenced wheatfields. This implied that wild boar causes significant damages to wheat fields when theseeds were ripening. This is supported by (Schley et al., 2008; Novosel et al., 2012) findings that a lot of wild boar damages occurs when the seeds are in the milky stage to when they are mature.

There was an inverse negative correlation between the pre-harvest damage and harvest yields in the fenced wheat fields thus areas with low damage tend to have high harvest yield. For example, the Mörkö study site had a higher harvest yield compared to the Boo site which had a lower yield and high damage. A plausible explanation is that one of the main economic activities in the Boo site is active forestry and farming and the forests cover approximately 11,600 hectares of productive woodland thus wild boar population is high due to the provision of habitats for bed sites and abundant food resources. Similarly, Linkie *et al*. (2007) reported a significantly higher amount of crop damage closer to the forest by wild pigs. Also, the findings by Lindblom's, (2010) study on the distribution of wild boar damage and harvest loss on crop fields found that wheat fields were the most damaged fields by wild boar and thus had high harvest loss.

Similarly, Honda *et al*. (2009) findings on the effective fencing design to reduce crop damage from both large and medium mammals established that all three designs of wires could prevent animals from invading crops. Also, the fence is effective only if properly constructed and managed through having higher voltage and weeding done periodically. In contrast, Geisser and Reyer, (2004) studies found no relationship between the frequency of damage with fencing activities and no evidence of a decrease in damage frequency in the agricultural fields on increased fencing efforts. Further, Also, Sapkota *et al*. (2014) results on the economic effect of electric fencing on reducing human-wildlife conflict in Nepal and found that the fences were significantly reducing crop damages for big mammals like elephant rhinos but not small animals and ungulates.

5.3 Economic feasibility

The primary objectives were to determine the economic feasibility of two mitigation measures used to steer animals away to reduce damages on susceptible crops, electric fences, and the use of supplementary feeding. Once all the variable costs and benefits were analyzed I found that using supplementary feeding, farmers incurred an economic profit of USD 499.63, and the farmers who installed electric fences incurred an economic loss of USD 235.74. Mitigation measures on crop-raiding are supposed to be cost-effective and this study identified that the use of supplemental feeding was cost-effective.

The results can be linked to high costs of installation of electric fences and huge maintenance costs where farmers used electric fences as a preventive measure to crop-raiding. Other studies outside Sweden found electric fences to be cost-effective in reducing damage (Honda *et al*., 2009; Vidrih and Trdan, 2008). Further, studies by (Geisser and Reyer 2004; Schley *et al*., 2008) found that none of the two mitigation measures were effective and rather hunting was the most efficient preventive measure on wild boar damages.

The use of supplementary feeding is mainly to steer animals away to reduce the damages to crops (Milner *et al*., 2014; Kubasiewicz *et al*., 2016; Felton *et al*., 2016). Other studies foundthat for the feeding to be effective, the food supplied to the ungulates in the landscapesshould be increased in consideration of the population density of the ungulates and providing the forage at strategic locations to redistribute the grazing/browsing pressure(Sahlsten *et al*., 2010; van Beest *et al*., 2010; Månsson *et al*., 2015).

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Habitat and crop selection on wild boar

Wild boar populations have increased rapidly in Southern-central Sweden and intensified farm raiding. Thus, the study was bridging the gap through first evaluating wild boar habitat and crop preferences which will help in improving management strategies and thus reduce farm raiding. Based on the results from the study a number of conclusions can be made.

1. Wild boar preferred feeding on clear-cuts, deciduous forests, and agricultural lands during the summer season. Coniferous forests and open wetlands weregenerally avoided by wild boar as there is surplus food in the farmlands and also deciduous forests contained nutrient-rich mast. Agricultural lands, particularly fields containing spring wheat, oat, and mixed crops, were the most attractive crops to wild boar.
2. Landscape factors influenced the selection of habitats and farmlands differently. The most influential factors were the availability of food resources in the habitat and other environmental variables like distance to the feeding stations and distance to main roads.
3. Feeding stations were mainly composed of pea, corn, maize, and wheat. These stations were purposed to attract wild boar to those sites and reduce damage to the agricultural fields and also used as baits by hunters. Most of the feeding stations were alongside forest and agricultural land. Distance to feeding sites influenced the selection of different habitats differently. For instance, the shorter the distance from feeding sites to agricultural lands the higher the probability that the field were selected by the wild boar.
4. Human disturbances like the noise of vehicles on roads affect the wild boar selection of given habitats and crops. Results showed statisticallysignificant impacts of roads on habitat selection by wild boar as increased

preferences of habitats increase with `increasing distance to roads. For instance, the increased distance to main roads increases wild boar preferences for deciduous forests. Nevertheless, there were negative correlations for clear-cuts and other open lands on main roads as preferences of these habitats decreased with an increase in distance from main roads. Thus, distance to main roads affects wild boar selection of different habitats differently.

6.1.2 Wild boar damages in fenced and unfenced wheat fields

1. There is a possible difference in the damaged area (< 1 month to pre-harvest) between the fenced and unfenced wheat fields.
2. There was an inverse relationship between the mean of damage area (< 1-month pre-harvest) and harvest yield in the fenced wheat fields. Therefore, the electric fences installed were effective in reducing crop damages.

6.1.3 Economic feasibility

This study cannot draw a major conclusion due to the study's limitations. However, as from the findings, both mitigation measures were not feasible to be used to reduce wild boar damages on the farmlands.

6.2 Recommendations

Based on the findings the study comes up with the following recommendations to the farmers, landowners, the government, and policy makers.

6.2.1 Landscape factors influencing habitat and crop selection

1. This study provides a first basis for further investigations of landscape factor's effects on the spatial and temporal variation in wild boar selection of habitat suitability in Sweden. Knowledge of what wild boar selects per season will be useful to improve future wildlife management strategies.
2. The study found the presence of feeding stations has a significant influence on wild boar selection of different habitats and crops. Therefore, this study recommends farmers to adjust cropping systems and that susceptible crops like

oat and wheat be grown far away from the forest and feeding stations to reduce damages on more selected crop fields.

3. The study sheds light on scientific and evidence-based wildlife management strategies for wild boar. Management practices should be improved to consider both time and space to reduce the damage they cause to natural ecosystems and agricultural fields.
4. Distance to roads had a positive and significant influence on wild boar selection on different habitats and crops. therefore, this study recommends to farmers and landowners consider having arable lands close to main roads as a way of keeping off wildlife from the farmlands.

6.2.2 Wild boar damages in electrically fenced and unfenced fields

1. This study sheds light on the importance of using electric fences as a way of reducing crop damages.
2. There is a need for the Swedish Environmental Protection Agency to incorporate other mitigation measures like increased protective hunting of wild boar in densely populated areas and also the use of artificial feeding in bait stations to improve the hunting of wild boar.

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