Landscape factors influencing habitat and crop selection by wild boar in Sweden

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Independent project • 30 HEC
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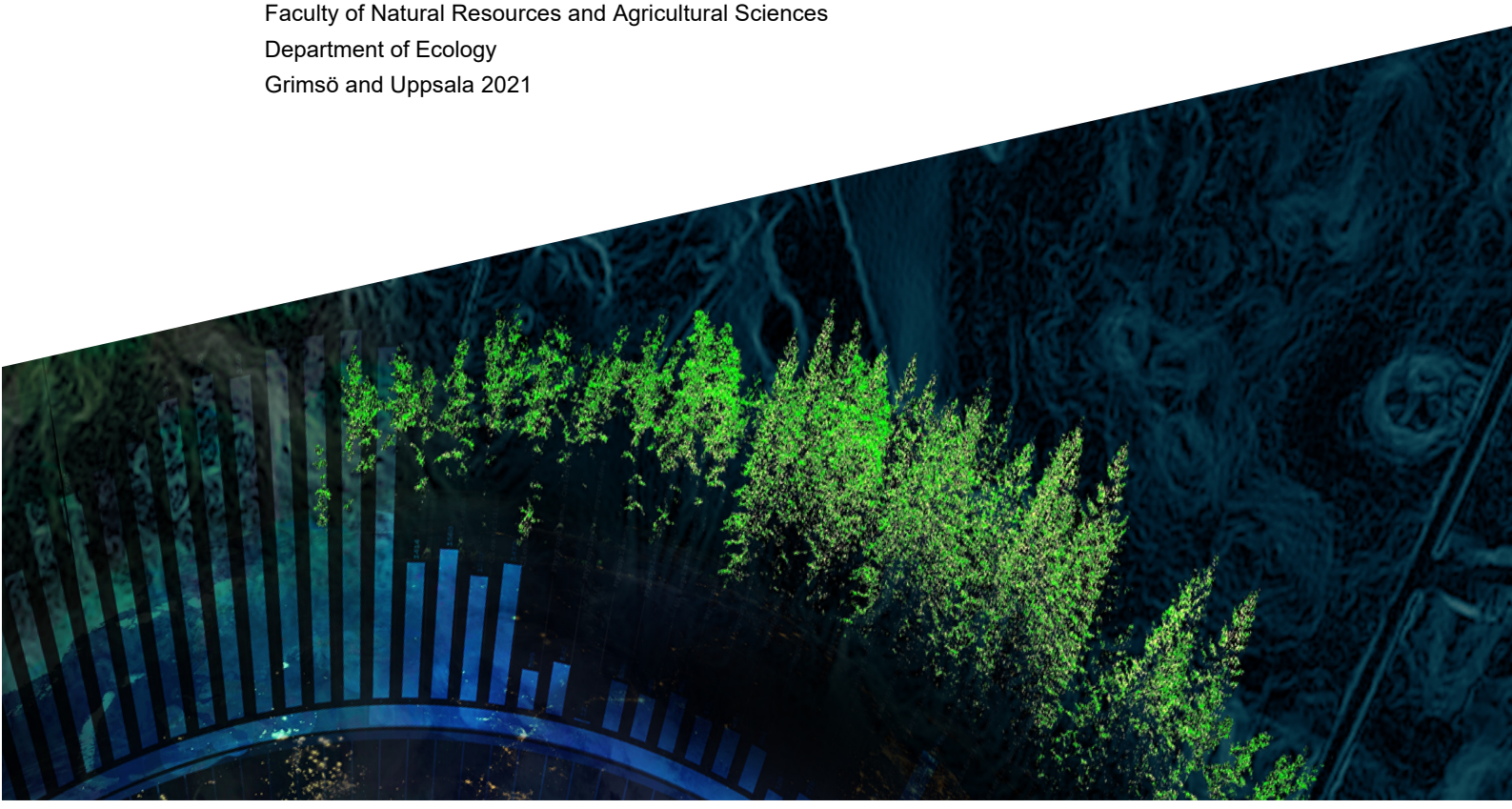
Grimsö and Uppsala 2021



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Credits:	30 HEC
Level:	A2E
Course title:	Master thesis in Biology
Course code:	EX0895
Course coordinating dept:	Department of Aquatic Sciences and Assessment
Place of publication:	Grimsö and Uppsala
Year of publication:	2021
Keywords:	Wild boar**,** Habitats and crop selection, Feeding stations, Q GIS, Binary logistic model

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Abstract

The wild boar population has increased rapidly during the last two decades in the southern and central parts of Sweden. This rise in population size has caused severe damages to agricultural fields through their foraging behavior. Thus, there is a need for improved knowledge about landscape factors influencing habitat selection which will help in the proper management of wild boar hence reducing the losses they cause in the agricultural sector. The main aim of this study is to evaluate landscape factors influencing wild boar selection of various habitats and crop fields in south-central Sweden. Eleven wild boar were fitted with GPS/GSM-collars to record movement among different habitats and crops. Data were analyzed using QGIS (version 3.10.0), R studio (version 3.6.2), and Microsoft Excel software. Descriptive statistics show that wild boar have a high preference for clear-cuts, agricultural fields, and deciduous forests, but show a lower preference for other kinds of open land. Wild boar tended to avoid growing and mature coniferous forests and open wetlands during summer but had a high preference for crop fields with oat, spring wheat, spring barley, 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. Distance to main roads also significantly influenced the proportion of selection of habitats and crop fields with both positive and negative correlation on the proportion of wild boar selection. As a general conclusion, feeding stations and roads influenced the selection of different habitats and crop fields differently. Further, wildlife management strategies on wild boar should be improved to consider both time and space to reduce damages on agricultural fields.

Keywords: Wild boar**,** Habitats and crop selection, Feeding stations, Q GIS, Binary logistic model

Popular science summary

The wild boar population has been increasing rapidly over the past decades leading to intensified farm raiding thus huge economic losses in the agricultural sector. Wild boar being a generalist that eat everything from plants to meat and able to adjust to adverse climatic conditions have been causing conflicts between landowners and farmers due to the damage and losses they cause in modern agriculture. Therefore, knowledge of factors influencing their habitat preferences and crop selection was important to help in mitigating these losses. The main aim of the study is to evaluate landscape factors influencing habitat and crop selection of wild boar in 4 study sites (Koberg, Boo, Mörkö, and Grimsö) in South-central Sweden.

The wild boar movement was examined through tracking 8 sows and 3 males wild boar marked with GPS/GSM-collars. This was done during the summer when crops are grown to determine their selection capacity to different habitats and crops and also to investigate how the distance from feeding stations and main roads influenced their selection. Previous studies have captured the aspect of wild boar preference of different habitats with limited information on the factors influencing the extent of selection. Further, previous studies focused on estimating the level of damages by wild boar on different crops, information on the factors leading to wild boar selecting different crops has not been well documented. Thus, using GPS-collars to monitor the movement of wild boar and the amount of time they spent in a certain habitats or crops could give a true picture of their preferences and assist in the development of preventive measures.

The findings reveal that wild boar prefer clear-cuts over all other habitats, probably for hiding during daytime. Other habitats preferred included; agricultural fields and deciduous forests probably because of the abundance of food resources in these habitats. Coniferous forests, open wetlands, and other open lands were not preferred. Among all different crops were oat fields the most selected crop by wild boar compared to spring wheat fields and various mixed crops (rapeseed spring, triticale fall and others).

The closer to an agricultural field, other open lands, or coniferous forest there was a feeding station, the more wild boar used those habitats. Further, at a more detailed level we found that several crop types (spring wheat and grasslands) were used more the closer they were situated to feeding stations. Main roads had a deterring effect on wild boar on the use of crops, meaning that mixed crops and spring wheat were avoided close to main roads while it obviously had the opposite effect and was not deterring for the use of fall wheat and spring barley.

In conclusion, wild boar prefer clear cuts, agricultural land (oat fields, spring wheat, and mixed crop fields), and deciduous forest. Further, distance from the feeding station and main roads influence the selection of different habitats including crop fields differently. We thus believe this study provide a first basis for further investigations on the effect of landscape factors on the spatial variation in wild boar selection of different habitats and crops. Wildlife management strategies for wild boar needs to be improved to consider both time and space to reduce the damage they may cause on natural ecosystems and agricultural fields.

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Abbreviations

2D	2-Dimensional
3D	3-Dimensional
ΔAIC	Delta Akaike Information Criterion
Cm	Centimeter
DOP	Dilution of Precision
GIS	Geographical Information Systems
GLMM	General Linear Mixed Model
GPS	Global Position Systems
GSM	Global Systems of Mobile Communications
GWRA	Grimsö Wildlife Research Station
SBA	Swedish Board of Agriculture
SEPA	Swedish Environment Protection Agency
SLU	Swedish University of Agricultural sciences

1. Introduction

1.1. Background information

A drastic increase of wild boar (*Sus scrofa*) population size in Europe over the last two decades has led to intensified farm raids, leading to big economic losses in the agricultural sector through their rooting and foraging behavior (Thurfjell *et al*., 2009). In Europe, wild boar have recently recolonized Sweden, Estonia and Finland (Massei *et al*., 2011). In Sweden, the wild boar population was extinct at the beginning of the 1700s; but in the 1970s, the population increased after escapes from enclosures (Massei *et a*l., 2015; Cozzi *et al*., 2019). Swedish Hunters Association, (2017) estimated the population of wild boar in Sweden to be 200,0000 – 300,000 and projected an annual increase to 25 – 30 %.

The increased population of wild boar signifies its adaptation to varying climatic conditions, and as such occupies an extremely wide range of habitats from semi-arid environments, marshes, forest, and alpine grasslands (Massei *et al*., 2011). They also extend their range to other habitats such as mixed forests that include deciduous species, Scots pine (*Pinus silvestris*), spruce (*Picea abies*), and oak (*Quercus robur*) (Olofsson, 2015). The daily activity pattern of wild boar differs between season as they have a low daily range between April and July due to the availability of resources as food, water and shelter and high range during December (Brivio *et al*., 2017; Johann *et al*., 2020).

They are known to live in groups of two or more, constituting sows (adult female wild boar) with their piglet, while adult boar (male wild boar) are found to live solitary outside the breeding season. They are known to be nocturnal although their activities tend to begin before sunset and stop after sunrise with mainly feeding, roaming between consecutive resting sites, and sometimes diurnal in the absence of predators and humans (Amici *et al*., 2011).

Wild boar is an omnivore and opportunistic species in which 90% of their feeds primarily consists of plant materials and secondarily animal foods (Schley *et al*., 2008). The feeding activity is mainly through rooting in forests and grazing on agricultural fields during the night (Felton *et al*., 2017). They have high preferences for crops like corn (*Zea mays*), potato (*Solanum*

tuberosum), bean (*Phaseolus spp*.), pea (*Pisum spp*.), and sugar beet (*Beta spp*.) (Herrero and Sergio, 2006; Oja, 2017). Besides, they also feed on earthworms, rodents, moles (*Talpidae spp*), and scavenge on dead animals (Barrios-Garcia & Ballari 2012). In Sweden, it has been established that they majorly feed on all sorts of cereals such as wheat (*Triticum aevistum*), barley (*Hordeum vulgare*), and oats (*Avena sativa*) but also on corn when available (Gentle *et al*., 2015).

1.1.1. Damages in Agriculture

The drastic increase of the wild boar population has led to increased damage of crops in many countries in Europe thus leading to economic losses. Wild boar causes damage to crops through consumption and also through trampling of the plant. Annual damage of crops (maize, wheat, barley, oats and potatoes) usually peak during late summer and early fall just before or during the ripening of crops and fruits (Herrero *et al*., 2006; Schley *et al*., 2008; Schlageter & Haag-Wackernagel, 2012). A study by Schlageter, (2015) shows that 5 - 10% of the damaged crops are by actual consumption by wild boar. The extent of grassland damage by wild boar is far more numerous and intense than the feeding and trampling of cereals as the damage in grasslands is through rooting and digging and varies across the region and with the season (Thinley *et al*., 2017). Lombardini *et al*. (2017) found that in Sardinia (Italy) wild boar crop damages are most predominant in summer and early autumn, while the lowest damage occurs spring. This is the result of a seasonal adaptation of the wild boar diet in response to the available feed resources.

In countries where wild boar is a protected species, farmers are compensated for the losses attributable to wild boar thus compensation payments amount to millions of Euros every year. Other countries like Sweden, wild boar have not been a protected species thus damage costs are not compensated for and losses in the agricultural sector due to wild boar have been estimated to be 60 - 70 million US dollars per year (Engelman *et al*., 2018). Damage mitigation measures are important to farmers, landowners, and government, and thus a study on factors that influence crop selection by wild boar is necessary.

1.1.2. Management of wild boar and its implications

In the management of wildlife particularly in Sweden, involves both farmers, landowners, forest managers and hunters. The impacts on wildlife are either positive or negative for example,

hunters in high-density areas of games can harvest more while farmers experiencing extensive damages on their crops. Recently, increased hunting pressure on widespread species like wild boar is one of the integrated management actions to mitigate the huge economic losses they cause to farmers. (Bieber and Ruf, 2005; Barrios-Garcia and Ballari 2012; Menichetti *et al*., 2019).

Moreover, other factors that contribute to the increase in wild boar populations are also likely to contribute, indirectly, to an increase in agricultural damage. In this context, supplementary feeding should be critically investigated on its mitigating effect on reducing crop damages as some studies support its effects in reducing damage while other studies confirm it leading to increased population size which in turn increases crop damages. Other mitigating measures include the use of scaring devices, use of electric fencing though permanent electric fences are expensive to construct thus farmers require the knowledge of the cost-effectiveness of fences in protecting their crops from wildlife (Vidrih and Trdan, 2008).

Wild boars are generalist feeders with a highly plastic diet that contributes to their wide geographical distribution. Thus understanding the factors influencing their food selection in combination with knowledge of seasonal patterns of space and habitat use may help inform the design of management plans. A detailed study of diet and the reproductive capacity could provide key information such as target species and susceptible habitats on which management efforts should focus (Ballari *et al*., 2014; Malmsten and Dalin, 2015; Malmsten *et al*., 2017).

1.1.3. Factors influencing habitat use

Several 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 reduce ectoparasites. Thus marshlands, bogs, and wetlands are preferred habitat during certain conditions and may have positive effects for wild boar population growth (Paolini *et a*l., 2018).

Moreover, the presence of a feeding station 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 wild boar or used in baiting traps to facilitate trapping or shooting of wild boars by hunters (Calenge *et al*., 2004; Geisser and Reyer, 2004; Massei *et al*., 2011). For damage prevention, on agricultural fields, the density and location of feeding stations seem to be important factors affecting the efficiency of artificial feeding. Also, other studies recommend supplementary feeding to be supplied when crops ripen and most attractive to wild boar (Cellina, 2008).

Through providing feeds in woodlands, the wild boar is expected to stay in that habitat and off from farmlands. Also, supplemental feeding is thought to satiate the appetite of wild boars thus limit feeding on crops. Studies have shown artificial feeding to be controversial as some studies indicate wild boar to successively reduce damage on agriculture, while other studies reveal unintended effects on wild boars such as high reproductive rates and increased survival rates which may be associated with increased damages (Geisser and Reyer, 2004; Novosel *et al*., 2012). This justifies the need for further studies on the effectiveness of feeding stations in reducing farm damages by wild boar.

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). Studies established that mixed coniferous forest and open areas were avoided by wild boar while agricultural fields were most preferred as they offer a large amount of high-quality food during the summer season (Schley & Roper, 2003; Cellina, 2008; Thurfjell et al., 2009).

Wild boar is termed 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 positive effects of enhancing biodiversity and richness of natural systems as many plants require “disturbed soil” for germination. Nevertheless, increased rooting on agricultural fields has negative effects as many plants may not have adapted to disturbances (Ballari, et al., 2014). Thus it is important to study the mitigating effects in reducing crop damages in agricultural fields and some natural ecosystems. To be able to fill this gap there is a need to focus on landscape factors influencing habitat and crop selection by wild boar. This study aimed to investigate the possible effects of landscape factors on habitat and crop selection by wild boar. More specifically, we evaluate how specific landscape factors such as the distance to feeding stations and roads influence habitat and crop selection of wild boar in southern Sweden.

2. Materials and methods

2.1. Description of the study sites

The study was conducted in four 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 in Södermanland 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. 1).

Koberg estate covers 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 covered with different types of forest (79%), mainly spruce and pine with some mixed deciduous stands. The remaining area consists of arable land and pastures (16%), mires and marshes (2%), lakes, ponds, parks and properties around houses (3%).

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.

Boo castle site receives an average precipitation of about 555 mm and has an annual average temperature of between 5.5°C. The main economic activities include active forestry and farming, as well as hunting and fishing. The forests cover approximately 116 km2 of productive woodland and the arable land consists of about 7 km^2.

The GWRA comprises 130 km^2 and receives an average precipitation of about 555 mm and average January temperatures of - 4°C to -6°C and average July temperatures of 15°C to 16°C. The area is covered mainly by mixed coniferous forest (74%), 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.

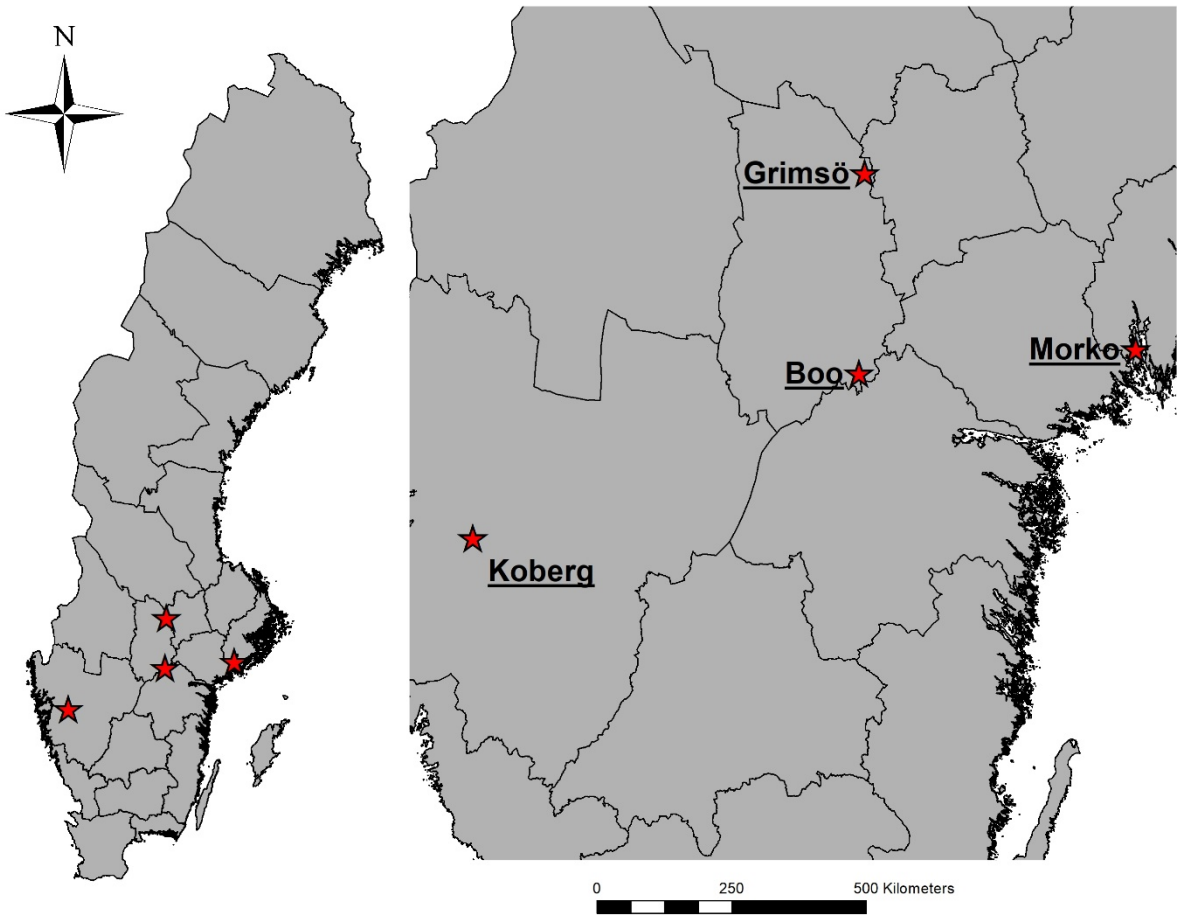

Figure 1: Map of the four study areas located in Southern Sweden, Koberg, Boo, Mörkö and Grimsö.

2.2. Data collection

Data collection was carried out from May to August 2019. A total of 11 wild boars including 8 sows and 3 males variously in four study sites were marked with Global positioning systems/Global systems of mobile communications (GPS/GSM) collars from May to August. Marking was achieved through first immobilizing the animal with a tranquilizer dart gun from a four-wheeled vehicle or on foot during the night, from stands with 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 a 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 m and 3D positions were calculated and at least four satellites were used in the analysis.

Detailed maps on habitat types and main roads (paved high ways with 1 lane in each direction of traffic, with a posted speed limit of 80 km/h and average daily traffic) were obtained from the Swedish Environmental Protection Agency (SEPA), (Nationella marktäckedata basskikt, 2018) where 6 different habitats were identified. They included open wetlands, agricultural fields, other open lands, coniferous forests, mixed deciduous forests, and clear-cuts. Data on crop type on the specific fields in the four study sites were obtained from the Swedish Board of Agriculture (2019). A total of 10 different types of crops were obtained and reclassified into 6 different crop classes. These were spring barley, fall wheat, spring wheat, oats, mixed crop (rapeseed spring, triticale fall, cereal other cereals), and grasslands. GPS coordinates for a total of 132 feeding stations were recorded.

2.3. Data analysis

Analysis of GPS data on wild boar positions was done in Microsoft Excel, Q GIS 3.10.0 and R studio (3.6.0). The transmitter data from the four study areas was uploaded into Microsoft Excel, and poor quality locations like in lakes, belowground and high elevations were removed. Also, the locations with 2D were removed as only 3D could provide sufficient locations with 4 satellites.

For the analysis of the effect of distance to the feeding station and distance to main roads on habitat and crop selection by wild boar, Concave hull (alpha shapes) was used to draw home range polygons and generate equal random points to the wild boar locations in the ratio of 1:1 in the same polygon (Fig. 2). The random points acted as control sites to show other areas in which wild boar could select for or visit apart from where they actually visited. The habitat map was generated by the use of Q GIS (version 3.10.0) for reclassification leading to the 6 different habitats.

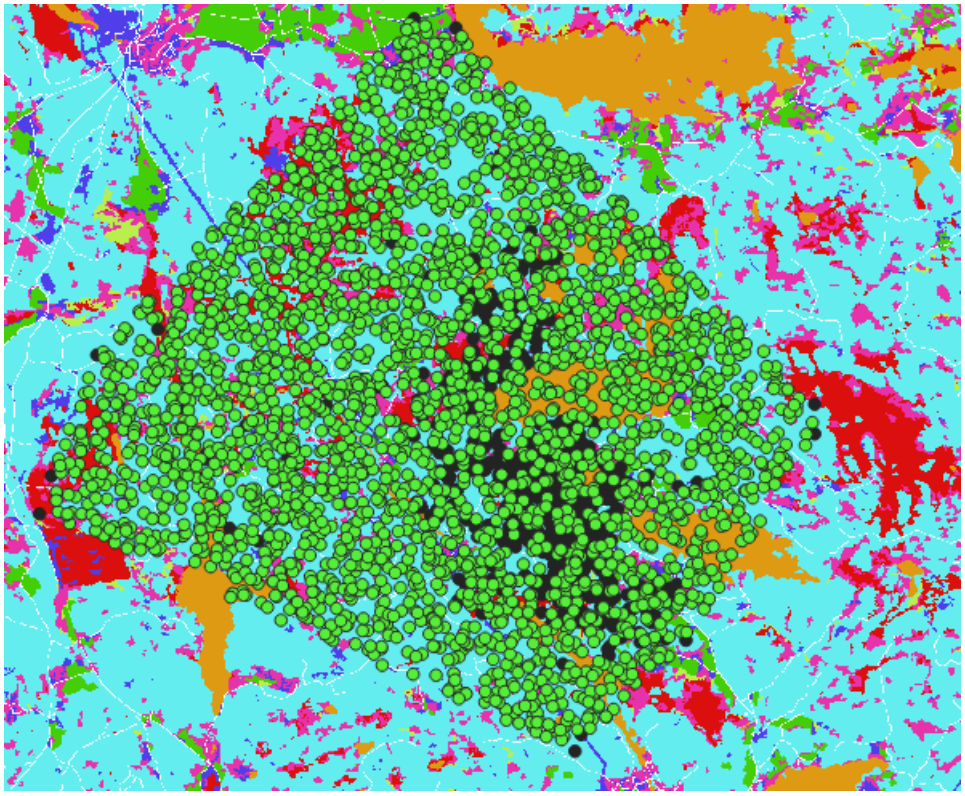

Figure 2: An example of the distribution of random locations (green dots) in the home range by a female wild boar (WB02) in Boo study site and her actual locations (black dots) in the ratio of 1:1 formed by Concave hull (alpha shapes) home ranges (in QGIS version 3.10.0). The random location show where the female could have been apart from where she actually was.

Random and actual wild boar locations (1 location per hour) visualized in Q GIS were used to analyze the probability of wild boar selection of different habitats and crop fields. The total number of GPS locations indicated the time wild boar spend in that habitat. Thus if the actual wild boar locations are more than the random locations in that habitat, then wild boar preferred that habitat and vice versa.

To evaluate the habitat and crop selection, General linear mixed model (GLMM), binary logistic regression models in R software (3.6.2) were used. The response variables, where "0" set for random locations in the available area and "1" set for the actual wild boar locations. The explanatory variables were; distance to main roads, different types of habitat, and distance to feeding stations. For crop selection, the explanatory variables were distance to the feeding station, distance to main roads, and crop types.

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

to the feeding station and distance to roads) were added respectively. The parameter "Dist. Feeds" was the $\log_{10}$ distance to the feeding station and "Dist. Roads" was the $\log_{10}$ distance to main roads. Multicollinearity test was applied using a correlation matrix to check for Multicollinearity problem within the independent variables. The rule of thumb is that if the pairwise correlation between the variables is greater than 0.5, a Multicollinearity problem exists (Gujarati, 2007). The results showed no Multicollinearity problem that was present (Appendix 1). The animal ID was the random factor in the models. From the GPS/GSM – collars data of the 11 wild boar recorded after every one hour for the four months a total of 26,911 locations were obtained.

3. Results

3.1. Descriptive results on habitat selection

Clear-cuts were the most selected relative to other habitats with a selection value of 0.74. Other selected habitats include agricultural field (0.63), deciduous forest (0.58), and other open lands (0.53; Fig. 3). Open wetland (0.44) and coniferous forest (0.30) were avoided (Fig. 3).

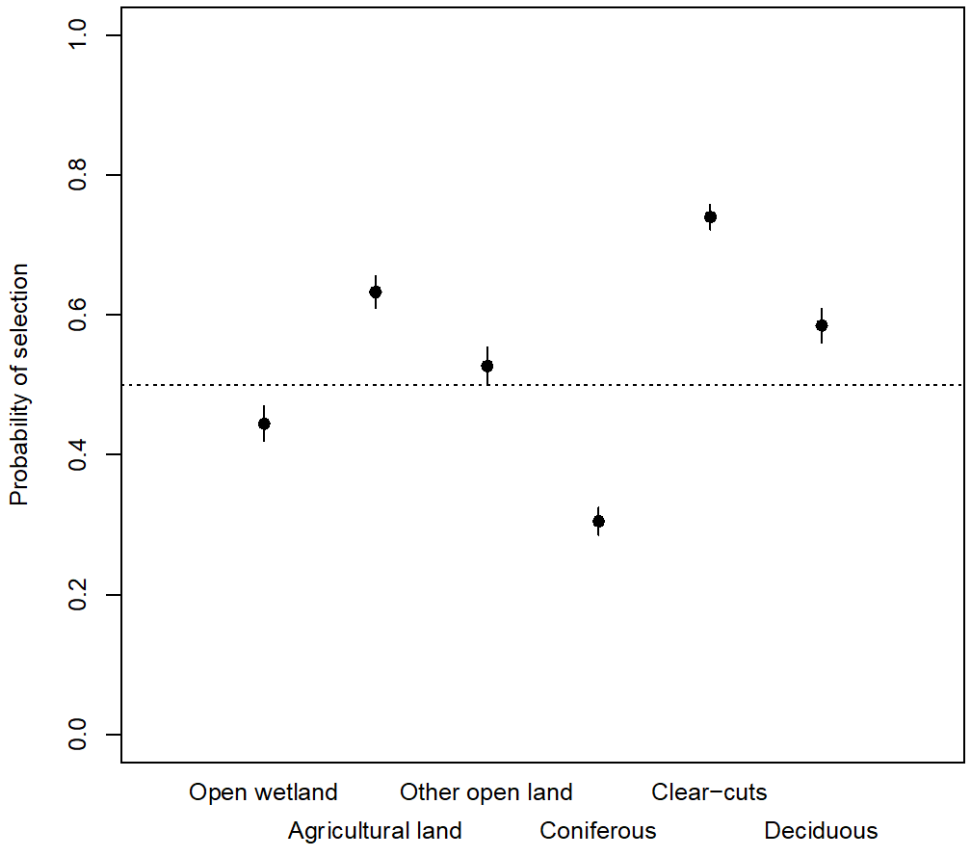

Figure 3: Wild boar selection for and against six different habitat types. A probability above 0.5 indicate a selection for that habitat and below 0.5 indicate avoidance of that habitat

In clear-cuts, wild boar locations were 42.5% of the locations found while only 6.6% of the random locations, implying that wild boar spend most of the time in clear-cuts (Fig. 4). On the

other hand, in coniferous forests, wild boar locations only had a proportion of 24.6% and 58.0% random locations. This implies that wild boar spent less time on coniferous forests compared to other habitats (Fig.4).

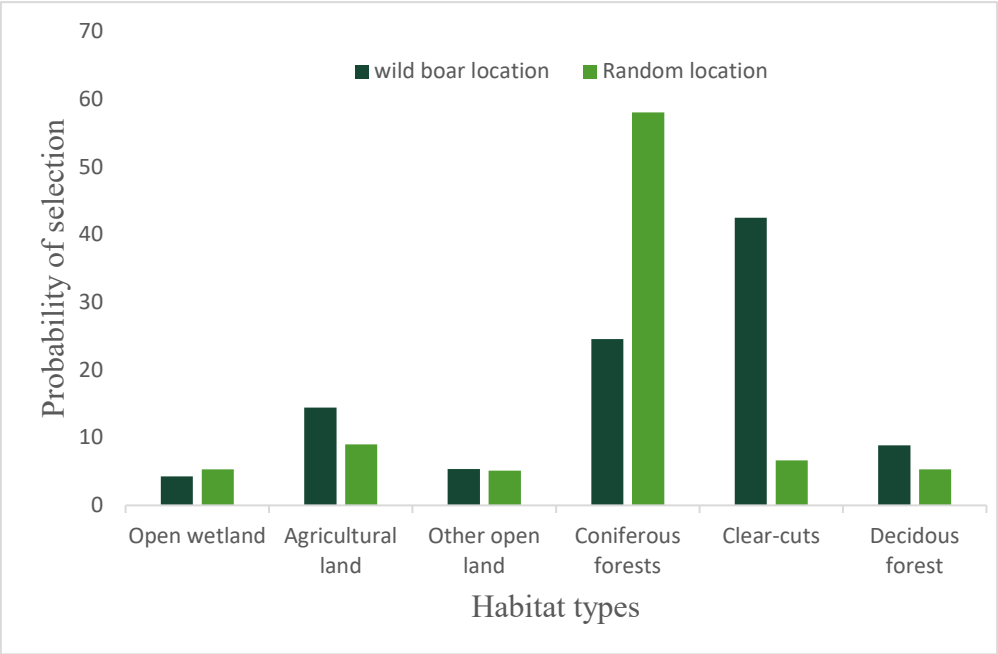

Figure 4: The proportion of wild boar locations in a habitat out of all wild boar locations in all habitats retrieved from 11 marked wild boars (one location per hour) in six different habitat classes, and the proportion of random locations in the four study areas in southern Sweden, 2019.

3.2. Binary logistic regression model results on habitat selection

Wild boar habitat selection was significantly different from random locations and show the highest preference for clear cuts compared to other habitats. Additionally, agricultural lands, deciduous forests, and other open lands are also preferred. Open wetlands and coniferous forests are both avoided during summer (Table.1, Fig. 3 and Fig. 4).

Table 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.

			Within habitat effect	
Fixed factor	Coefficient ±SE	P-value	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)

Model 1 containing $\log_{10}$ distance to the feeding station was the best with the smallest AIC of 64003.17 and the highest pseudo-R^2 of 19% hence most suitable in explaining the effect of feeding station on habitat selection by wild boars (Table 2).

Table 2: GLMM, binary logistic regression 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 R^2**
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)

3.3. Influence of distance to feeding station on wild boar selection of habitat types

There was a negative and significant influence of distance to the feeding station on habitat types. The negative coefficients on agricultural land, coniferous forest, and other open land

imply that a decrease in distance to a feeding station increases the probability of wild boar selection of agricultural lands, coniferous forest, and other open lands (Tab. 3).

Table 3: GLMM, binary logistic regression models for the influence of distance to feeding stations on habitat selection by wild boar.

			Within habitat effects	
Fixed factor	Coefficient ±SE	p-value	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)

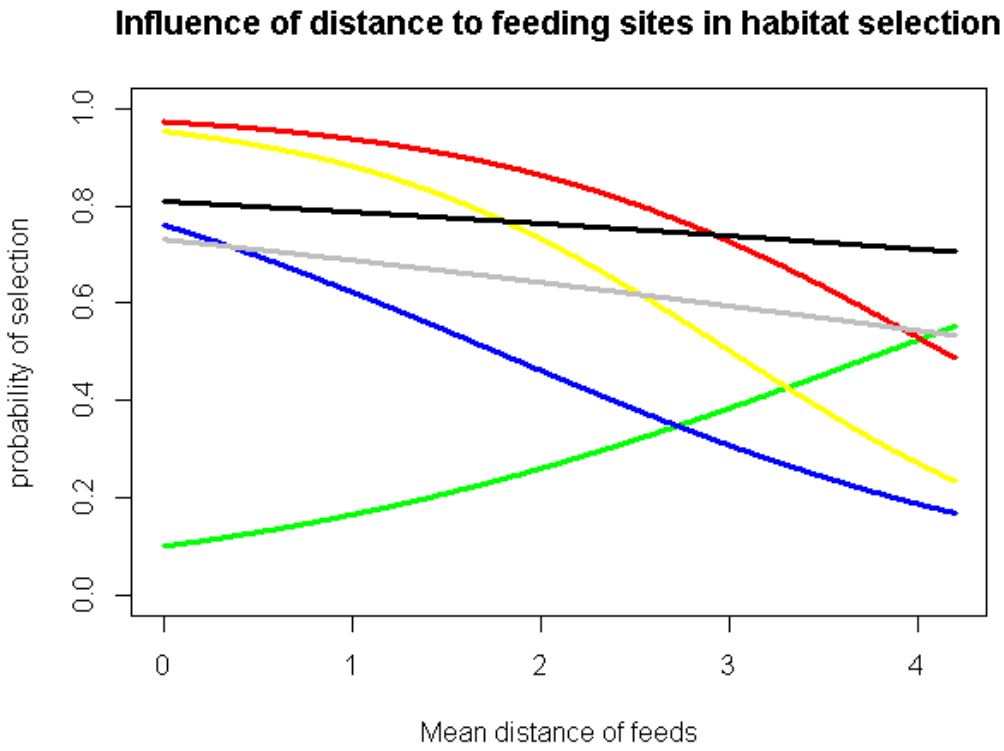

Figure 5: Slopes on the effect of log_{10} (distance to feeding station) on habitat types. The colors for slope indicate green- open wetland, red- agricultural land, yellow- other open lands, blue- coniferous forests, black – clear- cut and grey- deciduous forests. A proportion above 0.5 means wild boar selection for that habitat.

3.4. Influence of distance to main roads on wild boar selection of habitat types

Distance to main roads significantly influenced wild boar selection of habitat types (Table 4). More specifically, distance to main roads had a negative influence on the selection of "Other open land" as well as on the selection for "Clear- cuts". The negative coefficients in "Other open land" and "Clear- cut, implies that a decrease in distance to main roads increases the proportion of wild boar selection of either other open land or clear-cuts.

Furthermore, distance to main roads positively influenced wild boar selection on deciduous forests. The positive coefficient in deciduous forests implies that an increased distance to roads increases the selection for deciduous forests (Table 4 and Fig. 6).

Table 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	1.2 ± 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)

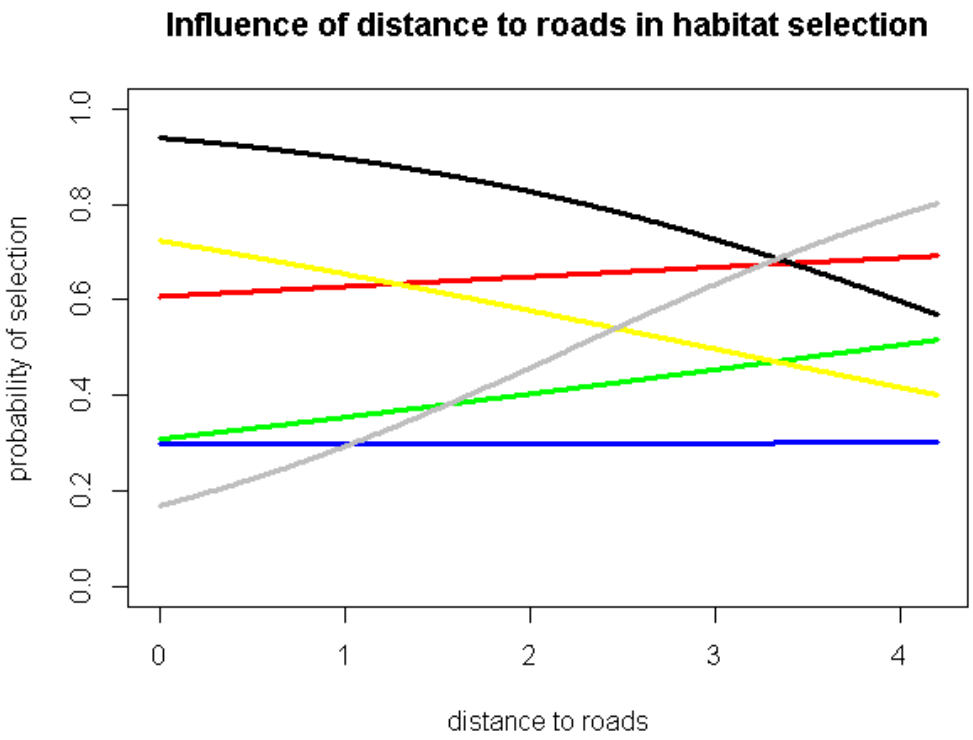

Figure 6: Slopes for the effect of log_{10} (distance to main roads) on the selection of habitat types. The colours for slope indicate green- open wetland, red- agricultural land, yellow- other open lands, blue- coniferous forests, black – clear- cut and grey- deciduous forests. A proportion above 0.5 means wild boar selection for that habitat.

3.5. Crop selection

Wild boar selected for "agricultural land"; the selection value was 0.63 (see above and Figure 3). This means that one has to use 0.63 as the reference value for neutral selection of crop types within the habitat type "agricultural land". A coefficient corresponding to a neutral selection of 0.63 in 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. 7). On the other hand, fall wheat fields (0.56) and grasslands (0.51) were avoided by wild boars during summer (Fig.7).

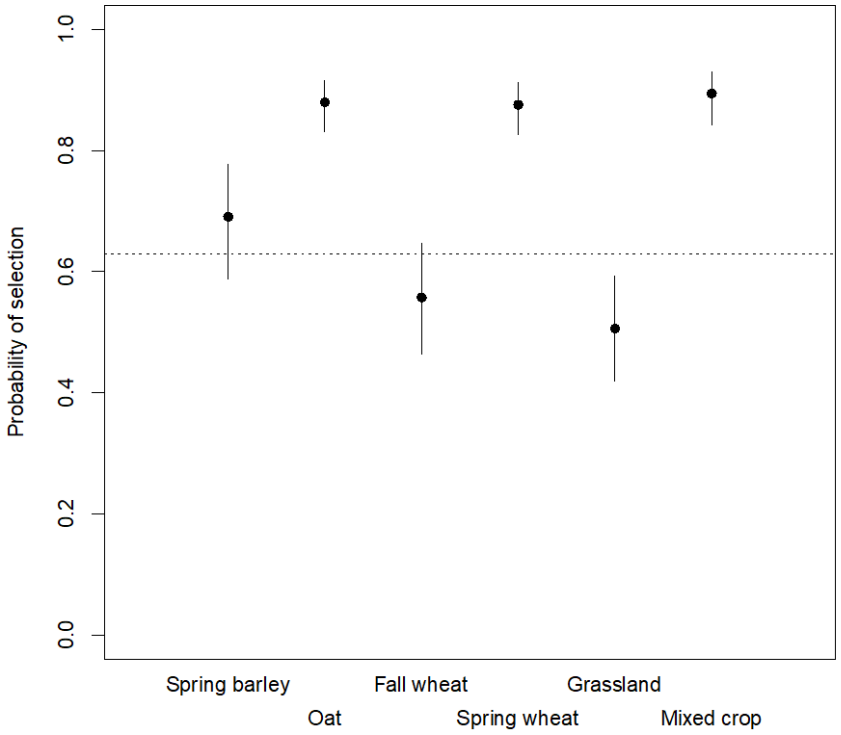

Figure 7: Wild boar selection for and against six different crop classes (spring barley, fall wheat, spring wheat, oat, grasslands and mixed crops) from 1st May - 31st August 2019 in four study areas (Koberg, Mörkö, Boo and Grimsö) in southern Sweden. Agricultural land has a threshold of 0.63 (see above and figure.3) 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 (3.1%) which implies that wild boar spend most of their time in that crop field (five times more time than expected). However, grassland fields have a higher number of random locations (77.4%) compared to actual wild boar locations (60.2%). This indicates wild boar spend a lot of time, but less than expected in grassland fields during this time of the year.

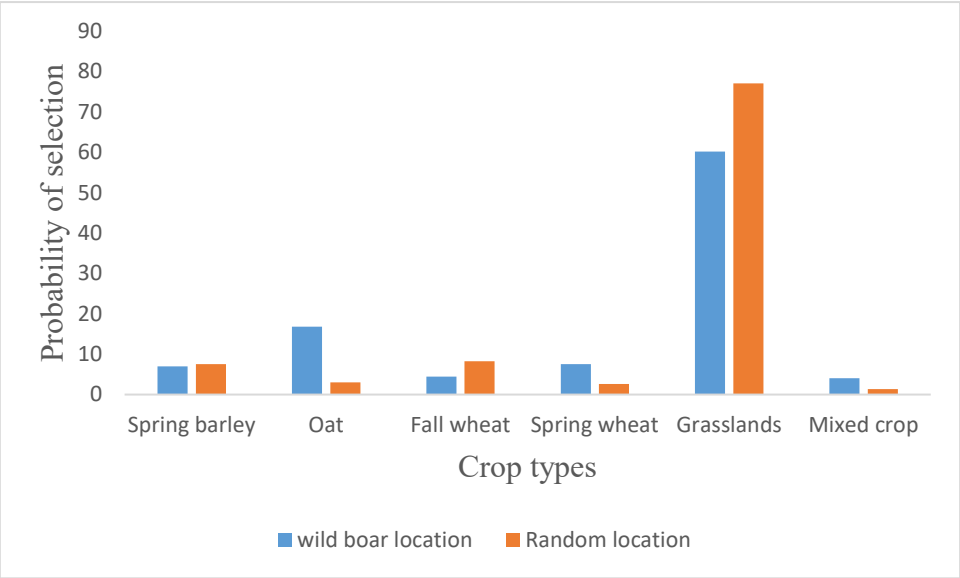

Figure 8: The proportion of wild boar GPS locations captured after every one hour, (wild boar location in crop field / total number of wild boar locations in all crop type fields) and proportion of random locations (random location of each crop field / total number of random locations in all different crop fields) pooled for all the four study sites.

The binary logistic model results show a positive significant selection for oat fields, spring wheat and mixed crop. Spring barley, grasslands and fall wheat were not significantly selected by wild boar during summer (Table.5).

Table 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.

			Within habitat effects		
Fixed factor	Coefficient ±SE	P-value	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
Fall 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)

3.6. Influence of distance to feeding station on wild boar selection of crop types

Wild boar selection for different crop fields was significantly influenced by distance to the feeding station. The negative coefficient on spring wheat and grasslands implies that a decrease in distance to the feeding station increases the proportion of wild boar selection of spring wheat and grasslands. On the other hand, mixed crop fields have a positive coefficient with distance to the feeding station. Thus, in a mixed crop, an increase in distance to the feeding station increases the proportion of wild boar selection (Table.6 and Appendix 2).

*Table 6: Binary logistic model of the effect of log_{10} 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
Fall 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: Fall 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 ±0.0.22	<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" + "habitat coefficient" For example, for Oat;
Coefficient 1.70 = 1.19 + 0.51 SE = 0.23 = sqrt ((0.26^2+0.20^2)/2)

3.7. Influence of distance to main roads on wild boar selection of crop types

Distance to main roads significantly influenced wild boar selection of different crops. For spring wheat and mixed crops, a positive coefficient shows that an increase in distance to main roads increases the proportion of wild boar selection for spring wheat and mixed crop. In fall wheat and spring barley, a negative coefficient implies that a decrease in distance to main roads increases the proportion of wild boar selection of fall wheat and spring barley (Table. 7).

*Table 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).*

			Within habitat effects	
Fixed factor	Coefficient ±SE	p-value	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
Fall 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: Fall 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. Discussion

4.1. Habitat selection

Descriptive statistics results indicate that specific habitats were preferred by wild boar while others were avoided. Clear-cuts seem to be the most preferred habitat by wild boar during summer with a 74% probability of selection (Table.1, Fig. 3 - 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 dense sprouts providing good shelter. Potentially could clear cuts 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.

Furthermore, 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 (Amendolia *et al*., 2019). 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 availability of acorns, 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 is due to its abundance of feeds in the forest floor in which the species structure comprises of herbs and grasses. Besides, the soil of these forests comprises 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) ripe 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 land was 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 in the Summer as there are abundant crops in the farmlands which are more attractive. These results are corroborated by (Morelle and Lejeune, 2015; Lee *et al*., 2018) who have 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 in each season but less strongly in the early growing season which coincides with increased resource availability. On the contrary, in areas and countries dryer than most parts of Sweden Ficetola *et al*. (2014) found that water was essential for drinking and also for wallowing to remove ectoparasites thus bog and marshy areas have high densities of wild boars.

Coniferous forests had a negative influence on wild boar selection during summer seasons. This is because it is less productive and lack the abundance of food and shelter the other habitats provide (deciduous forests, clear-cuts, and agricultural lands). Deciduous forests might provide more preferred bed sites for wild boar as well as hiding areas from predators and hunters due to their density, unlike coniferous forests that 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 the deciduous forests than in coniferous forests. Other studies by (Thurfjell *et al*., 2009; Zeman *et al*., 2016) also found that coniferous forests are avoided by wild boar during summer in comparison to other forest types.

4.2. 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 pronounced environmental variability and local variation in a microclimate 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 distance to near feeding stations increases 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 coefficient 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 (*Alces alces*) and red deer (*Cervus elaphus*) found extensive damage in the Scandinavian forests occurs within a distance of 1 kilometer from the feeding stations (Putman *et al*., 2004). High levels of damage were explained by the increased number of feeding stations in the forest stands (Gundersen *et a*l., 2004; Beest *et al*., 2010; Milner *et al*., 2014).

There were significant positive effects for open wetlands which means that an increased distance 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 provide.

Human activities along roads resulting in noise and pollution emitted by vehicles negatively influence wild boar use for different habitats. Thus, wild boar tends to avoid habitats that are close to the 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 implies that increased distance to roads increases the selection of this habitat. This is in agreement with Rhos` (2015) results which showed that wild boar prefer areas that have minimal 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 decreases wild boar selection of these habitats (Table 4 and Fig. 6). Clear-cuts and other open lands are mainly alongside roads thus negative relationships with distance to roads. Another finding 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. My results show that distance to main roads affects wild boar selection of different habitats.

4.3. Crop fields selection

Results showed significant preferences of some of the crop fields analyzed by wild boar. Cereals especially oats, spring wheat and mixed crop are highly preferred, especially during summer 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 Wretling-Clarin and Karlsson (2010) on the Swedish Board of Agriculture(SBA) report on cropland damages in Sweden, which showed a preference for oats, wheat and barley.

Additionally, mixed crops, oats, and spring wheat were more preferred relative to grassland fields. The results indicate a significant positive selection for spring wheat fields by wild boar while spring barley and fall wheat fields were less preferred. These results are in line with the findings of Herrero and Sergio, (2006) that wheat fields were more damaged by wild boars compared to barley fields. The difference in selection between spring and fall wheat is interesting and is probably explained by the difference in exposure time to damages. Since the fall wheat normally matures quicker and is harvested 2- 4 weeks earlier than the spring sawed wheat, the boar simply does not have the same time to visit mature fall wheat as they have to visit spring wheat fields (St. Martin *et al*., 2017).

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 comparably 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.

4.4. 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 implies that a decrease of distance to the feeding station increases the proportion of wild boar selection of spring wheat and grasslands. Wild boar are more attracted to feeding stations and thus tend 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 increases the chances of wild boar selecting those fields (Table.6 and Appendix 2). These results are in agreement with (Geisser and Reyer, 2005) and (Linkie *et al*., 2007) 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.6 and Appendix 2). On the other hand, other studies found 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; Henryson et al., 2019) while in another study it was not clear the effect of wild boar on agriculture fields (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 increases the proportion of wild boar selection on those fields. Similarly, Caruso *et al*. (2018) and Hellkvist (2019) reported a positive correlation on the distance to roads with damages that wild boar cause to the selected crop fields which are further from roads due to disturbances. However, spring barley and fall wheat had negative coefficients implying that a

decrease in distance to the main road increases the selection of those fields (Table 7 and Appendix 3).

4.5. Conclusion and Recommendations

Wild boar prefers clear-cuts, deciduous forests and agriculture lands during summer. Coniferous forests and open wetlands were generally avoided by wild boar as there is surplus food in the farmlands and also deciduous forests may contain nutrient-rich mast. Agricultural lands, particularly fields containing spring wheat, oat, and mixed crops, are the most attractive crop types to wild boar. Landscape factors seem to influence the selection of habitats and farmlands differently. The most influential factors are the availability of food resources in the habitat which is attributable to seasonal variations.

Feeding stations were mainly composed of peas, corn, maize, and wheat. These stations are purposed to attract wild boar to those sites and reduce the damage they cause to the agricultural fields and also used as baits by hunters. Most of the feeding stations were alongside forest and agricultural farms. Distance to feeding sites influences 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 is selected.

Human disturbances like the noise of vehicles on roads affect wild boar selection of given habitat and crops. The results showed statistically significant impacts of roads on habitat selection by wild boar as preferences of habitats increased 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 open wetlands 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.

This study provides a first basis for further investigations of landscape factor's effects on the spatial variation in wild boar selection of habitats in Sweden. Knowledge of what wild boar selects per season will be useful to improve future wildlife management strategies. Cropping systems should be adjusted to reduce damages on more selected crop fields. Wildlife management strategies for wild boar needs to be improved to consider both time and space to reduce the damage they may cause on natural ecosystems and agricultural fields.

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6. Acknowledgments

I extend my gratitude to the University of Embu for providing my MSc. Scholarship and SLU through the Linnaeus Palme program of the Swedish research council for an exchange visit to SLU. Special thanks to the Swedish Environmental Protection Agency (SEPA) and Marie-Clair Cronstedts foundation for funding the project and issuing permits for marking wild boars with GPS/GSM collars. I also profusely thank my supervisors, Dr. Justin. M. Nyaga, Professor Petter Kjellander, and Professor Henrik Andren for their tireless and professional guidance during proposal development, fieldwork and the entire process of my MSc program. Professor Henrik, your tremendous support with data analysis was always creditable.

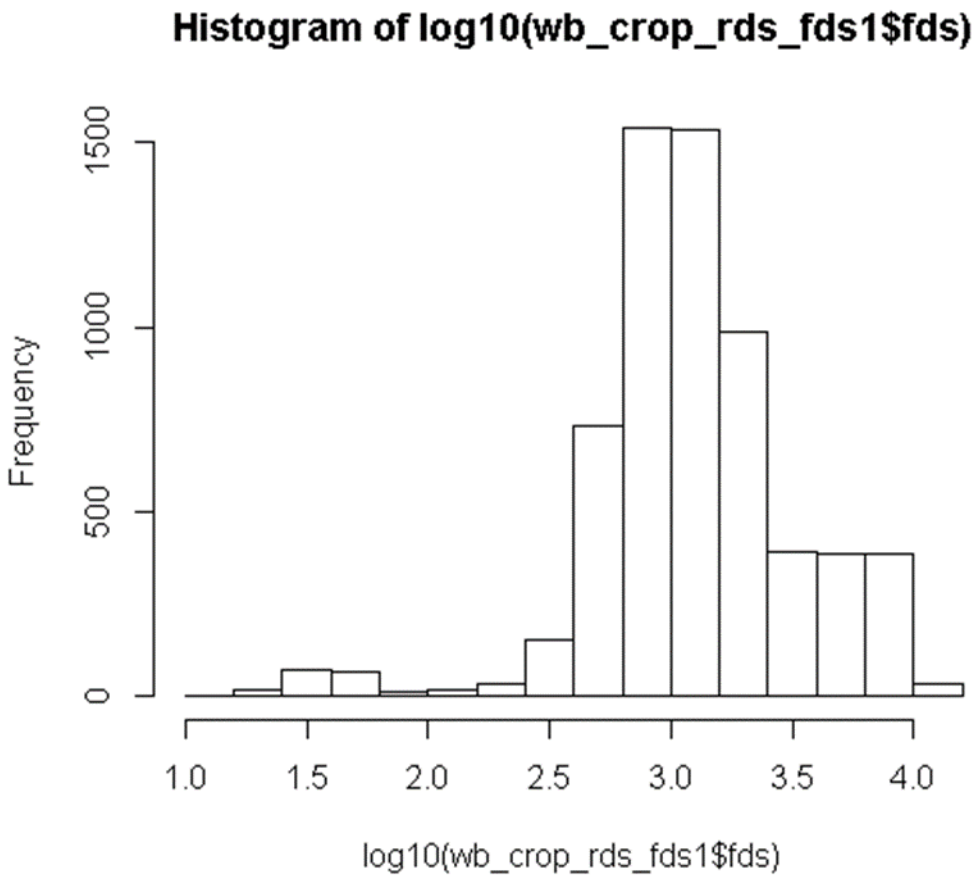
Special thanks to Charlotte Hansson, Madeleine Christensson, and Örjan Johansson for help with marking wild boar with GPS/GSM collars. Much appreciation to the SEPA and SBA for the provision with ground cover maps and crop field data. All Grimsö staff who participated in this work are greatly appreciated. Lastly and not the least my family and friends your physical and moral support was always at the right time. I could not have done it without you. May the almighty Lord bless you abundantly.

7. Appendices

Appendix 1: Multicollinearlity test of the independent variables

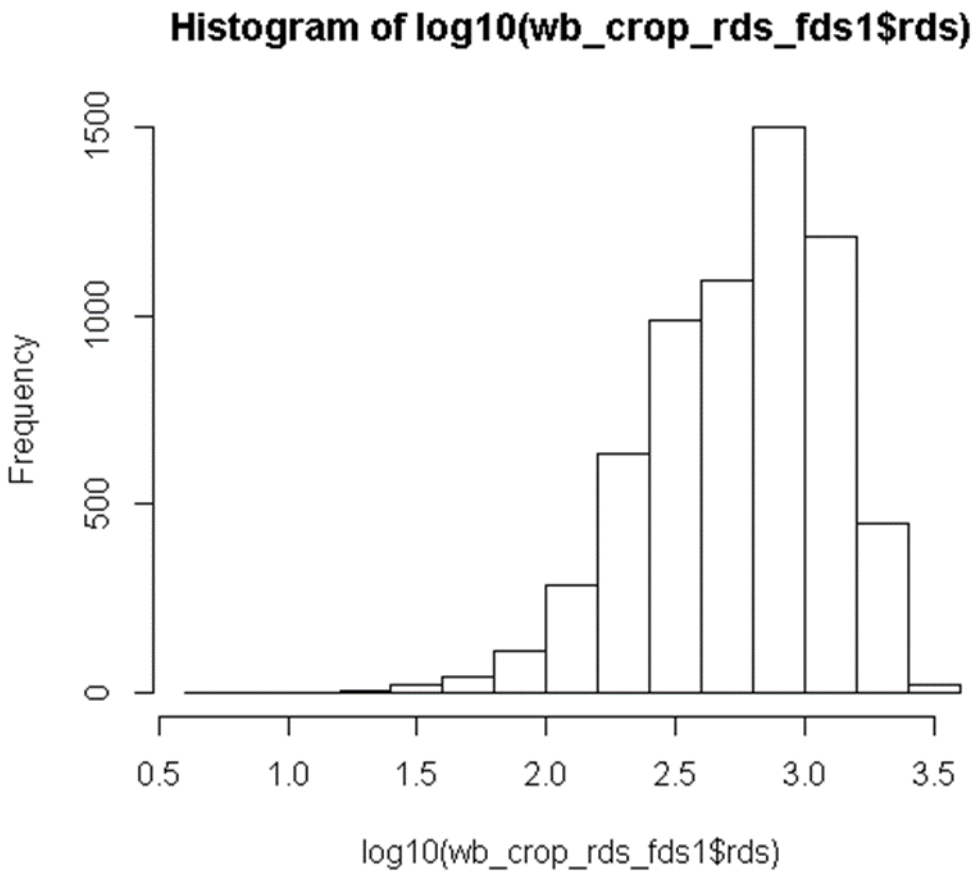
	Dist to feeding station	Dist to main roads
Dist to feeding station	1.0000	
Dist to main roads	0.2106	1.0000

Appendix 2



Histogram of log $_{10}$ distance to the feeding station with the frequency of wild boar location and random locations. The mean distance was 3.09 km while the minimum and the maximum distance was 1.00 and 4.14 km respectively.

Appendix 3



Histogram of log $_{10}$ distance to main roads with a frequency of wild boar location and random locations. The mean distance was 2.75 km while the minimum and the maximum distances were 0.74 and 3.52 km respectively.