Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

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– A spatio-temporal analysis of wild boar activities in Swedish agricultural fields

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Master´s thesis • 30 hec
Independent project
Grimsö Wildlife Research Station, Department of Ecology
Uppsala 2019

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Credits:	30 hec
Level:	A2E
Course title:	Master thesis in Biology
Course code:	EX0895
Course coordinating department:	Department of Aquatic Sciences and Assessment
Place of publication:	Uppsala
Year of publication:	2019
Cover picture:	Emma Hellkvist
Online publication:	https://stud.epsilon.slu.se
Keywords:	crop damages, wild boar, *Sus scrofa*, human-wildlife conflict

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Abstract

Wildlife damages to crops is one of the major factors for human-wildlife conflicts. Wild boar (*Sus scrofa)*, has during the last decades increased greatly in numbers, both in its natural and introduced range. By eating and trampling the crop, wild boar causes huge economic losses to farmers. To reduce wild boar damages to crops and to mitigate this conflict, it is important to understand the underlying factors of high-damage risk areas. In this study, I analysed the probability and size of damage, both in relation to several landscape features and time during the vegetative season. Damage data was collected in four study areas in southcentral Sweden, at five different occasions during the summer of 2017. Landscape features of interest were; distance to forest edge, feeding stations, water resources, roads and houses.

I found temporal differences in both probability and size of damage. In cereals, the damage level peaked in August, while it was slightly higher earlier in the season in ley fields. There was also a difference in damage level between crop types, with more and greater damages in cereal than in ley fields. Distances to the different landscape variables were non-consistent for probability and size of damage, as well as among the two crop types. In cereals, the damage level was highest in proximity to forest edge (probability and size) and feeding stations (only probability), and lowest close to roads (probability and size). Feeding station was the only landscape variable with a significant influnce on damage level in ley fields, showing a lower probability of damages close to feeding stations in ley. Time of season proved to contribute much more to both probability and size of damages in ley fields than distance to any landscape feature, indicating that it is a temporal matter rather than a spatial.

With the differences in damage level between the two crop types, both temporally and spatially, I suggest future studies to separate different types of crops when analysing damage distribution.

Keywords: crop damages, wild boar, *Sus scrofa*, human-wildlife conflict,

Sammanfattning

Mängder av djurarter orsakar skador på gröda i sin jakt på föda vilket skapar en konflikt mellan människor och djur. Vildsvinet är ett djur som ofta hamnar i denna typ av konflikt då antalet vildsvin har ökat snabbt under de senaste årtiondena. Vildsvin äter många olika grödor och bökar upp mark men orsakar även skada bara av att vara på fälten, där de gått eller legat blir grödan liggande och går inte längre att skörda. Eftersom vildsvin får jagas får jordbrukaren ingen ekonomisk kompensation för skadorna. För att på sikt kunna minska dessa skador och de ekonomiska förluster som följer, är det viktigt att förstå var och när skadorna uppkommer.

I denna studie har jag undersökt när under sommaren (maj-september) det är högst skaderisk och om storleken på skadorna varierar under säsongen. Jag undersökte även var risken för en skada är störst och om storleken på skadan påverkas av var i landskapet man befinner sig i förhållande till skogskanter, utfodringsstationer, vatten (diken, bäckar, sjöar och våtmarker), vägar och hus. Sådana sk. landskapselement har i tidigare undersökningar visat sig påverka vildsvinens rörelsemönster på olika sätt. Skogen erbjuder skydd och föda, utfodringsstationer används vid vildsvinsjakt och/eller för att locka svinen bort från åkrarna. Vatten är viktigt för att dricka, men också för att vildsvinen ska kunna reglera sin kroppstemperatur och få bort parasiter från kroppen. Vägar och hus utgör olika typer av mänsklig störning som de flesta djur undviker.

Data samlades in i fyra områden mellan Hjortkvarn söder om Örebro, till Bornsjön sydväst om Stockholm. Dessa områden inventerades totalt fem gånger under sommaren, ungefär en gång i månaden. Grödor av intresse var vall och olika sädesslag, inklusive vete, korn, havre och råg-vete (en hybrid mellan råg och vete). I varje fält inventerades 10 m breda korridorer (transekter), hur många berodde på fältets storlek och varierade mellan två och åtta. Alla skador inom dessa korridorer noterades tillsammans med information som vilken typ av skada det var (legor, bök, uppäten gröda osv), eventuella spår av vildsvin eller andra djur samt koordinater för skadan. I kartprogrammet ArcMap skapades så kallade ”noll-punkter” längs de inventerade transekterna för att representera punkter utan skador. I ArcMap kunde jag sedan mäta avståndet från skade- och nollpunkter till de olika landskapselementen. Med hjälp av detta och två statistiska analysmodeller kunde jag beräkna om det alls var någon skillnad och i så fall, när under sommaren skadorna var vanligast och störst.

Mina resultat visar att i spannmål är både skaderisken och skadornas storlek störst i augusti när sädaxen börjar mogna medan vall utsätts för skada lite då och då men mest tidigare under säsongen (maj-juni). Skadorna i sädesfält var dessutom fler och mycket större än de i vall. Effekten av de olika landskapselementen skiljde delvis mellan de båda grödorna. I sädesfält var skaderisken högst i närheten av skogskanter och utfodringsstationer, och lägst i närheten av vägar. Storleken på skadorna var också störst i närheten av skogskanter och minst i närheten av vägar. I vall däremot,

var skaderisken lägst i närheten av utfodringsstationer och i övrigt hade avståndet till de olika landskapsvariablerna ingen större påverkan på vare sig skaderisk eller skadans storlek.

Tidpunkt på säsongen visade sig ha en mycket starkare påverkan på både skaderisk och storlek, än något av landskapselementen. Det var också stora skillnader mellan de två typerna av gröda. Baserat på detta bör man överväga att vid analyser av framtida vildsvinsskador standardmässigt separera inte bara skador på vall och spannmål utan också undersöka eventuella skillnader i skador mellan olika spannmålssorter.

Avslutningsvis, med dessa resultat i åtanke, föreslår jag att placering av utfodringsstationer ska planeras väl och när det är möjligt kan val av gröda försöka anpassas till fältets placering i relation till skog.

Table of contents

1 Introduction

1.1 Background

The growing human population and our intensified land use are both resulting in habitat degradation and loss for wildlife, and this is a main driver for human – wildlife conflicts (Nyhus 2016). These conflicts occur all around the world, with the plausible exception of Antarctica (Torres *et al.* 2018), and with a variety of different species (Nyhus 2016). Drivers of conflicts include, amongst others; predation on livestock, shared prey, damage on crops, transmittable diseases and vehicle collisions (Nyhus 2016). Damage to crops is, at present, one of the major factors of conflict. In a review of conflicts between human and terrestrial vertebrates, Torres *et al* (2018), found just under 200 species linked to crop damages. The species range is large and include several families from the bird and mammal taxa, size-wise ranging from rodents to elephants (Torres *et al.* 2018). A currently highly discussed species in the subject of crop damages is the wild boar (*Sus scrofa*). The wild boar population have in the last decades increased, both in its natural and introduced range (Mayer 2009a, Massei *et al.* 2015, Lee *et al.* 2018,). This increase in numbers is leading to intensified wild boar damages on agricultural crops (Schley *et al.* 2008, Frackowiak *et al.* 2013, Bobek *et al.* 2017). Wild boar are omnivores but the major part of their diet is plant based and always contain at least one energy-rich item such as acorns or different types of crop (Schley & Roper 2003, Ballari & Barrios-Garcia 2014). By eating and trampling the crop, wild boar causes huge economic losses to farmers (Mayer 2009c, Wretling & Karlsson 2010). Added to these direct damages, there are also indirect losses such as broken machinery and additional work load (Wretling & Karlsson 2010). In Sweden, the wild boar was extinct from the beginning of the 1700s until the 1970s when runaways in Scania and the Stockholm area established in the wild. The species earned resident rights in the late ‘80s and since then the population have increased to a great extent. During the first decade of the 21:th century, the hunting bags of wild boar increased exponentially by 30%

annually, but since 2012 the average annual increase has been 1.1% (Anonymous 2017). This is in line with the rest of Europe where the annual growth rate (lambda), varies between 1.00 and 1.46, with reproductive peaks about every five year when lamda increase to 1.40-1.73 (Massei *et al.* 2015). In Sweden, there are governmental funds for prevention and compensation of wildlife damages to livestock and crop, and in 2017, 24 million Swedish crowns were disbursed (Risberg 2018). However, these funds only cover damages done by species protected by law which wild boar is not. Therefore, damages caused by the species do not grant any economic compensation to farmers in Sweden (Anonymous 2018a). With an increasing damage level the conflict between farmers and wild boar is naturally escalating and many have studied the issue of wild boar damages on crops (Calenge *et al.* 2004, Geisser & Reyer 2004, Schley *et al.* 2008, Thurfjell *et al.* 2009, Lindblom 2011, Amici *et al.* 2012, Frackowiak *et al.* 2013, Ficetola *et al.* 2014, Morelle & Lejeune 2015, Bobek *et al.* 2017, Lee *et al.* 2018).

1.2 Spatio-temporal influences on the distribution of wild boar damages

Several factors affect home ranges and spatial distribution of wild boar, thus also the distribution of damages caused by the species. Human presence is a disturbance to wild boar in agricultural areas and have an inhibiting effect on crop damages caused by the species (Schley *et al.* 2008, Amici *et al.* 2012, Ficetola *et al.* 2014). The disturbance of roads has shown both negative (Schley *et al.* 2008), and indifferent (Lee *et al.* 2018) influence on the damage distribution. Water resources are essential for wild boar, both for drinking and wallowing (Mayer 2009b). Wild boar wallows for thermoregulation and to get rid of ectoparasites. The behaviour has been observed year-round but increase at higher temperatures (Mayer 2009b). Marshland and water thus have positive effects on population density (Borowik *et al.* 2013) and Paolini *et al.* (2018), found a positive correlation between both population density and amount of damages, with the proximity to wetlands. Another study by Amici *et al.* (2012), also saw a higher risk of wild boar damages within a buffer of 1000 meters from rivers. However, water resources have shown no effects in other studies of wild boar damages (Morelle & Lejeune 2015, Lee *et al.* 2018). Forest is important as shelter for wild boar (Morelle & Lejeune 2015, Bobek *et al.* 2017) and landscape mosaics with more than 40 % forest cover have a positive effect on wild boar density (Borowik *et al.* 2013). Open areas are, on the contrary, avoided (Thurfjell *et al.* 2009). However, there is a seasonal shift in usage of habitat, with a higher usage of forest in winter and of open areas in summer, when the avoidance of these is significantly lower. This shift is clearly connected to food availability and cover (Boitani *et al.* 1994, Keuling *et al.* 2008, Keuling *et al.* 2009, Thurfjell *et al.* 2009). The open agricultural fields offer large amounts of high-quality food during growing season and being an opportunistic omnivore, this energy-rich food is hard to resist (Schley & Roper 2003, Cellina 2008, Ballari & Barrios-Garcia 2014). Nevertheless, cover from the forest is still important and wild boar damages on crops have repeatedly been reported to be higher closer to forest edges (Calenge *et al.* 2004, Thurfjell *et al.* 2009, Bobek *et al.* 2017, Lee *et al.* 2018).

Wild boar damages on crops comes in two clusters during a growing season. One peak is in spring when meadows have fresh grass and easily rooted soil, and cereals are being sowed. The damages emerge once again, in late summer when the crop is ripe (Schley *et al.* 2008, Frackowiak *et al.* 2013, Bobek *et al.* 2017). However, rooting activity in grasslands appear to be more frequent outside the growing season, specifically during winter (Welander 2000, Schley *et al.* 2008, Amici *et al.* 2012). Diversionary feeding is a method practised to alter the activity of a targeted species to reduce negative impacts, e.g. crop damages, by that specific species (Kubasiewicz *et al.* 2016). There are some controversial opinions if this method is successful or even increasing the damages. Milner *et al.* (2014), reviewed the intended and unintended effects of feeding wild ungulates. They reviewed 16 studies with the intendent effect of reducing damages to crop, forestry or natural vegetation. Of these 16 studies, six showed successful results and four resulted in significantly higher impact on the targeted area. For wild boar, studies have shown both positive (Calenge *et al.* 2004) and indifferent or possibly even negative (Geisser & Reyer 2004), results of diversionary feeding. An important note is that wild boar select food resources based on energy richness and the preference change during the season (Paolini *et al.* 2018). Mast and mature agricultural crops are energy-rich and selected for whenever available (Schley & Roper 2003, Cellina 2008). They are preferred to diversionary feeding, indicating that this may not work as a method to reduce the damages to ripe, agricultural crops (Cellina 2008). However, Calenge *et al.* (2004) argue that if done correctly, diversionary feeding is an useful method. When the purpose of feeding is to attract a targeted species to facilitate hunting, it is called baiting (Dunkley & Cattet 2003), and this is a common practise when hunting wild boar. No matter the purpose of the feeding, diversionary or baiting, it may result in unintended side effects such as increased population growth rate and decreased density dependence (Dunkley & Cattet 2003, Milner *et al.* 2014). Wild boar has a high reproductive rate but it is dependent on food availability (Geisser & Reyer 2005, Bieber & Ruf 2005, Cellina 2008). There is a positive correlation between body size, body mass and reproduction and body size also have an impact on litter size (Cellina 2008). In good conditions piglet/early survival and fertility increase and yearlings and even juvenile may reproduce (Bieber & Ruf 2005). Puberty has been found in individuals as young as four months (Cellina 2008). Higher temperatures also have a positive effect on population growth (Geisser & Reyer 2005), although drought seem to reduce the reproduction in wild boar (Cellina 2008). Hunting is the main cause of death and according to Keuling *et al.* (2013), the present hunting effort in Europe is far from enough if the goal is to keep the population from growing. Several authors agrees that hunting is the main solution to the problem (Geisser & Reyer 2004, Bieber & Ruf 2005, Schley *et al.* 2008, Amici *et al.* 2012, Morelle & Lejeune 2015).

1.3 Previous studies & Aim

In management, it is important to predict when and where wild boar damages occur in order to reduce economic losses and to mitigate human-wildlife conflicts. There are several studies about wild boar damages in crops (Lemel *et al.* 2003, Geisser & Reyer 2004, Schley *et al.* 2008, Thurfjell *et al.* 2009, Lindblom 2011, Amici *et al.* 2012, Ficetola *et al.* 2014, Morelle & Lejeune 2015, Lee *et al.* 2018), but only a few are conducted in Sweden. Nevertheless, Lemel *et al*. (2003), studied the activity behaviour of wild boar in mid-east Sweden. They concluded that the mobility of the species is high and that a wild boar may move through several hunting grounds in one night. Thus, even fields located at long distances from resting sites or feeding stations may still be damaged. They also suggest hunting teams to cooperate if hunting is meant to regulate and decrease the population size to possibly reduce damages to crops. Thurfjell *et al*. (2009) looked at seasonal variation in wild boar habitat selection, spatial patterns and the effect of forest edge on damage distribution in southern Sweden. They confirmed that wild boar utilizes agricultural fields mainly during summer and that distance to forest edge is an important factor influencing the spatial distribution of damages. They also found a tendency of animals to follow edges and ditches during winter and spring when crops are low. A study by Lindblom (2011), took it one step further and analysed the risk of damages in relation to shelter (forest and ditches), disturbance (roads and buildings) and feeding (baiting stations and game fields). She concluded that the risk of wild boar damages was higher in proximity to forest, ditches, roads and baiting stations. However, the study only surveyed each field once during a three-week period in August-September and was conducted on an island (59 km^2) in eastern Sweden.

To gain more knowledge about areas in high risk of wild boar damages in Sweden, the aim of this study is to further investigate the spatio-temporal occurrence of damages in cereal crops and ley fields. This will be done by analysing (1) the probability of a damage to occur, and (2) the size of a damage, both in relation to time of the vegetative season as well as distance to five landscape variables. The study took place at four different study sites in southcentral Sweden during the growing season of 2017. Crops studied were grass (for hay or silage) and cereals, including wheat, barley, oat and triticale (a hybrid between wheat and rye). Landscape elements considered were distance to forest edge, feeding stations, water resources (including ditches, streams, marshlands and lakes), houses and roads. All these factors have, as earlier mentioned, been reported to affect spatial movements of wild boar (Boitani *et al*. 1994, Calenge *et al*. 2004, Keuling *et al*. 2008, Schley *et al*. 2008, Keuling *et al*. 2009, Thurfjell *et al*. 2009, Amici *et al*. 2012, Ficetola *et al*. 2014, Bobek *et al*. 2017, Lee *et al*. 2018, Paolini *et al*. 2018).

2 Method

2.1 Study area and data sampling

Data was collected during the growing season of 2017 at four study sites in south-central Sweden (Fig. 1). Bornsjön (59°24', 17°75' WGS84), is a nature reserve and water protection area with only organic farming. Ökna (58°89', 17°15'), is also organically farmed and part of the area is a nature reserve. Björkvik (58°84', 16°52') and Boo (58°90', 15°44'). Yearly precipitation in the study area is 500-600 mm and the mean yearly temperature is 5°C. Mean maximum day-temperature of the hottest month (July), is 22°C and the mean minimum day-temperature of the coldest month (February) is -8°C. The climatic averages are collected by the Swedish Meteorological and Hydrological Institute (SMHI) and based on data from 1961-1990. The landcover composition differ between the areas, as do human density (measured by number of housing units per km^2), hunting bags (recorded for the entire hunting districts which the study sites are only parts of), number of feeding stations and number of fields surveyed (Table 1).

Table 1. *Information about the study sites; Landcover of forest, open fields and open water. Human density measured as number of housing units/km^2. Hunting bags of year 2017 (collected from vilt-data.se), from the whole hunting districts in which the study sites are located, number of feeding stations and fields monitored in the different study sites*

Study site	Forest %	Open fields %	Open Water %	Human density	WB harvest /1000 ha	Feeding stations	Cereal fields	Ley fields
Björkvik	32	31	36	6.85	10.5	20	33	3
Boo	39	56	3	4.77	12	54	20	4
Bornsjön	46	28	21	20.14	42	20	22	7
Ökna	58	31	8	3.75	16.6	39	22	23

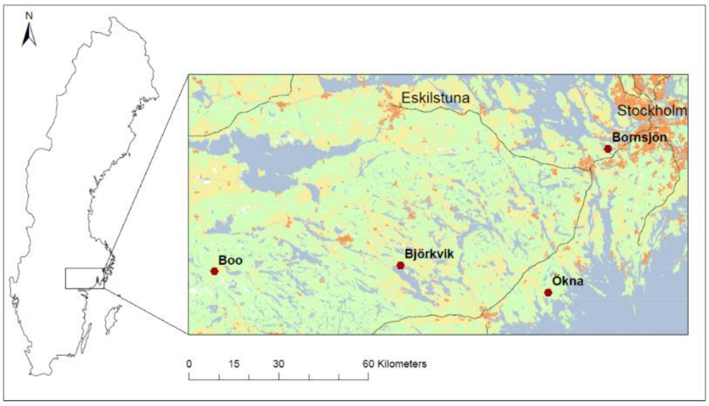

Figure 1. The four study sites in which damage data was collected during the vegetative season of 2017. All sites are located in southcentral Sweden between 58°90', 15°44' and 59°24', 17°75' (WGS84). Background map; "Vägkartan" (Vector) ©Lantmäteriet 2018.

In addition to wild boar, also red deer (*Cervus elaphus*), fallow deer (*Dama dama*), moose (*Alces alces*) and roe deer (*Capreolus capreolus*) are present in the study areas. These ungulate species are also known to cause damages to agricultural crop but wild boar cause significantly more damage (Reimoser & Putman 2011). It is possible that some of the damages reported in this study are done by any of the other ungulate species than wild boar, but since the majority of the observed damages was either the typical rooting or had wild boar tracks and/or scats present, the eventual error should be small.

Crops studied were grass for hay or silage (ley fields) and cereals, including wheat, barley, oat and triticale. Either 2, 4, 6 or 8 transects were monitored on each field. The larger the field, the larger number of transects in the field. Transects were 10 meters wide and, when possible, followed tractor tracks to avoid damaging the crops. Centre coordinates and type of damage (rooting, lying straw, chewed seeds or paths) were noted for observed damages.

The total size of the damaged area within the 10-meter-wide transect corridor, and the percentage of that area that was actually damaged, were estimated continuously while walking the transects. The study sites were surveyed five times during the vegetative season. Typically, on a monthly basis with the first visit occasion between April 24 and May 31, the second between May 31 and June 28, the third between July 3 - 26, the fourth between August 1 - 24 and the fifth between August 29 and September 20. Since the purpose was to investigate damages, cereal fields were not used in the analyses from the point they had been harvested. Ley however, is a perennial crop which may also be harvested several times during one vegetative season. Therefore, ley fields were kept in the analyses of all visit occasions.

2.2 Data analyses

Field data was separated by crop type into two different data sets; “Cereal fields” and “Ley fields”. Landscape variables of interest were; “forest edges”, “feeding stations”, “water resources”, “roads” and “houses”. For forest edges, only continuous forest was analysed, not non-arable outcrops. The water variable included all ditches, streams, wetlands and lakes marked on the map (“Vägkartan vector” ©Lantmäteriet 2018). The same is true for roads, all roads marked on the map was included and varies from small private roads to big, public ones. To be able to perform the binomial analysis, artificial “zero damage points” were generated along transects. This was done using Python (2.7.13) and ArcMap (10.5.1). The zeroes were systematically distributed at a 50-meter interval and removed when situated closer than 20 meters from a registered damage. Distance from damage centres and zeroes, to the five landscape variables were calculated in ArcMap, using python. Pearson correlation tests were performed on the distances to the five landscape variables for all study sites together, all correlations were weak (Table 2).

Table 2. *Pearson´s correlation coefficients between distances to the five landscape variables in all study sites combined*

	Feeding station	Forest edge	Water resources	Road	House
Feeding station	1				
Forest edge	0.16	1			
Water resources	-0.09	-0.06	1		
Road	-0.14	0.17	-0.15	1	
House	-0.10	0.10	0.05	0.34	1

The two data sets were analysed with two generalized linear mixed effect models (GLMMs) using the “lme4” package in RStudio (3.4.3). To calculate the probability of damage, a logistic regression model was performed and to analyse the damage size, a linear regression model on the log(damage sizes) was used. For both models, field and transect were used as random effects, with transect nested under fields. The distance to five landscape variables were scaled and coded as fixed effects together with time of the visit (occasion 1 - 5), and study site (4). Sample sizes were all large enough for the number of random and fixed effects ($N = 50 + 8 \times k$) (Mundry & Nunn 2009), and since stepwise model selection comes with a high risk of inflated Type 1 errors (Mundry & Nunn 2009), the full models were used and no model selection procedure was done. General linear mixed modelling (GLMM) was used to investigate the capability of the independent variables, to explain the variance in the dependent variable. R^2, was calculated for the full models and to investigate how much of the variance that was explained by each fixed effect, a simplified method was used; The models were run without a specific fixed variable (i), one at a time to generate the R^2-value of the full model minus factor i, and then equation 1 was used to calculate the proportional R^2-value of factor i. In addition to “lme4”, the packages “lmerTest”, “MuMIn” and “Hmisc” were also used for analyses and graphs in RStudio (3.4.3).

$$R_i^2 = \frac{R_{full}^2 - R_{full-i}^2}{R_{full}^2} \tag{1.}$$

3 Results

In total, 134 fields were monitored, 97 cereal and 37 ley fields (Table 1), and 1248 damages were identified. 1053 (84 %) of these damages were observed in cereals and 195 (16%) in ley fields (Table 3). The full binomial models explained (R^2) 24% (cereals) and 26% (ley fields) of the variation in damage probability.

Total area damaged was 43,289 m^2, of which 42,379 m^2 (98 %) was observed in cereals and 910 m^2 (2 %) in ley fields. Mean damage size was in cereal fields 40.25 m^2, and 4.67 m^2 in ley fields, but in general, individual damages were small in both cereal and ley fields. Approximately 20% and 50% of the damages in cereal and ley fields respectively, were smaller than, or equal to 2 m^2 (Fig. 3). The full linear regression models explained (R^2) 33% and 14% of the variation in damage size in cereals and ley respectively.

Table 3. *Damage information. All areal data are presented in m^2, except total area surveyed which is presented in km^2. Data collected in cereal and ley fields during five different occasions throughout the vegetation season of 2017. Visits were on a monthly basis, roughly following the months and starting in late April, for details see "Study area and Data sampling". Data was collected from four areas in southcentral Sweden, all located between 58°90', 15°44' and 59°24',*

Crop	Visit	No. fields surveyed	No. fields damaged [1]	No. damages	Mean No. damages/field	Tot. area surveyed[2]	Tot. size damages	Mean size damages	Mean area damaged/field
Cereals	May	64	26 (41)	99	1.6	1.14	2299	23.2	35.9
	June	72	25 (35)	109	1.5	1.10	1957	18.0	27.2
	July	84	37 (44)	147	1.8	1.30	3891	26.5	46.3
	Aug.	83	60 (72)	601	7.2	1.42	31,825	53.0	383.4
	Sept.	19	13 (68)	97	5.1	0.28	2407	24.8	126.7
Ley	May	28	20 (71)	97	3.5	0.28	310	3.2	11.1
	June	28	11 (39)	51	1.8	0.27	388	7.6	13.9
	July	25	4 (16)	7	0.3	0.26	49	7.0	2.0
	Aug.	31	9 (29)	16	0.3	0.27	43	2.7	1.4
	Sept.	28	10 (36)	24	0.9	0.26	120	5.0	4.3

1. Parentheses show the proportion of fields damaged/fields surveyed at that specific occasion
2. Presented in km^2

3.1 Temporal variation

The binomial model show that time during the vegetation season (visit occasion) explains (proportional R^2) 41% and 53% of the variation in damage probability, in cereals respectively ley fields. The difference in number of observed damages, as well as the proportion of damaged fields at the different visit occasions during the vegetative season, shows a higher probability of damage late in the season in cereals and early in the season in ley fields (Fig. 2, Table 3).

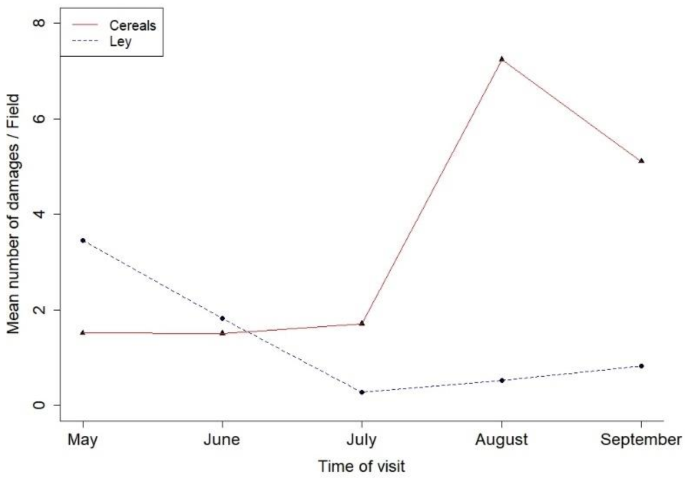

Figure 2. Mean number of damages in cereal and ley fields at five different occasions throughout the vegetation season. Visits were on a monthly basis, roughly following the months and starting in late April, for details see *"Study area and Data sampling".* Data was collected in 2017 from four areas in southcentral Sweden.

Time during the vegetation season (visit occasion) explain (proportional R^2) 40% and 82% of the variation in damage size, in cereals respectively ley fields. Damage size was largest at the fourth visit occasion in cereal fields while more even in size throughout the season in the ley fields (Fig 3-4). Damages in cereal fields reached larger sizes than in ley fields. However, many of the observed damages were small in both types of crops (Fig. 3). There was one apparent outlier in Bornsjön during the second visit, a ley field damage that was three times larger than the second largest damage in ley (Fig. 3, Fig. 6). The model was run both with and without that specific damage, but it was kept in the dataset since the results differed marginally. With the outlier removed, mean size of damaged area per ley field decreased from 13.9 m^2 to 10.3 m^2 at the second visit occasion. This is still larger than the mean size of area damaged at the three later occasions (Table 3).

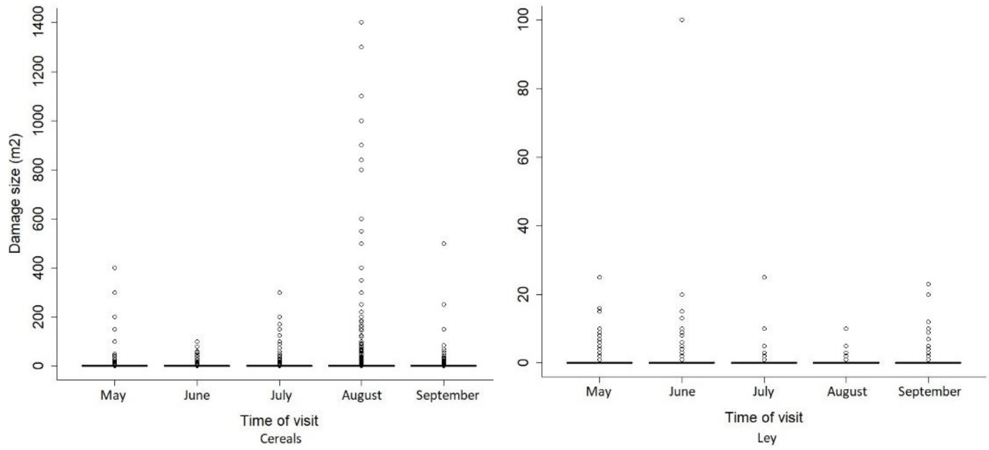

Figure 3. Size of individual damages (m^2), at the different visit occasions in cereal and ley fields, at five different occasions throughout the vegetation season. Visits were on a monthly basis, roughly following the months and starting in late April, for details see "Study area and Data sampling". Data was collected in 2017 from four areas in southcentral Sweden. Note the different scales at the y-axis in the two figures.

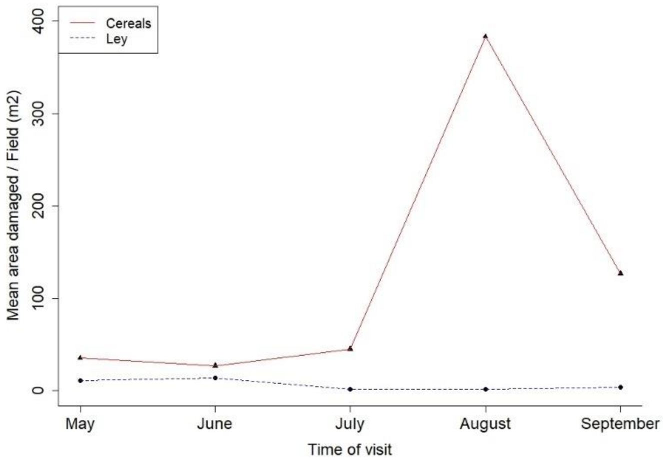

Figure 4. Mean size of area damaged (m^2) in cereal and ley fields, at five different occasions throughout the vegetation season. Visits were on a monthly basis, roughly following the months and starting in late April, for details see "*Study area and Data sampling*". Data was collected in 2017 from four areas in southcentral Sweden.

3.2 Study sites

Study sites explained (proportional R^2) 28% and 7% of the variation in damage probability in cereal respectively ley fields in the full binomial model. For cereal fields, the damage probability was highest in Boo and in ley fields, the damage probability was highest in Bornsjön (Table 4, Fig. 5). Study site explained (proportional R^2) 35% of the variation in the size of the damages in cereal fields in the full linear regression model. Cereal damages were largest in Ökna, while damages in ley fields appeared to be largest in Bornsjön (Table 4, Fig. 6-7). However, study site did not contribute in explaining the variation in damage size in ley fields (Table 7).

Table 4. *Data of damages in cereal and ley fields. Areas are presented in m^2, except total area surveyed which is presented in km^2. Data was collected in four study areas in southcentral Sweden, all located between 58°90', 15°44' and 59°24', 17°75' (WGS84), during five different occasions throughout the vegetation season of 2017*

Crop	Study site	No. fields surveyed	No. fields damaged[1]	No. damages	Tot. area surveyed[2]	Tot. size damages	Mean size damages	Mean area damaged/field
Cereals	Björkvik	33	27 (82)	295	2.17	10,408	35.3	315.4
	Boo	20	19 (95)	453	1.09	7,857	17.3	392.9
	Bornsjön	22	16 (73)	173	1.54	6,650	38.4	302.3
	Ökna	22	18 (82)	132	0.45	17,464	132.3	793.8
Ley	Björkvik	3	2 (67)	13	0.09	52	4.0	17.3
	Boo	4	4 (100)	35	0.18	133	3.8	33.3
	Bornsjön	7	6 (86)	91	0.46	525	3.8	75.0
	Ökna	23	15 (65)	56	0.60	200	3.6	3.6

1. Parentheses show the proportion of fields damaged/fields surveyed at that specific occasion
2. Presented in km^2

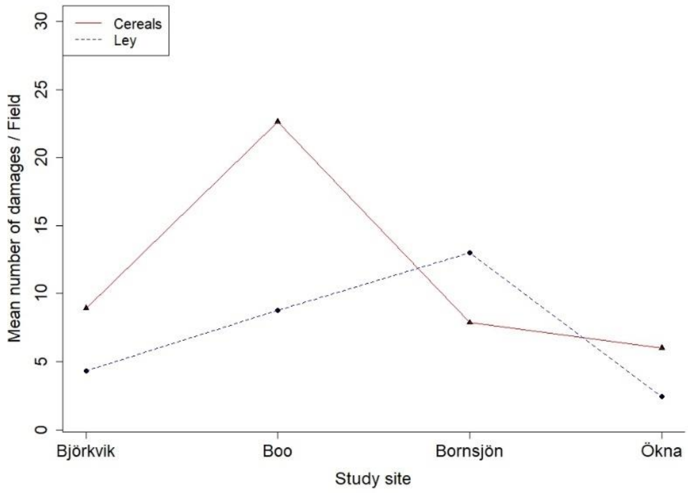

Figure 5. Mean number of damages in cereal and ley fields at the four study sites in southcentral Sweden. Data was collected in the summer of 2017.

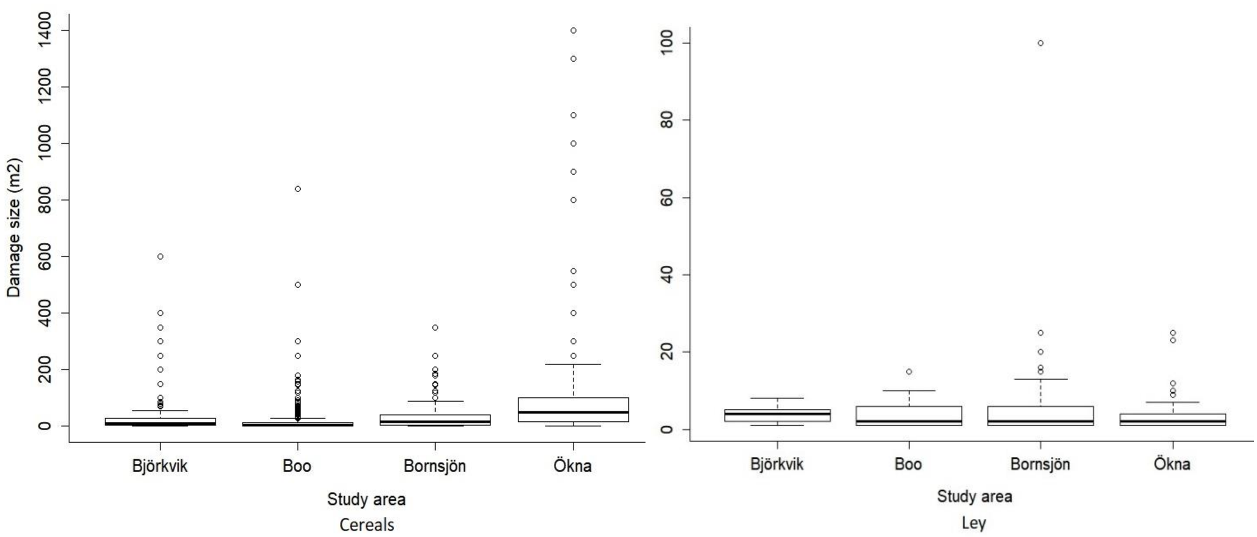

Figure 6. Individual damage size in cereals (left) and ley (right) at the four study sites in southcentral Sweden. Data was collected in the summer of 2017. Note the different scales at the y-axis in the two figures.

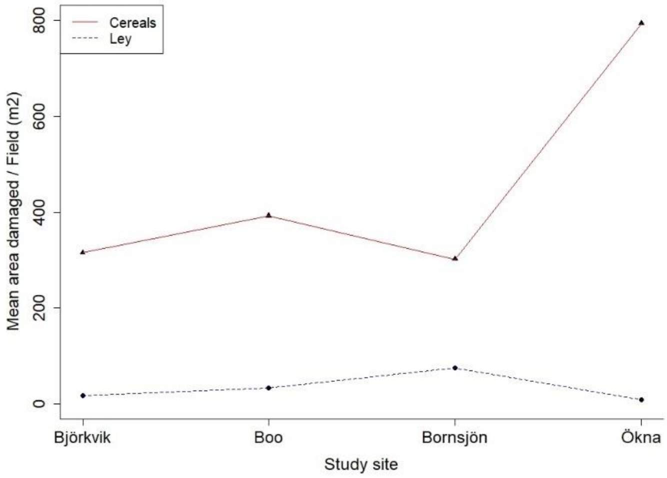

Figure 7. Mean size of area damaged in cereal fields and ley fields at the four study sites in southcentral Sweden. Data was collected in the summer of 2017.

3.3 Landscape variables

In cereal crops, the damage probability decreased significantly with distance to forest edges and feeding stations, while it increased with distance to roads ($R^2_{\text{Forest edge}}$ = 0.05, $R^2_{\text{Feeding station}}$ = 0.08, R^2_{Roads} = 0.01, $P < 0.01$, in all cases, Table 5, Table 7, Fig.8). In ley fields, only distance to feeding stations significantly contributed to explain the damage probability, which decreased with distance ($R^2_{\text{Feeding station}}$ = 0.12, $P = 0.04$, Table 5, Table 7, Fig.8). In cereals, damage size decreased significantly with distance to forest edges and increased with distance to roads (R^2_{Forest} = 0.04, R^2_{Road}= 0.04, $P < 0.01$ in both cases, Table 6, Table 7, Fig. 9). Distance to houses and water resources did not contribute significantly in explaining either the probability or size of damage in cereal fields (Table 5-6). In ley fields, none of the landscape variables significantly contributed in explaining the variation in damage size (Table 6).

Table 5. *Results of the full binomial models (i.e.damage probability). Intercept represent study site "Björkvik" in May (the first visit occasion)*

Crop	Fixed effect	Estimate	Std.Error	z- value	p-value
Cereals	Intercept	-4.049	0.251	16.126	< 0.0001
	Boo	1.519	0.362	4.192	< 0.0001
	Bornsjön	-0.071	0.383	0.186	0.853
	Ökna	0.637	0.378	1.684	0.092
	June	0.375	0.152	2.460	0.014
	July	0.207	0.141	1.470	0.142
	August	1.969	0.123	15.990	< 0.0001
	September	1.408	0.186	7.569	< 0.0001
	Dist.feeding	-0.411	0.142	-2.903	0.004
	Dist.road	0.315	0.069	4.592	< 0.0001
	Dist.forest	-0.383	0.058	-6.601	< 0.0001
	Dist.house	0.001	0.061	0.013	0.990
	Dist.water	-0.082	0.071	-1.162	0.245
Ley	Intercept	-2.139	1.067	-2.005	0.045
	Boo	0.348	1.295	0.269	0.788
	Bornsjön	1.279	1.178	1.086	0.278
	Ökna	1.361	1.230	1.107	0.268
	June	-0.682	0.204	-3.341	<0.001
	July	-2.830	0.410	-6.907	< 0.0001
	August	-2.143	0.299	-7.176	< 0.0001
	September	-1.541	0.256	-6.011	< 0.0001
	Dist.feeding	1.460	0.712	2.051	0.040
	Dist.road	0.265	0.155	1.717	0.086
	Dist.forest	0.136	0.213	0.637	0.524
	Dist.house	0.140	0.158	0.883	0.377
	Dist.water	-0.264	0.158	-1.674	0.094

Table 6. *Results of the full linear regression models (i.e log(damage size). Intercept represent study site "Björkvik" in May (the first visit occasion)*

Crop	Fixed effect	Estimate	std.Error	df	t-value	p-value
Cereals	Intercept	1.333	0.236	135.595	5.647	< 0.0001
	Boo	-0.985	0.316	75.747	-3.115	<0.001
	Bornsjön	0.308	0.344	80.430	0.894	0.374
	Ökna	0.807	0.336	83.256	2.402	0.019
	June	0.638	0.191	1025.384	3.342	<0.001
	July	0.704	0.164	1035.701	4.307	< 0.0001
	August	1.526	0.151	1029.930	10.140	< 0.0001
	September	2.328	0.197	1034.715	11.816	< 0.0001
	Dist.feeding	-0.089	0.147	165.110	-0.607	0.545
	Dist.road	0.173	0.062	491.308	2.809	0.005
	Dist.water	-0.029	0.062	382.975	-0.471	0.638
	Dist.forest	-0.171	0.052	695.092	-3.266	0.001
	Dist.house	0.043	0.054	639.120	0.799	0.424
Ley	Intercept	0.928	0.335	10.857	2.771	0.018
	Boo	-0.256	0.382	10.706	-0.671	0.517
	Bornsjön	-0.441	0.362	9.739	-1.218	0.252
	Ökna	-0.371	0.398	10.651	-0.932	0.372
	June	0.745	0.161	176.933	4.634	< 0.0001
	July	0.957	0.371	166.358	2.575	0.011
	August	-0.015	0.259	173.666	-0.058	0.954
	September	0.552	0.221	168.741	2.494	0.014
	Dist.feeding	-0.069	0.236	14.552	-0.292	0.775
	Dist.road	0.056	0.066	31.389	0.845	0.404
	Dist.water	0.128	0.088	115.697	1.447	0.151
	Dist.forest	-0.232	0.118	55.745	-1.965	0.054
	Dist.house	-0.145	0.083	68.566	-1.751	0.084

Table 7. *The fixed effects proportional R^2 – values (%) of the full models R^2. The full binomial model had R^2 24 % for cereal fields and 35 % for ley fields. The full linear regression had 31 % respectively 14 %. For the five landscape variables (distance to feeding station, road, forest edge, water and house), * indicates significance*

	Proportional R^2 (%)			
	Damage probability		Damage size	
	Cereals	Ley	Cereals	Ley
Feeding station	8*	12*	1	2
Road	1*	7	4*	2
Forest edge	5*	1	4*	13
Water resources	1	8	0	6
House	0	0	0	9
Visit occasion	41	53	40	82
Study site	28	7	35	0

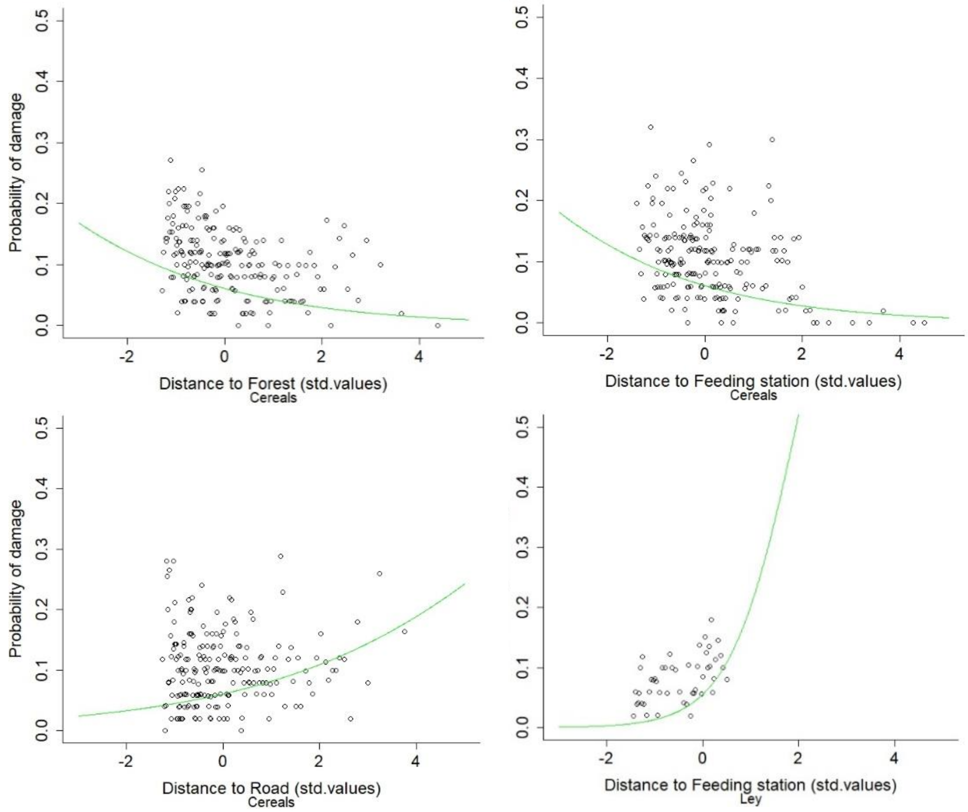

Figure 8. Relationships between damage probability in cereal fields and distance to forest edge, feeding stations and roads, and correlation of damage probability in ley fields and distance to feeding stations. 0 on the x-axes represent mean distance which is, approximately, 130 meters for forest edge, 1500 and 1000 meters for feeding stations in cereals respectively ley fields, and 180 meters for roads. Data was collected in 97 cereal fields and 37 ley fields.

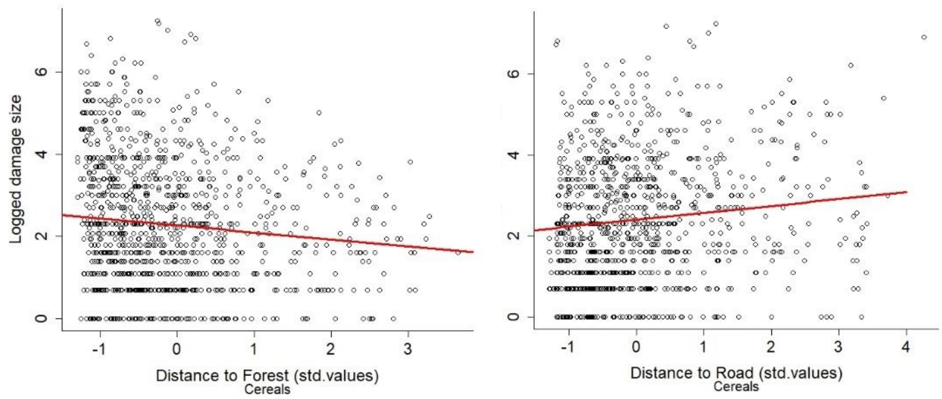

Figure 9. Log(damage size) in cereal fields in relation to distance to forest edge and roads. 0 on the x-axes represent mean distance which is, approximately, 110 meters for forest edge and 180 meters for roads. Data was collected in 97 fields, N= 1053.

4 Discussion and conclusion

This study, of Swedish wild boar spatio-temporal activity in cereal crop and ley fields, show temporal differences in both probability and size of damages. In cereals, the damage level peaked when crop ripened (August) while in ley fields the level of damage was higher early in the growing season (May-June). The study also revealed a difference in damage level between the two crop types, with a higher risk for damages as well as larger areas damaged in cereal fields than in ley fields.

The spatial analyses show that some of the landscape variables had a significant influence on the damage level. However, these effects were non-consistent for the probability and size of damage, as well as among the two crop types. The relatively low proportional R^2-values, all lower than 14 % (Table 7), show that the distance to these landscape variables only slightly contribute to explaining the variation in damage probability and size, in comparison to time of season. Below, I will discuss these results in further detail.

4.1 Temporal variation & differences between study sites

Like earlier studies conducted in Luxembourg (Schley *et al.* 2008), Italy (Amici *et al.* 2012), Poland (Frackowiak *et al.* 2013, Bobek *et al.* 2017), and Sweden (Welander 2000), I found a higher amount of damages in ley early in the growing season and in cereals later in the growing season. Cereal damages peaked at the fourth visit occasion (Aug. 1 - 24). August is when grains normally mature and ripens in this part of Sweden and damages have been shown to be greatest when crop is ripe also in other countries (Schley *et al*. 2008, Amici *et al*. 2012, Frackowiak *et al*. 2013, Bobek *et al*. 2017). This is explained by the energy richness of mature cereal crops (Schley & Roper 2003, Cellina 2008, Ballari & Barrios-Garcia 2014). Ley field damages occur, to a higher extent, during winter and in the early growing season (Welander 2000, Schley *et al*. 2008, Amici *et al*. 2012, Bobek *et al*. 2017), probably due to the low availability of alternative food sources at that time of year (Schley &

Roper 2003, Giménez-Anaya *et al.* 2008). Still, rooting activity occur in ley fields even when diversionary food is provided, and this might be explained by nutrient contents. Dry maize, which is often used for divisionary purposes, are rich in carbohydrates but low in protein which then must be ingested elsewhere. Insect larvae and root bulbs are high in protein and diversionary feeding have been suggested to even increase rooting activity in order to balance the nutrient contents in the diet (Schley & Roper 2003). Ley field damages decrease when other crop ripens but there is a continuous activity in ley throughout the vegetation season and this could probably also be explained by the need of different nutrients.

With the proportional R^2-values ranging from 40 % to 82 %, time of visit was clearly the most important factor for both damage probability and size, in both crop types. For the damage size in cereals, also study site contributed greatly, explaining 35% of the variation explained by the full model (Table 7). This is probably due to the much greater damages done to cereals in the Ökna area late in the season. Damage sizes were largest in Ökna but mean number of damages per fields surveyed, were highest in Boo.

Larger wild boar populations lead to a higher severity of damage (Bobek *et al*. 2017, Frackowiak *et al*. 2013, Schley *et al*. 2008). Hunting effort is necessary when relating hunting bags to population size (Imperio *et al*. 2010), and due to habitat factors, population sizes may vary on a local scale (Borowik *et al*. 2013). Unfortunately, I don't have hunting data for the local areas, but for the whole districts of which my sites are only minor parts. Nor do I have any data of hunting efforts and therefore I cannot evaluate if the bag statistics reflects the relative population sizes and thus, if damage level is correlated to population size in my study area.

In the analyses, time of visit was used as a factor of five. However, since the survey was conducted on a continuous, rolling schedule, data collected in the beginning or end of one period was closer in time to some surveys in the adjacent period than of some made in the same visit period. To reduce the risk of missing important information, future studies should use time of visit as a continuous factor, like Julian day. Unfortunately, due to time constraints, it was not possible in this study.

4.2 Landscape variables

With one exception (damage probability and distance to feeding station), distance to the different landscape variables had no influence on either the probability or size of damage in ley fields. There was a large difference in sample size between ley (195) and cereal (1053) fields. Nevertheless, distance to feeding stations explained 12% of the damage probability in ley fields (with the lowest sample size), which is higher than the proportional R^2 - values of all landscape variables in cereal fields, this unbalanced sampling should not have any practical meaning. To my knowledge, earlier studies have not analysed their data separated into crop types when looking at distances to landscape variables (see; Bobek *et al.* 2017, Lee *et al.* 2018, Lindblom 2011, Thurfjell *et al.* 2009). Since there seems to be quite a difference in distribution of high-risk areas between the two types of crop, I suggest that future studies should differentiate between crop types when analysing distribution and severity of wild boar damages.

Distance to feeding stations was significantly correlated with damage probability in both cereals and ley. However, the correlation was negative in cereal fields while positive in ley fields. Why distance to feeding stations did not affect the size of damages is unclear. A possible explanation for the results in cereal fields, with a higher damage probability in proximity to feeding stations but a non-significant effect on damage size, could be that feeding stations attract wild boar to the local area (see also Geisser & Reyer 2004), and with more individuals roaming the area, the probability of damages is likely to increase. However, with extra food supplied in the sheltered forest, wild boar may spend less time in the nearby fields (Vassant & Breton 1986, Vassant *et al.* 1987, both cited in Cellina 2008). Thus, the probability of damages could increase even though the damage sizes do not. However, this is partly in contrast to Cellina (2008), who found an increase in agricultural food with a corresponding decline in supplemental food in the stomach contents as soon as agricultural food sources became available. As mentioned earlier, diversionary feeding has been suggested to increase rooting activity in ley fields due to the need of protein (Schley & Roper 2003), which is contradicting to my results of a positive correlation between distance to feeding stations and probability of damage in ley fields.

Like several earlier studies (Calenge *et al.* 2004, Thurfjell *et al.* 2009, Lindblom 2011, Bobek *et al.* 2017, Lee *et al.* 2018), I found a higher damage level closer to forest edges, however only in cereals. This is probably explained by a need of shelter (Bobek *et al.* 2017, Morelle & Lejeune 2015).

Distance to roads showed significant, positive correlations for both probability and size of damages in cereals. Thus, the damage level was higher further away from roads. Road density have been showed to have a negative effect on wild boar damages before (Schley *et al.* 2008) and this is probably due to the disturbance.

Distance to houses had no significant effect on either probability or size of damage, in the two crop types. In other studies, when human disturbance has been shown to negatively affect the occurrence of wild boar damages, it has been analysed as urban cover (Ficetola *et al.* 2014), human population density (Schley *et al.* 2008), and as human presence represented by the number of buildings (Amici *et al.* 2012). With the exception of Bornsjön which is close to the city of Södertälje, the human density was fairly low in my study sites (3.75; 4.77; 6.85 and 20.14, Table 1). This low human density with houses scattered may not be as disturbing to wild boar as communities can be. Gardens might even attract wild boar with their potential food resources such as fruit trees and vegetable cultivations. Also, being an opportunist, wild boar can learn to live in close relation to humans and there are wild boar populations thriving in cities as big as Berlin (Stillfried *et al.* 2017).

Earlier studies have shown contradicting results of the effect of water on wild boar damages. Rivers (Amici *et al*. 2012), wetlands and flowlines (Paolini *et al*. 2018), have been shown to increase damage risk, while streams and watercourses have been found to be non-significant in other studies (Lee *et al*. 2018, Morelle & Lejeune 2015). In this study, distance to water showed to be non-significant for damage probability and size, in both crop types. This could be because the variable included all water resources marked on the map, but many of the smaller ditches running through the fields are often empty of water during the summer. Thus, it is possible that many of the water resources closest to damages were dry during the study which could lead to a type two error in estimating the influence of water resources on the level of wild boar damage i.e. falsely inferring the absence of a water effect even though it is likely there is an effect. Another explanation could be that water have an influence but detectable only on a larger scale, thus on population density (Borowik *et al*. 2013, Paolini *et al*. 2018), or when it is a limited resource. My study areas are quite rich in water resources and as Lemel *et al*. (2003) concluded, wild boar is a highly mobile species which may roam large areas during their active hours. Thus, distance to water may not have an important influence on wild boar distribution in areas where water is not limiting, like in these study sites (see also Morelle & Lejeune 2015).

4.3 General discussion

The three main and accepted methods in prevention of wild boar damages to crops are; diversionary feeding, electrical fences and hunting (Geisser & Reyer 2004). Several authors question, or even argue against, the method of feeding wild boar because of the positive effect it has on reproduction rate and its apparent insufficiency to attract wild boar when crop is ripe (Bieber & Ruf 2005, Cellina 2008, Geisser & Reyer 2004, Schley et al. 2008). Despite earlier fencing experiments with apparent success, Geisser & Reyer (2004) deem that fencing only shift the problem elsewhere. This shift in distribution of damages together with high cost of fences, make the method inappropriate for the purpose (Geisser & Reyer 2004). Of the three prevention methods, hunting is what most authors recommend (Geisser & Reyer 2004, Bieber & Ruf 2005, Schley et al. 2008, Amici et al. 2012, Morelle & Lejeune

2015). In Sweden, the landowner holds the hunting rights but may lease it out to hunters (Wretling & Karlsson 2010). An interview survey by the Swedish Agricultural board, showed that farmers leasing land for cultivation had higher economical losses due to wild boar damages than landowning farmers. The farmers leasing land seldom lease the hunting rights and there is probably a gap in the communication between land leasing farmers and leasing hunters (Wretling & Karlsson 2010). One goal of the wild boar management in Sweden is a better cooperation between hunters, farmers and other stakeholders (Anonymous 2010). Lemel *et al.* (2003) also suggest cooperation, but that of hunting teams, for a better management of the wild boar population and thereby, damages to crops.

Another problem is the hassle of selling wild boar meat. It is a both time consuming and somewhat costly procedure (Anonymous 2010), and several farmers state that they throw away meat due to the excess instead of selling it (Wretling & Karlsson 2010). Facilitating the procedure was a goal of the management plan already in 2010 (Anonymous 2010), but it has yet to improve.

4.4 Management implications

The severity of cereal damages showed to be highest close to feeding stations and forest edges. Thus, I advise to carefully consider placement of feeding stations and when possible, take the distance to forest edge into account when planning crop type. Fields with high proportion of forest edge should benefit from choosing a cheaper crop (see also Lindblom 2011), or trichomatous cereals such as barley, which have been shown to be negatively selected in other studies (Schley *et al.* 2008, Lindblom 2011).

4.5 Conclusion

The severity of damages (probability and size), was higher in cereals than in ley fields (even though the majority of damages were small in both crop types). There was a seasonal difference in both types of crop. In cereals, the damage level peaked in August, while the damage level was highest earlier in the season (May-June) in ley fields.

Spatially, the level of damage in cereals was higher in proximity to forest edge (probability and size) and feeding stations (only probability), and lowest close to roads (probability and size). In ley, feeding stations was the only landscape variable with a significant influence on damage level, showing a lower probability of damages close to feeding stations. However, time of season showed to be of higher importance than distance to any of the environmental variables tested, indicating that reducing wild boar damages is rather a temporal matter than a spatial.

With the differences in damage level between the two crop types, both temporally and spatially, I suggest future studies to separate different types of crops when analysing damage distribution.

Acknowledgements

I want to thank my supervisors, Petter Kjellander for all your comments improving the report, and Henrik Andrén for getting me started, and helping me through all the statistical errors. Henrik, your words of encouragement always came at the right times, boosting my self-esteem and making the hardest parts of this thesis endurable. I would also like to thank Madeleine Christensson, Johan Nilsson, Bosse Söderberg and the students who collected all the field data necessary for the analyses. Vojtech Nezval, thank you for helping me code in python, you saved me so much time! Finally, thanks to my friends and family for helping me cope when statistics and excel files became too overwhelming and, to be honest, sometimes made me feel nothing but bore… Thank you all, I could not have done it without you!

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