Swedish University of Agricultural Sciences
The Faculty of Natural Resource and Agricultural Sciences
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Vildsvinsskador – fördelningsmönster och skördeförlust i ett jordbrukslandskap

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Abstract
The last decades the populations of wild boar (*Sus scrofa*) has increased rapidly over the species' entire European range, including Sweden. This is followed by increasing human-wildlife conflicts as a result of the wild boar foraging behavior, causing damage to agricultural crop fields due to trampling and feeding. To be able to minimize damage we need more knowledge of where in the fields the risk of damage is high and what features in the landscape that affect this risk. I analyzed damage distribution in relation to the distance to six different landscape features; forest, road, ditch, building, game field and bait station, in the study area, the Island Mörkö in eastern central Sweden. A binary logistic regression analysis showed that damage increased with proximity to forest, road, ditch and bait station, strongest affected by the distance to forest and bait station. The damage also showed to be more severe closer to the forest edge. I also calculated the cost of wild boar damage, during the harvest season of 2010, based on the field survey. The apparent income loss due to damaged and reduced harvest in wheat, oats and barley fields was this year about 120 000 SEK. This sum indicates a significant problem and point at the need for measures to minimize damage. My results suggest, for example, that sensitive crops like wheat should be cultivated on fields with less edge towards the forest, and that bait stations should be placed as far away from fields as possible.

Keywords: *agriculture, cost, damage, edge effect, human-wildlife conflict, Sus scrofa, wild boar*

Sammanfattning

Konflikter mellan vilt och människa uppkommer överallt där människans intressen påverkas och begränsas av viltets aktiviteter. Ofta beror dessa konflikter på ekonomiska förluster då arten ifråga till exempel orsakar skada på skogsbruk, anläggningar eller grödor. Ett exempel på en sådan art är vildsvin, som ökar i antal i Sverige. Idag beräknas vi ha ungefär 150 000 vildsvin i Sverige, ofta märks deras närvaro framförallt av de skador de åstadkommer; uppbökade gräsmarker, uppätna och nedtrampade grödor. Dessa skador innebär ofta en allvarlig ekonomisk förlust för den drabbade jordbrukaren, och i många europeiska länder finns sedan länge statliga ersättningssystem för att kompensera för skadan. Även i Sverige har vi problem med skador på gröda i vissa områden och mer kunskap är nödvändig om de faktorer som påverkar risken för skador men också hur stora förlusterna är i drabbade områden. Jag har därför haft två syften med denna studie. Det första var att relatera förekomsten av vildsvinsskador mot avstånd till sex olika landskapsvariabler; skog, väg, dike, hus, foderplats och viltåker i mitt studieområde, som var beläget på den Sörmländska ön Mörkö. Det andra var att räkna ut den direkta vildsvinsorsakade skördeförlustens kostnad under odlingssäsongen 2010.

Inventeringen av skador genomfördes under tre veckor precis innan skörden i augusti och september 2010. Genom att gå transekter (vartannat sprutspår) genom fält av vete, havre och korn noterades alla vildsvinsskador. Skadade ytor koordinatsattes, ytan (m^2) och skadegraden (fem klasser) uppskattades. De inmätta ytorna bearbetades i GIS-programmet ArcMap 9.3 där jag med kartor från Lantmäteriet tog fram kortaste avstånd till tidigare nämnda landskapsvariabler. Genom en logistisk regressionsanalys kunde jag sedan testa den gemensamma påverkan från dessa element genom att jämföra dem mot samma antal slumpade punkter. Skördeförlusten beräknades på produkten av den uppmätta arean multiplicerat med den procentuella skadegraden i skadefläcken. Vilket sedan applicerades på uppgifter om kostnader i studieområdet. Därigenom utrycktes den totala vildsvinsskadan som förlorad skörd (kg) och inkomstförlust (SEK) som resultat av förlorad skörd.

Min inventering visade en total skördeförlust på 2,8 % för vete, 2,2 % för havre och 1,8 % för korn av den respektive odlade arean. Den inventerade skadegraden varierade mellan grödorna, med höga skadenivåer för vete och låga i kornfälten. Dessa skador motsvarade under odlingssäsongen 2010, i mitt studie område, 78 720 kg i förlorad skörd och därmed 119 740 SEK lägre inkomst. Det innebar totalt en förlust på 253 SEK per hektar odlad vete, 66 SEK/ha korn och 133 SEK/ha odlad havre.

Jag visar i den här studien att risken för vildsvinsskada ökar med kortare avstånd till skog, väg, dike och foderplats. Av dessa fyra landskapsvariabler hade närhet till skog och foderplats störst påverkan på förklarandegraden i modellen. Att risken för skada ökar närmare väg hänger troligen ihop med den låga trafikintensiteten och att dessa därför liksom diken snarare fungerar som skydd (ofta kopplade till diken och kantzoner) i det annars öppna landskapet. Man bör enligt mina resultat så långt som möjligt undvika känsliga, dyra grödor nära skog och foderplatser samt vara uppmärksam på smala åkrar och som omgärdas av mycket skog.

***Nyckelord**: jordbruk, kanteffekter, kostnader, skador, Sus scrofa, vildsvin, viltkonflikter*

Index

Introduction

Human-Wildlife conflicts arise worldwide whenever the interests of humans are affected by the activities of a wildlife species (Conover 2002). This may involve anything from competition over the same prey (Sand et al. 2006), damage to forests caused by foraging ungulates (Lavsund et al. 2003) or the spread of diseases from wild populations to domestic animals (Alexander 2007). These conflicts are therefore often caused by economical loss or any other to humans' negative effect; economical, physical or reduction of a person's lifestyle as a result to the wildlife's activities (Conover 2002). To find good solutions to resolve these conflicts we need knowledge of the species causing damage and the affected ecosystems (McCarthy & Possingham 2007).

One such trouble-making species is the Wild Boar (*Sus scrofa*), that often start conflicts due to their foraging behavior (Anonymous 2010a; Geisser & Reyer 2004; Mackin 1970). Being obligate omnivores their diet is a product of the available resources within their environment. In a Spanish study the diet of wild boar was found to consist predominantly of agricultural plants (88%), the most important crops being maize (*Zea mays*) and wheat (*Triticum aestivum*) (Herrero et al. 2006). Wild boar damage to the agricultural landscape does not occur only due to consumed biomass, but also due to trampling during feeding and moving in the crop fields (Herrero et al. 2006; Campbell & Long 2009). The type of damage varies throughout the year, but the type that probably causes most conflicts starts as soon as the spikes are in ripeness, with trampling and feeding in the crops until the harvest (Schley et al. 2008).

In an agricultural landscape this may lead to severe economic loss for individual farmers, but also for the society in general due to reduced income and expense of governmental compensation of damage. In several European countries, farmers may get economical compensation for their harvest loss. In Luxemburg, for example, compensations encompassed € 5.7 million between 1997 and 2006 (Schley et al. 2008) and in the Italian province of Siena the government paid € 0.23 million per year between 1992 and 1994 (Mazzoini Della Stella et al. 1995).

The wild boar is distributed over the whole of the Eurasian continent and European populations have spread and increased dramatically in recent decades; including France (Calenge et al. 2004), Germany (Keuling, Stier & Roth 2009), Luxemburg (Schley et al. 2008), Italy (Mazzoini Della Stella et al. 1995), Poland (Mackin 1970), Spain (Herrero et al. 2006) and Sweden (Lemel 1999; Anonymous 2010a).

The risk of damage is a function of the wild boar behavior and their high rate of population increase and expansion, and this necessitates the development of improved tools for their management. To minimize and predict the extent of wild boar damage, we need more knowledge about their foraging ecology and damage patterns in the agricultural landscape (Conover 2002). These patterns then need to be related to measures that can be used to mitigate damage and optimize their preventive effectiveness. Furthermore, since several interest groups (e.g. hunters and farmers) are involved in the management, tools are also needed for quantifying damage in order to compare costs and incomes sufficiently.

Wild boar are known for their cautious behavior (Baskin & Danell 2003; Thurfjell et al. 2009) and this has been suggested as the reason for rooting in pastures and meadows not being randomly distributed but rather related to landscape features providing shelter, such as forest edges (Lemel, 1999; Geisser & Reyer 2005; Thurfjell et al. 2009). Probably, a similar pattern may be expected when it comes to the distribution of damage in cereal crop fields i.e. more patches of damage in the parts of the field close to elements of shelter such as the forest edge and ditches, whereas less damage would be expected close to elements of disturbance such as buildings and roads.

At least three different management methods have been used to prevent damage on agricultural fields caused by wild boar: 1) intensive culling of the population, 2) diversionary feeding (i.e. supplemental feeding to steer the groups away from sensitive crops), 3) electric fencing (preventing wild boar from entering the crop fields) (Mazzoini Della Stella et al. 1995; Geisser & Reyer 2004; Reidy et al. 2008). Geisser and Reyer (2004) showed that out of these three methods, only culling significantly reduced crop damage.

There are few clear results concerning the possibility of controlling wild boar movements and damage with diversionary feeding. Moreover, supplemental feeding of wild boar has been shown to cause an increase in the rate of population growth compared to natural conditions (Geisser & Reyer 2005). Supplemental feeding sites may also be used to promote effective culling of the nocturnal wild boar, then called bait stations, and therefore play an additional important role for management (Anonymous 2010a). However, a recent Norwegian study showed that damage to trees caused by browsing moose (*Alces alces*) increased with proximity to diversionary feeding sites but that the time spent by moose in young forest plantations was unaffected further away (van Beest et al. 2010). If the same pattern applies for wild boar, we could expect an increase in crop damage closer to the bait stations and game fields (fields sown with crop left as supplemental feeding for game) as a result of higher wild boar activity in that area.

The aim of this study was twofold; (1) to relate the spatial distribution of patches of damage to factors in the landscape. More specifically I tested whether the distribution of patches of damage related to distance from a) elements of shelter; the forest edge and ditches b) elements of disturbance; roads and buildings and c) arranged supplementary feeding sites; bait stations and game fields and (2) to estimate the apparent economic loss caused by reduced crop harvest as a consequence of wild boar damage in wheat, oats and barley fields in the study area during the 2010 harvest season.

Material and methods

The study species

Wild boar lives in matriarchal groups (generally consisting of one leading sow, her daughters, granddaughters and their piglets) whereas the males are generally solitary (Briedermann 1990; Baskin & Danell 2003). They are nocturnal and can cover significant distances to feed (covering a mean distance of 7.2 km per night; Truvé 2004). Wild boar are a typical r-selected species, being highly opportunistic in choice of diet and habitat and with the highest potential reproductive rate among ungulates in relation to body-mass (Lemel 1999; Geisser & Reyer 2005). They were accidently reintroduced into Sweden in the 1970s, but were formally accepted by the Swedish parliament as part of the fauna in 1988 (SFS 1987:905). Wild boars have increased rapidly in numbers since and now the population has reached approximately 150 000 individuals (Jansson et al. 2010).

The highly adaptable nature of the wild boar makes it difficult to keep them out of areas such as crop fields and gardens (Geisser & Reyer 2004). Studies of different preventive methods have not so far shown any long-term effects (Geisser & Reyer 2004; Campbell & Long 2009; Anonymous 2010a). Types of wild boar damage vary over the year and with crop and land use, for example grasslands such as pastures suffer damage from rooting in spring when they are searching for nutritious bulbs and roots. After that comes the time for sowing maize and cereals, when seeds are eaten directly from the ground, and when the crop is high enough to work as shelter it is also used for nesting, and the trampling and feeding inside the crop fields starts as soon as the spikes are in ripeness, until the harvest (Schley et al. 2008; Mackin 1970).

The study area

The study was conducted on the island Mörkö (east coast of central Sweden 16°06’90”, 65°42’96”; Fig. 1). The average annual temperature is 5-6°C and average yearly precipitation is 500 mm (Raab & Vedin 1995). The period of vegetative growth (defined as days with average temperature above 5°C) lasts about 200 days (Raab & Vedin 1995). The Mörkö island is approximately 59 km^2 large and measure 20 km from north to south. The island consists of approximately 25 % agricultural land. The landscape is undulating and 60 % of the island is covered by coniferous forest, consisting mainly of spruce (*Picea abies*) and pine (*Pinus sylvestris*). Patches of cereal fields, ley fields (17 %) and fallow fields (6 %) form a mosaic-like pattern in the landscape. This study was conducted on the grounds of Hörningsholm manor which makes up 98 % of the island and 87 % of the island's agricultural land on which the cultivated crops during 2010 consisted mainly of wheat (*Triticum aestivum*) (32 % of Hörningholms grown crop 2010), barley (*Hordeum vulgare*) (7 %) and oats (*Avena sativa*) (3 %).

During the survey there were 14 active bait stations available on the island. Six different types of supplemental forage were used (vegetables/fruit, sugar beet, hay silage, wheat silage, wheat bran and peas) to steer (mainly late spring/summer) and supply wild boar with forage (mainly late autumn/winter and spring; Fig. 2). In total 370 000 kg (vegetables/fruit: 75 000 kg, sugar beet: 70 000 kg, hay silage: 35 000 kg, wheat silage: 97 000 kg, wheat bran: 63 000 kg, peas:

30 000 kg) were used as supplemental food during year 2010 (Stephan Gäfvert pers. comm.). The months prior the inventory (January to August) the forage was dispersed at a total of 800 refill occasions (Stephan Gäfvert pers. comm.) and the number of refills varied between seasons, with most food provided the first three months of the year as a supplement during the harsh months of deep snow (Fig. 2).

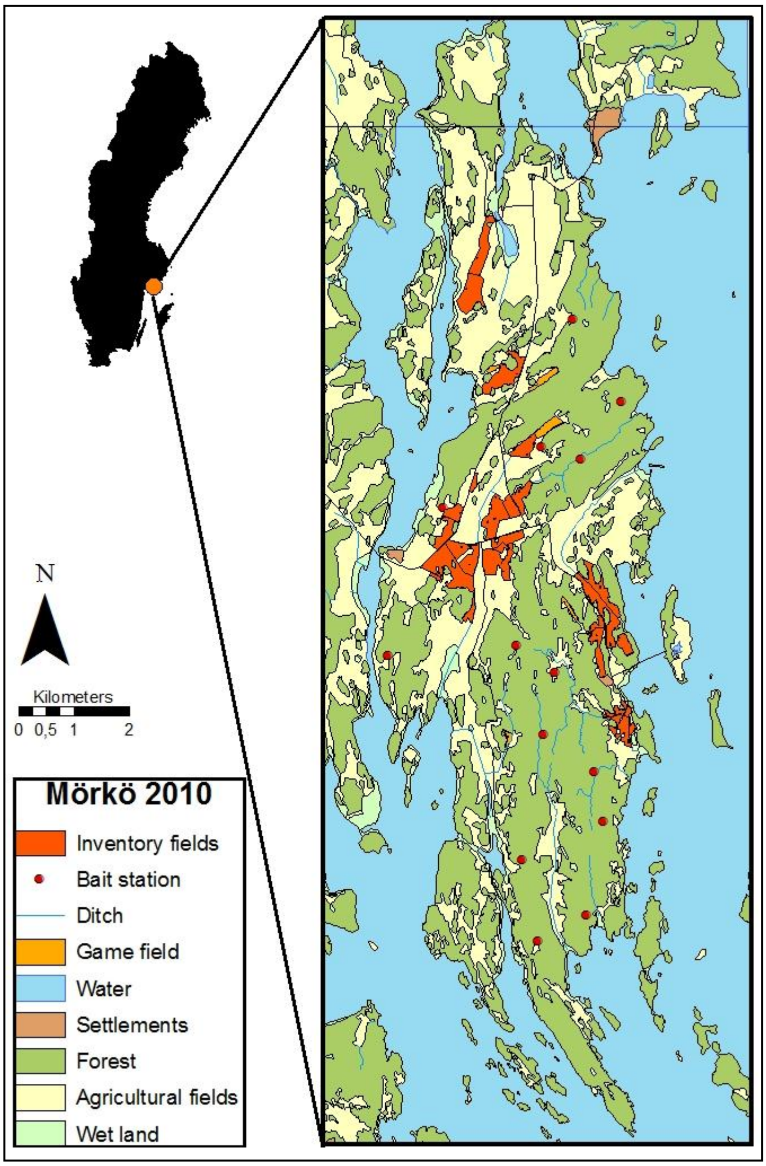


Figure 1. The study area is located in mid-east Sweden. Most of the crop fields are found in the north and mid parts of the island. Bait stations (red dots) being spread in more forested areas. *Swedish mapping, cadastral and land registration authority (Lantmäteriet), Gävle 2010. Permission I 2010/0055.*

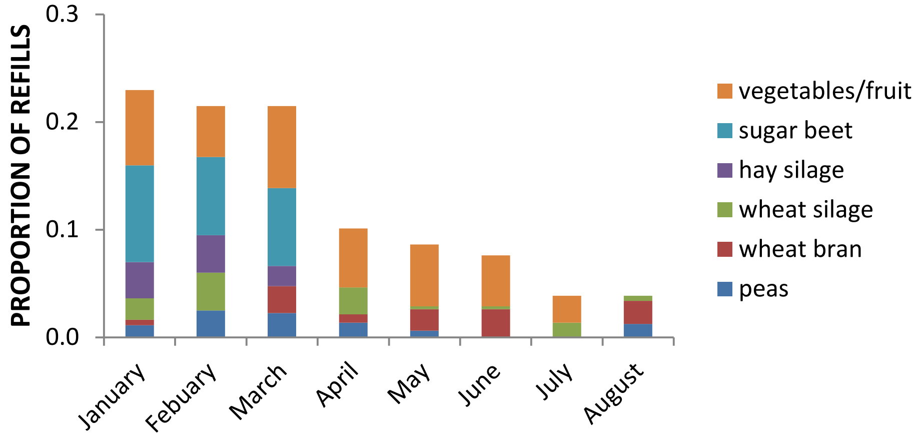


Figure 2. In total 370 000 kg of supplemental forage were used during 2010 on Mörkö´s 14 bait stations. In total 800 refills of supplemental food were conducted at the bait stations and the number of refills varied between the months during the study period.

In addition to this, there were five game fields present within the study area (2 wheat, 1 oats, 1 oats/clover (*Trifolium sp*.), 1 barley/oats/clover field) covering 21.0 ha in total. In areas of dense forest some small fields have been converted into game pastures which are sown with the pre-fabricated mixture "Viltvalle", consisting of 20 % red fescue, (*Festuca rubra*); 20 % smooth meadow-grass (*Poa pratensis*); 15 % timothy-grass (*Phleum pratense*); 15 % meadow fescue (*Festuca pratensis*); 10 % lacy phacelia (*Phacelia tanacetifolia*); 5 % white clover (*Trifolium repens*); 5 % red clover (*Trifolium pratense*); 5 % alfalfa (*Medicago sativa*); and 5 % Cock's-foot (*Dactylis glomerata*). There are a total of 37 of these game pastures spread over the island covering a total area of 86.4 ha.

Wild boar has been present on the island since the 1970s and has been hunted since that time. In the years between 2000 and 2010 the mean annual bag of Hörningsholm manor was 192 wild boars, and consisted in average of 15 % boars, 14 % sows and 71 % piglets/yearlings culled over the last decade (Stephan Gäfvert pers. comm.).The most common hunting method is to use hunting dogs, but stalking also occurs, mainly for crop protection during summer. In 2010 protective culling efforts on crop fields totaled 179 hours, of this 87.5 hours (48 %) was spent on wheat or oat fields (Stephan Gäfvert pers. comm.). The remaining hours was an attempt to protect peas and maize, which are not included in this study. Hunting is the major cause of mortality of the wild boar on the island; no large predator species are present (Stephan Gäfvert pers. comm.).

Apart from wild boar also moose, red deer (*Cervus elapus*), fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*), mountain hare (*Lepus timidus*), european hare (*Lepus europeus),* badger (*Meles meles*), and several herbivorous birds, for example greylag goose (*Anser anser*) and crane (*Grus grus*) may contribute to crop field damage in this area.

Survey of crop damage

To enable an estimation of the extent and distribution of wild boar damage an inventory of 35 crop fields (14 wheat, 3 oats, 8 barley, 5 oats/clover and 5 game fields) was carried out during a period of three weeks, in August and September of 2010 (i.e. just prior to the harvest). The fields were surveyed in the same order as they were harvested i.e. first wheat fields followed by oats, barley, oats/clover and game fields (Fig. 1). Because of the difficulties to find and determine wild boar damage in oats/clover fields, these were excluded from the analysis.

A total of 29 crop fields, with a total area of 319.2 ha, were surveyed for wild boar damage. These comprised 14 wheat fields (158.8 ha, i.e. 42 % of the total area of Hörningholm manors cultivated wheat 2010), eight barley fields (98.9 ha, 100 % of total), three oat fields (43.3 ha, 100 % of total), four game fields (18.2 ha, 100% of total). The mean size of the fields was similar across the three crop types, wheat: mean area of 12.8 ha (range 1.3 - 32.6 ha), oats: 14.3 ha (6.7 - 21.0 ha) and barley: 12.4 ha (3.7 - 21.9 ha). The game fields were smaller, with a mean size of 4.2 ha (2.0 - 8.0 ha).

The fields were surveyed by walking transects (the transects consisted of tracks created when spraying the fields by tractor). The distance between transects was about 50 m. The start and end of each transect was marked using a handheld GPS (Garmin Astro 220 Nordic). Because of the asymmetric shape of fields the length of transects varied. The transects' start and end positions were later used to determine the length of the transects using the GIS program ArcMap. When a damaged patch was found, the length and width of the patch was measured cross-wise (90°) by using a two m long stick for lengths under 15 m, and a laser meter (Bushnell Yardagepro, Compact 600; by aiming at a wooden plate) for distances over 15 m. The position of the patch was achieved by using a handheld GPS. Only patches >1 m^2 were included. Patches separated with a border (> 2 m) of standing crop was defined as separate patches. No walking paths were included as damage. A damaged patch was defined as wild boar damage if at least two out of six signs (tracks, trails, rooting, nests, wallows or droppings) of wild boar activity were found.

Level of damage

The level of damage was estimated by determining the cover of harvestable crop i.e. spikes above > 15 cm from the ground (Anders Johansson pers. comm.). The methodology is similar to what has been used to estimate ungulate forage cover in forest stands (Hörnberg 2001; Månsson et al. 2007). The coverage was classified into five categories of damage intensity (Tab. 1), from which the median of the interval was used for calculating the affected area (Tab. 1). This was done by multiplying the measured area of each damaged patch with the median of interval for the defined damage intensity class. For example a patch of 10 m^2 classified as category "3" gives: 10 * 0.62 = 6.2, giving us an affected area of 6.2 m^2 in that patch.

Table 1. A five-category system was used to estimate the coverage, i.e. the level of damage for each patch of wild boar damage found in the survey of wheat, oats and barley fields in the study area in 2010. The median of each category was used to estimate the affected area of each damage patch.

Damage intensity	1	2	3	4	5
Crop damaged	1-24 %	25-49 %	50-74 %	75-99 %	100 %
Factor for estimating affected area (median)	12 %	37 %	62 %	87 %	100 %

Some patches were damaged due to other factors such as weather, wind, snow mold and tractors. If there were signs of wild boar activity on top of these; they were positioned and used in the spatial distribution analysis but excluded from the harvest loss calculations (i.e. only wild boar damage was included).

Compared to the crop fields the game fields were more severely damaged and therefore the intensity of damage was determined for the whole field. However individual patches of damage were positioned if the game field had a damage level lower than 5. Because the purpose of game fields is not to produce a crop harvest, they have not been included in the harvest loss calculations.

Distance between patches of damage and features in the landscape

The occurrence of patches of damage was related to distances from certain landscape features. The information on these features was acquired from the Swedish mapping, cadastral and land registration authority (Lantmäteriet), GSD – road map "Blå kartan". The function "Near" (ArcMap 9.3) was used to calculate the closest distance, from each patch of damage (n = 1034), to six different variables in the landscape; forest edge, bait station, road, building, ditch and game field. The area and transect lengths were also estimated using (ArcMap 9.3, extension Hawth tools).

Statistical analysis

In order to test whether the spatial distribution of damaged patches differed from a random pattern, I created the same number as patches of damage found (n = 1034), of randomly distributed points (within the surveyed fields; using the Hawth tools extension, ArcMap 9.3). Distances from random points to the six landscape features were then calculated in the same way as for patches of damage (see above). In the logistic-regression analysis (see below), these points were assumed to be un-damaged patches.

I tested the correlation (Pearson) between the explanatory variables (PASW statistics 18). No variables were strongly linked ($r < 0.5$ in all cases, Tab. 2).

Table 2. The matrix shows the correlation (r) between the six different landscape variables used in this study to analyze the risk of wild boar damage in relation to the distance from a certain patch to the six different variables. The ones significant on a level of $p < 0.05$ are shown in bold. None of the parameters were correlated closer than $r > 0.5$.

	Forest	Ditch	Bait station	Building	Road	Game field
Forest	1					
Ditch	**-0.163**	1				
Bait station	**-0.188**	-0.015	1			
Building	**-0.070**	**-0.243**	**0.312**	1		
Road	**-0.199**	**-0.202**	0.001	**-0.228**	1	
Game field	**0.325**	**-0.189**	**-0.284**	-0.048	**0.067**	1

Binary logistic regression analysis

A binary logistic regression analysis was used to estimate the risk of damage in relation to the distance of the six different landscape features. The backward function in PASW Statistics 18 was used to exclude all variables which had low significance for the log likelihood ratio of the model, so that only those variables with $p < 0.05$ were included. The distance data was ln-transformed (ln(x+1). As presence of damage I used all patches of damage found (n=1034), i.e. regardless of damage level, and for non-presence the randomized patches were used.

$$P(Y) = \frac{e\^{}(a+bx_b+cx_c+dx_d+ex_e)}{1 + e\^{}(a+bx_b+cx_c+dx_d+ex_e)}$$

Equation 1. Probability of damage P(Y) as a logistic function of distance from elements in the landscape i.e. (x_b) (x_c) (x_d) and (x_e).The function has a constant (a) and four gradients (b, c, d, e) representing the effect (B) from the specific variable.

Risk of damage in relation to specific landscape features

A two-sample t-test, assuming equal variances, were used to test if the distance between patches of damage to forest edge and feeding stations differed from the corresponding distances to randomly distributed points. I also produced histograms with the distance from the random patches (n = 1034) and the patches of damage (n = 1034) to forest edge and bait stations. Histograms were also made over the distribution of level of damage in relation to the six landscape features.

Calculation of economic loss

To calculate how much the estimated affected area of crop damage in wheat, oats and barley fields, corresponds to in actual harvest loss in kilograms (kg) and costs (Swedish kronor, SEK; 1 SEK~ 0,11 € (Oanda 2010)). The net mean harvest (kg/ha) from the last five growing seasons (year 2005 - 2009) in the study area was used (Tab. 3). I used the level of damage found in this study to adjust for wild boar damage (i.e. lost harvest due to wild boar was added). Economic loss in SEK due to damage caused by wild boar in the year 2010 were calculated using the prices and expenses, supplied from Hörningsholm manor for the 2010 growing season (Tab. 3).

Table 3. The prices for harvested wheat, oats and barley used in this study were provided from Hörningholms manor. The mean harvest, based on the last five years, for the three crop types in the survey, was used to estimate the expected harvest in the affected area after adjustments for expected wild boar damage (assumed to be of same level for the last five years as found in this study for 2010).

Harvest data	Wheat	Oats	Barley
Price of harvested crop (SEK/1000 kg)	1540	1290	1455
Mean harvest (kg/ha)	6280	5160	4040
Expected harvest without wild boar damage (kg/ha)	6541	5311	4114

Calculation of income

To estimate the income gained from culled wild boars I used the mean meat prices from two purchasers of wild boar meat close to the study area, the mean slaughter weights of culled wild boars from the whole bag of Hörningsholm manor in 2009 and the mean annual bag from the last ten years (Tab. 4).

Table 4. Mean slaughter weight and meat price based on 98 culled wild boar in 2009 and the mean annual bag with data from the study area at the Hörningsholm manor in south eastern Sweden, 2000 – 2009. The meat price was based on the mean price offered in 2010, by two local purchasers.

Wild boar data	Conditions for the study area
Mean slaughter weight (2009)	**17.3** kg/wild boar
Mean price of meat (slaughter weight)	**30** SEK/kg
Mean annual bag (2000-2009)	**192** wild boar

Software

All data management in this study, such as sorting and calculations, was carried out in Microsoft Excel 2010. For distances and maps ArcMap 9.3 was used and the statistical analysis was done in PASW Statistics 18.

Results

The total length of the 225 transects was 73.4 km, with a mean length of 278 m. During the survey a total of 1034 patches of damage were measured and positioned (Tab. 5). The proportion of damaged crops within the patches of damage varied between crop types. Patches of damage was in general more severe within wheat fields i.e. most of these patches were classified as category 4 (76 – 99 %) or 5 (100 %), whereas such levels were less common in fields of oats where the lower categories 2 (24 – 50 %) and 3 (51 – 75 %) were more common (Fig. 3). Patches of damage with level 1 (1 – 25 %) where rare in all crop types (Fig. 3). The mean area size of patches was considerably larger than the median (Tab. 5). The affected area did not vary considerably between the different crop types, but was slightly larger for wheat followed by oats (Tab. 5).

Damage to game fields was more severe and uniform (Fig. 3). The game field with oats was classified as having damage level 3 all over and 12 patches of level 5. One of the two game fields with wheat was entirely damaged, with a level 5 over the whole field, while the second wheat field was categorized as being half level 4 and half level 5. The game field sown with barley/oats/clover was not evenly damaged and 24 patches of different damage levels were defined within these fields.

Table 5. Each wild boar damage patch found during the survey of the three crop types within the study area on Mörkö during 2010, was measured for area and categorized according to the coverage of the damage. This damage level was used to estimate the affected area by multiplying the median of damage level with the damaged area of the patch.

Crop type	Affected area (m^2)	Affected area of field (%)	Damaged patch (mean area, m^2)	Damaged patch (median area m^2)	Total number of patches
Wheat	36922	2.8	73.9	15	697
Oats	8327	2.2	95.7	22	174
Barley	10929	1.8	53.1	12	163
Sum					**1034**

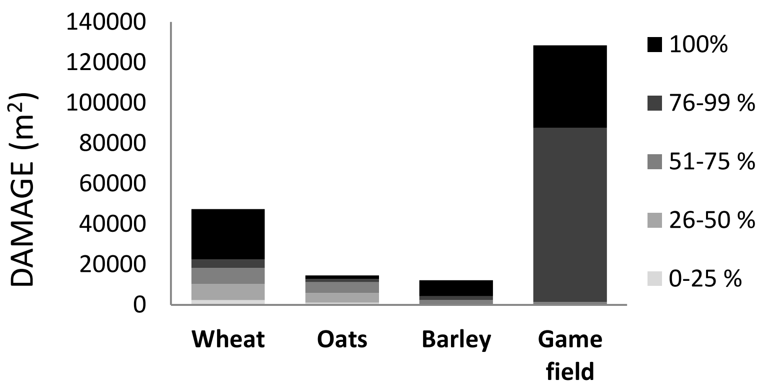


Figure 3. The total area of found and measured patches of wild boar damage in the surveyed fields of wheat, oats, barley and game fields within the study area in 2010. Each patch was estimated and categorized in one out of five damage classes, from 0-25 % (light gray) to 100 % (black) losses of expected harvest.

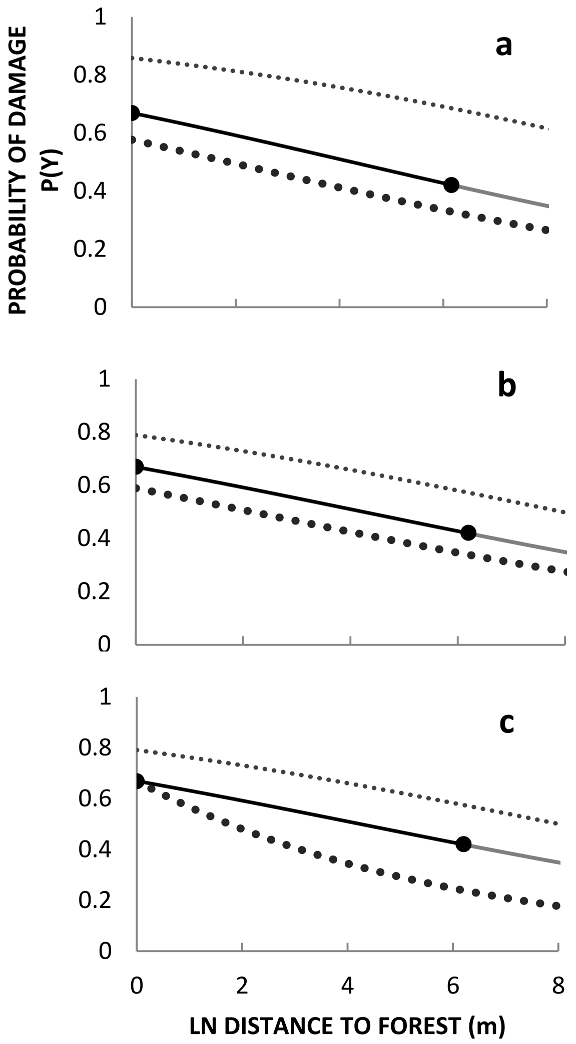
Binary logistic regression analysis

The backward process for logistic regression excluded two variables from the model, namely; distance to house and distance to game field. The final model thus consisted of four variables, the logarithmic distances to; forest edge (x_b); bait station (x_c); road (x_d) and ditch (x_e) (Equ. 1, Tab. 6). The model was significant ($p < 0.001$, Negelkerke $r^2 = 0.044$). Wald's test gave the highest values for distance to forest (Wald = 15.62; $p < 0.001$) and bait station (Wald = 26.86; $p < 0.001$) indicating that these two are the strongest predictors within the model (Tab. 6).

Table 6. The risk of wild boar damage for patches at different distances from six different landscape variables was tested in a binary logistic regression analysis. The final logistic model was two tailed ** significant and included distance to forest, bait station, road and ditch, according to Wald's test.

Model variables	Model	Forest	Bait station	Road	Ditch
Chi-square	68.95	-	-	-	-
r^2 (NK)	0.04	-	-	-	-
log likelihood	2797.91	-	-	-	-
Constant	5.63	-	-	-	-
P	< 0.001	< 0.001	< 0.001	< 0.001	0.002
Wald	-	15.62	26.86	14.57	9.60
B	-	- 0.17	- 0.47	- 0.18	- 0.12

Therefore, I chose to visualize the risk of wild boar damage depending on the distance to forest edge (Fig. 4 a-c) and bait station (Fig. 5 a-c). The probability of damage increases with proximity to both forest edge and bait station (Fig. 4a-c; Fig. 5a-c). Furthermore, at a given distance to forest edge the risk of damage increases with decreasing distance to the other explanatory variables, i.e. bait station (Fig. 4a), road (Fig. 4b) and ditch (Fig. 4c). The same pattern appear for a given distance to the bait station, as the probability of damage increases with proximity to forest (Fig. 5a), road (Fig. 5b) and ditch (Fig. 5c).



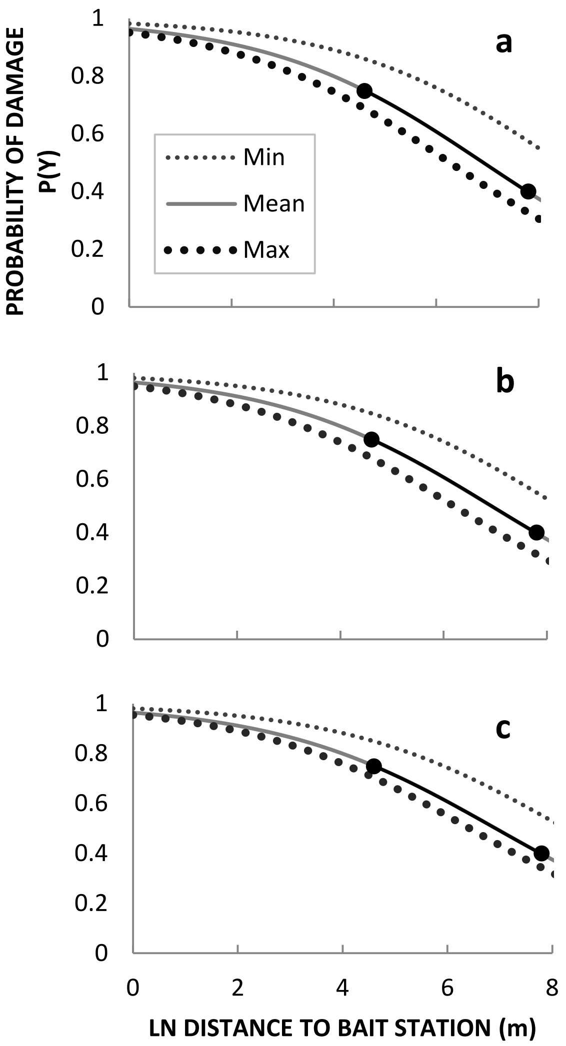


Figure 4 a-c. The relative risk of wild boar damage on crop fields in relation to the logarithmic distance to forest. The value for the explanatory variables are set as the mean value (found in the study) but is changed for one variable at a time (bait station (a), road (b) ditch (c), according to the min, max and mean value). The data range for distance to bait station is 0-490 m, indicated on the log scale (●—●).

Figure 5 a-c. The relative risk of wild boar damage on crop fields in relation to the logarithmic distance to bait station. The value for the explanatory variables are set as the mean value (found in the study) but is changed for one variable at a time (forest (a), road (b) ditch (c), according to the min, max and mean value). The data range for distance to bait station is 37-876 m, indicated on the log scale (●—●).

Risk of damage in relation to specific landscape features

According to the logistic model, the distances to forest edge and bait stations were the strongest predictors of damage occurrence (Tab. 6). Therefore, mean distance to forest edge and bait stations were compared for patches of damage and random patches. The distance to patches of damage (mean distance; 101 m ± 81 S.D.) were found to be significantly ($t = -5.72$; $p = < 0.001$; $df = 2066$) closer to the forest than the randomized patches (mean distance; 124 m ± 102 S.D.; Fig. 6). A similar pattern was found for bait stations i.e. patches of damage (mean distance: 1070 m ± 391 S.D.) were significantly closer ($t = -7.73$; $p = <0.001$; $df = 2066$, Fig. 7) to bait station compared to random patches (mean distance; 1218 m ± 473 S.D.).

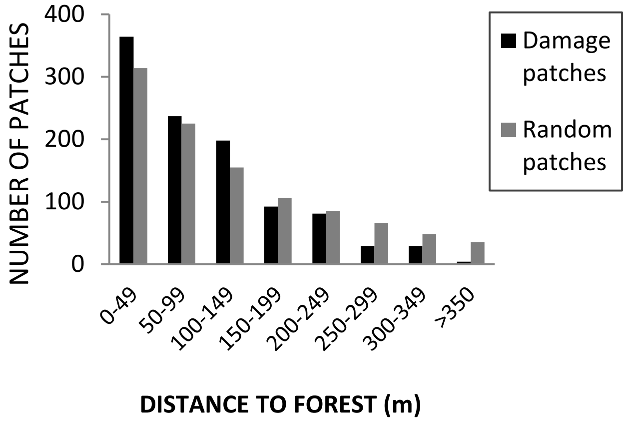


Figure 6. The number of patches (both damaged by wild boar and randomly distributed) found at different distance to forest. Damaged patches were found in the survey of crop fields in the study area and randomized patches were distributed within surveyed crop fields by using ArcMap (GIS-tool).

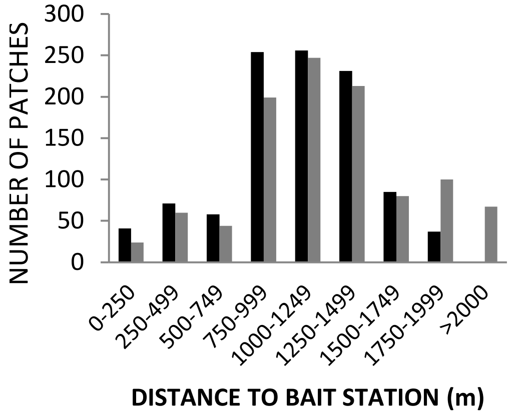


Figure 7. The number of patches (both damaged by wild boar and randomly distributed) found at different distance to bait station. Damaged patches were found in the survey of crop fields in the study area and randomized patches were distributed within surveyed crop fields by using ArcMap (GIS-tool).

The surveyed patches were more severely damaged closer to the forest edge (Fig. 8) and at distances between 750 and 1500 m from bait stations (Fig. 9).

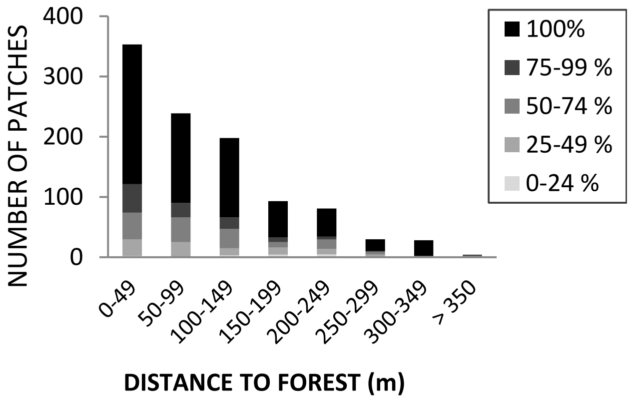


Figure 8. All surveyed patches of wild boar damage were estimated and categorized in one out of five damage classes, from 0-25 % (light gray) to 100 % (black) losses of expected harvest. The damage level varied in relation to proximity to the forest edge.

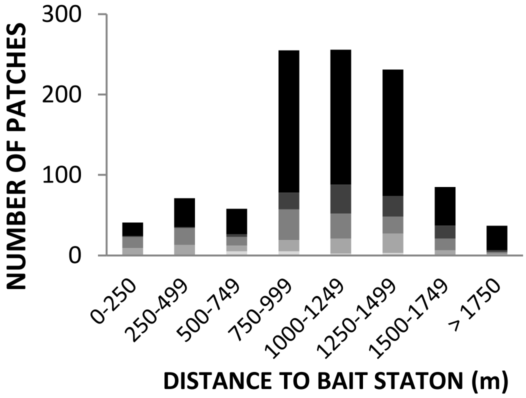


Figure 9. All surveyed patches of wild boar damage were estimated and categorized in one out of five damage classes, from 0-25 % (light gray) to 100 % (black) losses of expected harvest. The level of damage did not vary in relation to proximity to bait station.

Cost of wild boar damage

The cost of wild boar damage in crop fields in 2010 was calculated for the total area of cultivated crops and was based on the sample from the surveyed fields (Tab. 7). Harvest loss for the surveyed fields was 33 069 kg which corresponds to an income loss of 49 439 SEK for the three crop types combined (Tab. 7).

Table 7. The harvest loss and cost of damage caused by wild boar in the study area on Mörkö during 2010 as estimated for the three crops on the surveyed fields (Wheat, Oats and Barley). The surveyed wheat fields comprised 42 % of the total area of cultivated wheat at Hörningholms manor during 2010. Thus, the percentage of harvest loss in wheat found in this study (2.8 %) was used to estimate the total harvest loss for all wheat fields in the whole study area i.e. including fields not covered by the survey (Wheat*).

Units of loss	Wheat*	Wheat	Oats	Barley
Harvest loss (kg)	69 801	24 151	4 422	4 496
Income loss (SEK)	107 493	37 192	5 705	6 542

However, all fields were not covered by the survey. By assuming the same level of damage (2.8 %) for the 245 ha of wheat (not covered by my survey) 45 650kg corresponding to 70 301 SEK should have been added to the harvest loss. This means that for the income loss for fields with wheat, oats and barley the total income loss for Hörningsholms manor during 2010 was 119 740 kr.

The cost of damage per cultivated hectare was three times higher for wheat than for barley (Fig. 10), whereas the cost of damage per damaged area was more similar between crop types although it was still highest for wheat (Fig. 11).

Figure 10. An index of the income loss due to wild boar damage in crop fields per hectare cultivated crop in my study area on Mörkö during 2010, based on the damage costs for 100 % of the cultivated wheat, oats and barley this year.

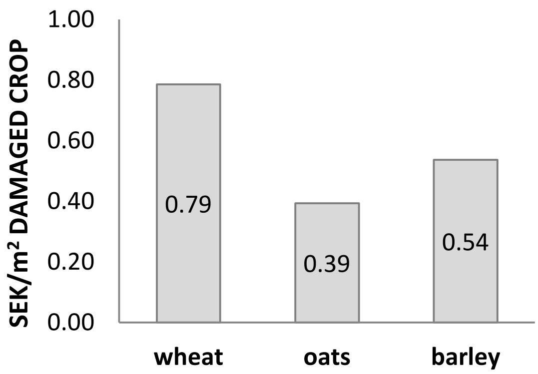


Figure 11. An index of the income loss due to wild boar damage in crop fields per square meter damaged area found in the surveyed fields in the study area on Mörkö during 2010. A damaged patch of wheat cost most and oat the least.

Income from wild boar meat

By applying the mean slaughter weight from the 2009/2010 hunting season to the mean annual bag of wild boar, between the years 2000 and 2009, I get a total of 3321.6 kg of wild boar meat per year gained from hunting. By assuming the price of 30 SEK per kg this corresponds to 99 600 SEK.

Discussion

This study showed that features in the landscape influence the distribution of wild boar damage in agricultural fields, where shorter distance to forest and bait stations increased damage frequencies most strongly among the tested variables. I also showed that damage have significant consequences for the profitability of agriculture. During the growing season of 2010, the harvest loss was 2.8 % for wheat, 2.2 % for oats and 1.8 % for barley in my study area. This was equivalent to a harvest loss of 78 720 kg and a total income loss of 119 740 SEK.

The risk of damage is affected by several factors i.e. distance to shelter, disturbance and forage. My results showed that proximity to forest, ditch, road and bait station increased the risk for wild boar damage. Proximity to a forest edge has earlier been described to have this effect before both in Sweden (Thurfjell et al. 2009), France (Calenge et al. 2004), Great Britain (Wilson 2004) and Japan (Honda 2009). This is probably due to the wild boars requirement of shelter and protection, and that is probably also why I found a similar effect from ditches, as these seem to act as corridors and therefore reduce the exposure in open fields that has been described earlier (Thurfjell et al. 2009).

According to my results concerning risk of damage in relation to forest edge, the cultivation of sensitive and costly crops should be placed as far away from the forest edge as possible. This may be hard to adopt in a mosaic landscape and the recommendation, besides acknowledging the distance to forest, is therefore to, as far as possible, use fields with short edge towards the forest for these crops. It is possible that fields of high risks are characterized by being long and narrow and surrounded by forest, on the other hand are those fields perfect in the role of game fields. The advantages of reducing the edge towards forest showed clearly through field observations, as the only fields that had been left entirely undamaged were two barley fields with no border towards the forest.

The distance to bait station significantly affected the risk of damage in the crop fields. This result is supported by similar evidence from studies on moose management (van Beest et al. 2010), but is contradictive to results from wild boar damage in wine yards (Calenge et al 2004). My study showed that an increased distance to bait station reduced the risk of wild boar damage combined in a logistic model with the three other landscape features (forest, ditch and road).

Game fields are established, like bait stations for supplemental feeding, to benefit and divert game from sensitive areas (Jensen 2001). The game fields in my study area certainly attracted wild boar as three out of four fields were almost totally damaged, but in the logistic regression they did not have neither positive nor negative significant effect on the distribution of damage in the crop fields (excluded from the model). This may have been due to the small number of game fields.

Supplemental feeding at a bait station has low effect for reducing crop damage (Geisser & Reyer 2004). Geisser and Reyer (2004) therefore questioned supplemental feeding as a preventive action as it in the long run may lead to higher densities in the population than would be possible under natural conditions (Geisser & Reyer 2005). In my study, I show that the risk of damaged fields increased close to the bait stations, but could not conclude anything about the total effect on the wild boar affected area. To reveal such potential patterns, a comparative study between areas with and without bait stations is needed.

I expected roads and buildings to have negative effect on the damage distribution because of the disturbance from human activities (Thurfjell 2009; Baskin & Danell 2003). However, the distance to building had no significant effect and proximity to roads actually increased the risk of damage. This pattern, may be explained by low traffic load in combination with the fact that roads may be placed in edge zones that also may act as shelter. Corresponding patterns have been shown for vehicles and noises that seemed to have little effect on the distribution of other ungulates (Stankowich 2008). Furthermore, buildings did not have a disturbing effect; a result that may have been affected by the fact that inhabited houses could not be separated from low activity summer cottages in the maps used. Moreover, since I present the results from the logistic function beyond the data range, precaution with interpretations should be taken in that range of data.

For the logistic regression I used randomized patches to compare with surveyed patches in relation to different landscape features. This method does not fully follow the adoption of binary logistic regression analysis because I have not controlled the randomized patches to be undamaged, which may have influenced the results but they should however be conservative. Therefore, it may still be concluded that the different variables affected the risk of damage, but one should not make exact interpretations regarding risks at different distances.

Levels of harvest loss were found to be quite uniform across the crop types, and not as high as expected (Mackin 1970). However there was a slight difference in the utilization and proportion of damaged area between wheat and barley. The wheat fields were in general more severely damaged, whilst two fields of barley were un-damaged. Such a preference is supported by several studies (Herrero et al. 2006; Mackin 1970; Schley & Roper 2003). This avoidance of barley may be due to the long coarse hairs of the spiklets (Mossberg & Stenberg 2003) which are quite unpleasant when eating and walking through (Schley et al. 2008).

It has been considered difficult to determine the extent of wild boar damage in crop fields (Thurfjell et al. 2009), and apart from a study in Poland (Mackin 1970) few reports are to be found in the literature. In my study some underestimation may have occurred when it comes to damage in oat fields, as the structure of oat straws make these fields hard to overview. Furthermore, patches of damage smaller than 1 m^2 were not included, which meant that all wild boar paths were excluded, and this may also have led to underestimation. The method I used here is a rough measure of harvest loss and would be possible to refine with more detailed measurements. The choice of method is obviously a trade of between being able to cover large areas with a crude estimation, or a more precise measure on small areas. Since my method is rather time-consuming and large areas may be affected by wild boar, I recommend that other methods should be tested in the future. For example, aerial photography could be used to find large patches of damage, and with a few field controls to exclude wind or other damage factors. Moreover, a way to increase the precision of the method would be to also include damage due to trampling, i.e. to also include the wild boar walking paths.

Few studies have focused on harvest or economic loss due to wild boar damage. However, as mentioned before, different kinds of governmental compensation occur in many European countries, but there are no descriptions of the methods used to estimate harvest loss and compensation rates (Calenge et al. 2004; Geisser & Reyer 2004; Mazzoini Della Stella et al. 1995; Mackin 1970; Schley et al. 2008). The generality of this study is slightly restricted due to the certain conditions on Mörkö from a Swedish perspective. At Mörkö, a single landowner owns a large area (98% of the island) and combines forestry, agriculture, hunting and game tourism within the economic activity. A professional hunter manages the wildlife populations and a high wild boar density is allowed, which also demands time consuming efforts for preventive actions such as hunts in order to protect crops during the most sensitive stages (Mackin 1970; Lemel 1999; Schley et al. 2008). Therefore, some cautions should be used when applying the calculations of economic figures to other areas. However, the figures in my study still give a rough picture of the costs of wild boar damage and are strengthened by similar findings in other studies (Anonymous 2010b). Here indicating my results of income loss per hectare cultivated crop. As these were comparable to the figures presented in a study for the county of Södermanland (which includes Mörkö), where a cost of 279 SEK per cultivated hectare was calculated for areas with wild boar damage (Anonymous 2010b), compared to my figures of 253 SEK per hectar cultivated wheat, 66 SEK/ha barley and 133 SEK/ha for cultivating oats. However, one should be aware of some differences between the studies, e.g. I just included crop damage in wheat, oat and barley fields and used a study area with a high density of wild boar.

However, a dense wild boar population does not only result in costs, but also incomes e.g. by hunting (meat and hunting fees; Anonymous 2010b). For example, from an annual bag of 192 animals (as in my study area), the income of meat would be approximately 100 000 SEK (520 SEK per shoot wild boar). This amount covers about 80% of the cost of damage (623 SEK per shot wild boar). The amounts differ substantially, meaning that additional income is needed to compensate for the economic loss. In my calculations, however, not all incomes from wild boar were included (e.g. figures on hunting fees, trophy fees, wild boar safaris etc.). On the other hand, not all costs are included either (e.g. cost of establishment of damaged crop, damage to other crop types, hunting efforts for crop protection, cost for diversionary feeding etc.). According to a report from the Swedish board of agriculture, only 25 % of the asked landowners suffered from wild boar damage compared to 80 % of agricultural leaseholders (Anonymous 2010b). Therefore, because farming leaseholders seldom have access to additional income from wild boar meat etc., it is important that landowners and leaseholders communicate and collaborate. To be able to find an agreement that is satisfactory for both parties, and take special consideration to the economic loss caused by wild boar damage to leaseholders' crops (Anonymous 2010a).

My correlation matrix showed all variables in this mosaic structured landscape to be more or less related to each other. If the same study made in a larger-scale agricultural landscape, we would likely find even stronger effects in the distance analysis. Because the open areas of the fields would be larger and would therefore probably induce more avoidance from the wild boar. However I have here showed important patterns of wild boar behavior that should be considered in management. Because as the wild boar population in Sweden is increasing (Magnusson 2010); the economic problems are growing. This will most likely be followed by conflicts when the communication does not work appropriate between landowners and leaseholders (Anonymous 2010a). This conflict may be eased by being aware of the here presented potential economic damage in discussions, and by planning the crop distribution as well as the placement of bait stations etc. in relation to landscape features and composition.

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