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ORIGINAL PAPER

# Patterns of crop damage by wild boar (*Sus scrofa*) in Luxembourg over a 10-year period

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**Abstract** In many European countries, the wild boar (*Sus scrofa*) is often associated with crop damage. In this study, we analyse data relating to 13,276 cases of wild boar damage to agricultural crops over a 10-year period in Luxembourg (an area of 2,586 km$^2$ in Western Europe). Results show that (1) damage is more severe in this area than in others; (2) damage to permanent grassland is far more frequent and more severe than damage to annual crops; (3) trichomatous crops such as barley are avoided; (4) damage is seasonally distributed according to type of crop; (5) damage is distributed spatially in a non-uniform manner; (6) damage intensity is significantly correlated with wild boar hunting bags, both over time and space. We suggest that wild boar management strategy should always take into account the issue of damage to agricultural crops. Our results imply that measures for preventing or reducing damage should be more targeted in time and space and that adjustments to cropping patterns should contribute towards a reduction of wild boar damage.

**Keywords** Agriculture · Game species · Human–wildlife conflicts · Hunting records · Ungulates

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## Introduction

Conflicts between humans and wildlife have been reported from all over the world and include problems such as transmission of disease from wild populations to domestic animals (Spiecker 1969), attacks by wild predators on domestic animals (Oli et al. 1994) and humans (Tilson and Nyhus 1998), as well as damage to forests by game ungulates (Reimoser and Gossow 1996). One of the most common problems, however, is damage by wild animals to agricultural crops: Indeed, crop damage by mammals ranging in size from rodents to elephants has been described, affecting a wide range of crops and often leading to significant economic loss (e.g. Singleton and Petch 1994, Naughton-Treves 1998, Linkie et al. 2007).

In Europe, one species that has often come into conflict with humans is the wild boar (*Sus scrofa*). Wild boar have adapted well to agricultural changes in Europe: In many countries, their numbers have increased dramatically during the past three decades (e.g. Poland: Genov 1981; Scandinavia: Erkinaro et al. 1982; Spain: Tellería and Sáez-Royuela 1985; Germany: Feichtner 1998; France: Klein et al. 2007). Individuals can survive and thrive even in areas highly influenced by human activity (Geisser and Bürgin 1998). The wild boar is an omnivorous species whose diet consists primarily of plant and only secondarily of animal foods (see Schley and Roper 2003 for a review in Western Europe). Any locally appearing abundant food source is often exploited, and conflicts with humans have resulted from this behaviour (Gérard et al. 1991, Herre 1993). In Europe, these conflicts have arisen mainly because of interbreeding with domestic pigs (Anonymous 1998), transmission of diseases to domestic livestock, pets and humans (Anonymous 1998, Klein et al. 2007) and, most importantly, trampling and consumption of agricultural crops and rooting of grassland (Klein et al. 2007).

In Luxembourg, the wild boar is considered the most important game species on a national level, and hunting of wild boar is carried out year-round. The main hunting season, when battues are allowed, starts in mid-October and ends on the last day of February. During the remainder of the year, hunting of wild boar is only allowed from raised hides and by stalking. More details on wild boar hunting in Luxembourg can be found in Cellina (2008). Although there is a possibility for the government to organise hunts so as to reduce populations in problem areas, not a single such government hunt has ever been organised. As a consequence, all hunting is carried out by leisure hunters.

The leisure hunters also carry out other management of wild boar. In relation to agricultural damage, supplementary feeding of wild boar needs special mention. Indeed, in Luxembourg, it is sometimes claimed that supplementary feeding can help to reduce damage by keeping wild boar away from agricultural areas (Anonymous 2002). On the other hand, in the scientific literature, it seems generally accepted that crop damage is not avoided through supplementary feeding (Geisser 2000; Geisser and Reyer 2004; Sułkowski et al. 2004; Cellina 2008, but see also Baubet 2008). In Luxembourg, a recent study of 1,200 wild boar stomachs showed that the diet of the species contains 41% of supplementary food supplied year-round by leasure hunters: This is the highest percentage of supplementary food ever found throughout the species' range (Cellina 2008). Supplementary food consisted nearly exclusively of dried grain maize, which can easily be differentiated in the stomach contents from fresh maize originating from fields (Cellina 2008). Interestingly, several populations across Europe began their significant increase in the 1970s (e.g. Austria and Germany: Arnold 2005; France: Klein et al. 2007; Luxembourg: this paper), roughly at the time when, according to Vassant (1997), the practice of supplementary feeding started to be more broadly used in traditional wild boar areas after the appearance of maize as a widely grown crop.

To improve strategies for agricultural damage prevention, it is important to better understand the mechanisms that determine damage caused by wild boar. In this study, we examine 13,276 cases of agricultural damage by wild boar to permanent grassland and annual crops in Luxembourg to investigate (1) the nature and severity of crop damage; (2) seasonal, temporal and spatial variation in the damage; (3) whether crops are damaged according to their availability; and (4) which factors determine damage distribution. Finally, on the basis of our results and of a thorough literature search, we aim to give recommendations for the management of the wild boar with a view of reducing or preventing damage to agricultural crops.

## Materials and methods

### Study area

The study was carried out over the entire territory of Luxembourg, which is located between 49°26′ and 50°10′ Northern latitude and between 5°44′ and 6°31′ Eastern longitude, with a total surface area of 2,586 km$^2$. The country borders Belgium to the West and North (border length, 148 km), France to the South (73 km) and Germany to the East (135 km).

Luxembourg is made up of two clearly differentiated geological regions. The Northern area or Oesling (828 km$^2$) forms part of the Ardennes hills and is largely made up of uneven schistose and schistose-sandy terrains from the Lower Devonian. Mean altitude is around 450 m above sea level. The Southern part or Gutland (1,758 km$^2$) consists primarily of calcareous marl and sandstone terrains from the Triassic and the Jurassic and, in the southwest, of a narrow band of Dogger iron ore. The Gutland landscape is less hilly than the Oesling; mean altitude is around 250 m above sea level (Melchior et al. 1987). Annual rainfall varied between 700 and 1,000 mm, and mean annual temperatures were between 7.0°C and 9.5°C (EFOR 2002).

About one third of the country is covered with forest (886 km$^2$). On the acidic and nutrient-poor soils of the Oesling, only about 15% of the traditionally widespread beech (*Fagus sylvatica*) forests persist: The remainder have been replaced predominantly by oak (*Quercus* sp.) coppice and by spruce (*Picea abies*) and Douglas fir (*Pseudotsuga menziesii*) plantations. On southern slopes, high oak stands are sometimes present. In the Gutland, which is dryer and warmer, only land unsuitable for farming is still covered with forest, the predominant type of which is high beech stand with sparse undergrowth (Melchior et al. 1987; EFOR 2002).

About half of Luxembourg (1,278 km$^2$) is used for agriculture which is generally mixed and heterogeneous throughout the country. About half of the agricultural land is used as grassland (pasture and meadows) and half as arable land; a detailed list of land use types can be found in Harperath and Schmitz (2005).

Data collection and analysis

In Luxembourg, farmers who discovered damage by wild boar (or other game species) in their fields were obliged by law to declare the damage immediately (Gouvernement du Grand-Duché de Luxembourg 1925). Verification of all damage in the field with regard to the culprit species and the surface area damaged was carried out by government officials from the Administration des Eaux et Forêts. More details can be found in Krier (2005).

During the study period, damage by wild boar to agricultural fields was financially compensated—for surface area damaged—in accordance with specific national legislation to this effect (see Schley 2000; Krier 2005). Therefore, detailed records of all officially declared cases of damage since 1997 were available for analysis. We analysed 13,276 cases of crop damage by wild boar for which compensation was paid out over a period of 10 years, between January 1997 and December 2006. For each case, we extracted the following information: (1) the amount of compensation paid for the damage, (2) the surface area of the damage, (3) the type of crop damaged, (4) the timing of the damage and (5) the geographic location of the damage within Luxembourg.

For analysis of seasonality, we used the date of discovery, but in a few cases, this information was missing. In those rare cases, we used the date of declaration of the damage, which was generally at most a few days after the date of discovery. We considered damage to have occurred during the previous month in cases when it was discovered on the first day of a month. We only analysed seasonality for the three most important types of damage (grassland, maize, other cereals), pooling all types of cereals other than maize to allow for a large enough sample size for this category. We looked for seasonal differences using $\chi^2$ goodness-of-fit tests.

To investigate the extent to which wild boar population density influences the severity of damage, we used official hunting records from the Administration des Eaux et Forêts as a reflection of wild boar density. It has been suggested that data from hunting records are a useful tool with which to evaluate trends in game populations (Gérard et al. 1991). Because hunting conditions and pressure have not changed over the study period—if anything, number of hunters has slightly decreased since the 1970s (Schley et al. 1998)—and because the data were collected with great precision and cover the whole country, they should accurately reflect trends in wild boar population size. For spatial analysis, we used the number of wild boar shot per square kilometre per year over the period 1997–2005 in each of 118 communes (mean surface area, 22 km$^2$).

We looked for geographic differences at the level of communes using a $\chi^2$ goodness-of-fit test. We then went on to investigate the impact of seven potential predictors on the spatial pattern of three variables: total damage, grassland damage and arable damage. The data of the three variables were log-transformed to improve normality (Zar 1999). The seven predictors examined were wild boar hunting bags (expressed as wild boar shot per square kilometre per year; source: Administration des Eaux et Forêts, unpublished data), human population density (expressed as persons per square kilometre; source: Anonymous 2006), forest, grassland and arable cover (expressed as proportion, arcsine transformed for the analysis; source: Administration des Eaux et Forêts and Service d'Economie Rurale, unpublished data), forest fragmentation (expressed as kilometre of forest edge per square kilometre of forest; source: Administration des Eaux et Forêts, unpublished data) and road density (expressed as kilometre road per square kilometre; source: Administration des Ponts et Chaussées, unpublished data) for each of the 118 communes.

We first tested for correlation between predictors using Pearson product moment correlation. Significance levels were determined using the Bonferroni correction for multiple testing. Given the multiple significant correlations between predictors (see "Results"), we carried out a principal components analysis (PCA) to show main relationships. To control multi-colinearity as well as possible, we used redundancy analysis (RDA) to measure relationships between the three damage variables and the seven predictors (see above). As a part of multi-colinearity can be induced by spatial autocorrelation, we also used partial RDA with, as a covariable dataset, the $X$–$Y$ coordinates and their products ($X^2$, $Y^2$, $X \cdot Y$). This partial analysis allows to visualise changes in relationships between damage and environmental predictors when most part of spatial autocorrelation is eliminated. RDA also allows to calculate the proportions of variation of the damage data set that are explained by (1) the set of environmental predictors, (2) spatial autocorrelation process only and (c) both (Borcard et al. 1992). Some regression analyses were also applied to different models, and the choice among them was made using Akaike's information criterion (AIC).

For the analysis of temporal variation, we compared the total number of wild boar shot per year with the total amount of compensation payments per year during the period 1971–2004.

To investigate whether damage to agricultural crops occurred in proportion to availability of crops in the field, we used land use statistics produced annually by the Service central de la statistique et des études économiques (STATEC; 1997–2004: Harperath and Schmitz 2005; 2005: STATEC, unpublished data). For each type of crop, we used the mean surface area per year for the period 1997–2005. Year to year changes, both in overall surface of agricultural land and in terms of agricultural activity, were minimal, and thus, it was considered that they would not influence our results (see Harperath and Schmitz 2005; STATEC, unpublished data). We compared the overall availability of crops with the proportion of surface area damaged for the main annual crops (maize, wheat, barley, oats, rye, triticale and potatoes) using a $\chi^2$ goodness-of-fit test.

We carried out all statistical tests using MINITAB® version 14 (Minitab Inc. 2004), except for PCA and RDA which were conducted with CANOCO version 4.0 for Windows (ter Braak and Smilauer 1998), and regression analyses and AIC, which were carried out using SAS Enterprise version 2.0.

## Results

### Severity of damage

We analysed a total of 13,276 cases of wild boar damage. Compensation payments amounted to around 5.27 million EUR for about 3,900 ha of damage over a 10-year period between January 1997 and December 2006. On average, 396 EUR were paid for individual claims. Mean surface area damaged was 0.297 ha. Annually, around 394 ha were damaged, which corresponds to about 0.31% of the total surface area used for agriculture in Luxembourg.

Most claims (91.1%) involved damage worth less than 1,000 EUR. The highest single claim amounted to 11,500 EUR and involved damage to grassland. Most cases involved areas of less than 0.25 ha.

### Types of crops damaged

Damage to grassland occurs when the sward is destroyed by rooting activities of wild boar while searching for food. Damage to annual crops is made through consumption of the fruit as well as through trampling.

Damage to grassland accounted for 50.1% of damage cases and for 57.8% of the total financial compensation volume over the 10-year period, followed by maize (30.1% of cases, 29.5% of the damage) and wheat (11.7% of cases, 6.5% of the damage; Table 1). The highest mean amount per case was paid for damage to grassland (458 EUR), followed by rape (457 EUR), potatoes (451 EUR) and maize (387 EUR; Table 1).

### Damage versus availability of crops

The proportion of observed damage for various cereals and potatoes differed from the proportion of their respective availability ($\chi^2_6$=4,435, $P$<0.001; Fig. 1). Maize was damaged more than expected, whereas barley was negatively selected. Wheat, oats, rye and potatoes were consumed slightly less than would have been expected according to their availability.

### Seasonal variation

In some cases, it may be impossible to detect the damage immediately after it is made: This applies mainly to maize fields because the height of the plants may prevent seeing the damaged surface from the outside of the field. This means that results of seasonality analysis have to be treated with relative caution.

Maize and other cereals were especially damaged during their respective sowing periods and as soon as the fruit is in milk (Fig. 2). Cereal harvest is usually finished in summer, which explains why damage stopped in summer. Maize, on the other hand, was damaged especially in September and October before harvest. Damage to grassland almost exclusively occurred during winter. There were seasonal

**Table 1** Number of cases, surface area (ha) and compensation payments (EUR) for each type of crop damage by wild boar in Luxembourg (1997–2006)

| Crop type | Cases | % Cases | Range (ha) | Mean area (ha) | Damage (€) | % Damage (€) | Range (€) | Mean amount (€) |
|---|---|---|---|---|---|---|---|---|
| Grassland | 6,652 | 50.1 | 0.002–10.17 | 0.294 | 3,046,361 | 57.8 | 5–11,516 | 458 |
| Maize | 4,013 | 30.2 | 0.001–7.20 | 0.309 | 1,553,173 | 29.5 | 5–5,600 | 387 |
| Barley | 158 | 1.2 | 0.015–8.80 | 0.391 | 40,412 | 0.8 | 8–4,424 | 256 |
| Oats | 184 | 1.4 | 0.01–3.60 | 0.262 | 28,143 | 0.5 | 6–2,142 | 153 |
| Rye | 41 | 0.3 | 0.04–7.00 | 0.484 | 8,626 | 0.2 | 31–786 | 210 |
| Triticale | 230 | 1.7 | 0.01–4.20 | 0.317 | 52,125 | 1.0 | 6–3,079 | 227 |
| Wheat | 1,548 | 11.7 | 0.003–6.70 | 0.252 | 342,212 | 6.5 | 7–3,553 | 221 |
| Peas | 17 | 0.1 | 0.05–1.60 | 0.426 | 3,438 | 0.1 | 19–720 | 202 |
| Potatoes | 160 | 1.2 | 0.005–1.30 | 0.114 | 72,196 | 1.4 | 19–5,589 | 451 |
| Rape | 103 | 0.8 | 0.02–6.50 | 0.583 | 47,048 | 0.9 | 17–6,162 | 457 |
| Other crops | 170 | 1.3 | 0.01–4.52 | 0.385 | 74,146 | 1.4 | 8–9,326 | 436 |

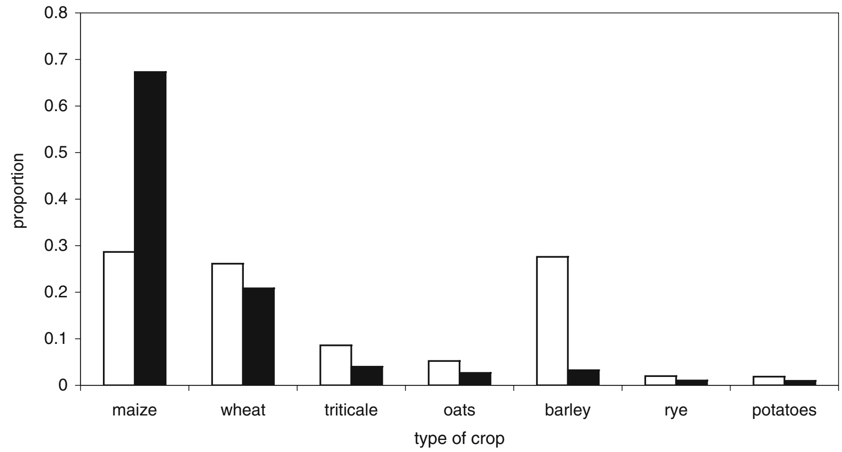


**Fig. 1** Proportion of wild boar damage (EUR; *black bars*) versus availability of the main annual crops (*white bars*) in Luxembourg (1997–2006)

differences for grassland ($\chi^2_{11}$=35,654, $P$<0.001), maize ($\chi^2_{11}$=10,458, $P$<0.001) and cereal ($\chi^2_{11}$=4,656, $P$< 0.001) damage.

## Temporal variation

Although detailed information regarding wild boar damage (in terms of financial volume) was only available from 1997 onwards, values of total yearly compensation payments since 1971 could be used for analysis. In Luxembourg, crop damage by wild boar increased by 1,600% between 1971 and 2004 (linear model: $r^2$=0.756, $F_{1,32}$= 99.04, $P$<0.001; Fig. 3). During that time, the number of wild boar shot per year increased by 800% (linear model: $r^2$=0.840, $F_{1,32}$=167.76, $P$<0.001). The total number of wild boar shot per year correlated with the total amount of compensation payments made per year over the period 1971–2004 (Pearson: $r$=0.848, $n$=34, $P$<0.001).

## Spatial variation

Damage was non-uniformly distributed across Luxembourg (0–1,500 € per km$^2$ per year; $\chi^2_{117}$=9,566, $P$<0.001; Fig. 4). Four communes had very high levels of damage: Colmar–Berg (1,498 € per km$^2$ per year), Fischbach (1,464), Beaufort (1,324) and Reisdorf (1,145); the next highest was Vichten with 657 € per km$^2$ per year. The top 22 communes affected in terms of damage (expressed as € per km$^2$ per year) made up 18.3% of the country in terms of surface area, but consumed 50% of the total damage compensation (three highest categories on Fig. 4). Indeed, damage compensation in these 22 communes amounted to 548 € per km$^2$ per year, whereas in the remaining 96 communes, it amounted to 126 € per km$^2$ per year.

Pearson tests showed high levels of correlation between the seven predictors: There were many significant correlations between pairs of predictors, partly with high $r$ values (Table 2). To visualise relationships among predictors, a PCA was carried out, which resulted in two components being retained, representing 35% and 28% of the variability of the initial predictors. These two proportions are already atypical for very strong multi-colinearity among predictors. The most important component, PC1, showed that damage increased markedly with proportion of forest cover and number of wild boar shot (reflecting high populations) and decreased with high proportions of agricultural land and/or

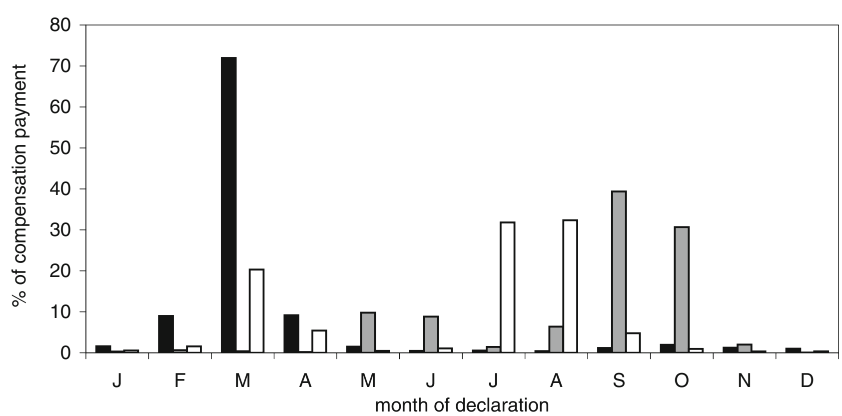


**Fig. 2** Seasonal distribution of wild boar damage (EUR) to grassland (*black bars*), maize (*grey bars*) and other cereals (*white bars*) in Luxembourg (1997–2006)

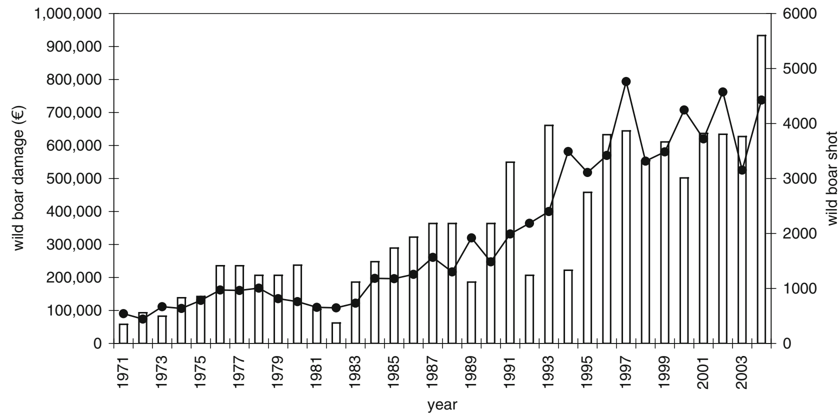


**Fig. 3** Wild boar damage (EUR; *white bars*) and hunting records (*black line*) in Luxembourg (1971–2004)

high forest fragmentation (Fig. 5). The second component retained, PC2, showed that high human influence (represented by human population density and road fragmentation) lead to a reduction in wild boar damage, whereas forest cover and number of wild boar shot again turned out to increase damage.

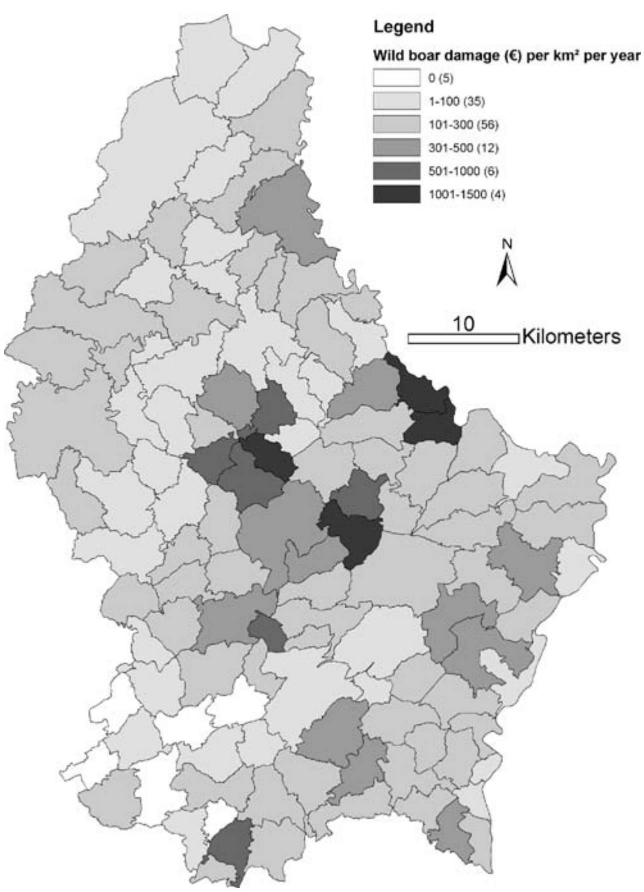


**Fig. 4** Spatial distribution of wild boar damage in Luxembourg (1997–2006). *Numbers in brackets* denote the number of communes in the respective categories

RDA between the three damage variables and the seven predictors shows clearly that now damage is positively correlated with the proportion of forest cover and number of wild boar shot and negatively correlated with forest fragmentation (Fig. 6a). Variance partitioning of the three damage variables indicates that 24.4% is explained exclusively by the seven predictors, 7.9% by only geographic coordinates ($X$, $Y$, $X^2$, $Y^2$, $X{\cdot}Y$), and 11.2% is explained by predictors and geographic coordinates combined. The low influence of spatial autocorrelation on the explanation of damage is confirmed by the comparison of RDA plots with (Fig. 6a) and without geographic coordinates (Fig. 6b). It shows only very small differences in the significance of predictor influence. CANOCO allows testing the significance of the relationship between damage and predictors without spatial autocorrelation effect. In our case, the test is highly significant ($F$=40.77, $P$<0.0001).

Univariate regression analyses of all combinations of one to three predictors have been done, and we retained the model with the lowest AIC value for total, grassland and arable damage, respectively (lower AIC values indicate a better fit of the data to the model; see Burnham and Anderson 1998). Overall analysis of variance for the best AIC model gave significant results for the distribution of total (retained model: wild boar density, forest cover, grassland cover; $F_{3,114}$=20.08; $P$<0.0001), grassland (retained model: wild boar density, forest cover, grassland cover; $F_{3,114}$=21.3, $P$<0.0001) and arable (retained model: wild boar density, arable cover, forest fragmentation: $F_{3,114}$=14.84, $P$<0.001) damage, and $r^2$ values indicated that about a third of the variance in damage distribution was explained (total damage: $r^2$=0.346; grassland: $r^2$=0.360; arable: $r^2$=0.281).

From 1997 to 2006, 3,903 (SE=181) wild boar were shot per year (range, 3,153–4,764), corresponding to 4.4 animals shot per 100 ha of forest. On a spatial scale, compensation payments paid per square kilometre per year correlated highly with the number of wild boar shot per square kilometre per year (Pearson: $r$=0.478, $n$=118, $P$< 0.001).

**Table 2** Results of Pearson correlation tests

| | *Sus* | hum | for | gra | ara | fof |
|---|---|---|---|---|---|---|
| hum | $r$=−0.131 ns | | | | | |
| for | $r$=0.317 | $r$=−0.268 ns | | | | |
| gra | $r$=−0.268 ns | $r$=**−0.336** | $r$=**−0.563** | | | |
| ara | $r$=−0.166 ns | $r$=**−0.527** | $r$=−0.214 ns | $r$=**0.347** | | |
| fof | $r$=**−0.301** | $r$=0.166 ns | $r$=**−0.574** | $r$=0.223 ns | $r$=**0.322** | |
| rof | $r$=−0.059 ns | $r$=**0.432** | $r$=−0.100 ns | $r$=**−0.347** | $r$=**−0.445** | $r$=0.028 ns |

Significance threshold after Bonferroni correction, 0.05/21=0.0024. Bold type indicates significance

*Sus* wild boar hunting bags, *hum* human population density, *for* forest cover, *gra* grassland cover, *ara* arable cover, *fof* forest fragmentation index, *rof* road fragmentation index

## Discussion

### Severity of damage

High dependence on plant material as a major component of their opportunistic diet, coupled with large body size and a propensity to trample crops as well as consume them, means that wild boar can cause significant damage to a variety of agricultural crops (Schley and Roper 2003). In addition, when rooting and digging for invertebrate prey and underground plant parts, wild boar make holes of up to 60 cm in depth and, in the process, cause substantial damage to grassland (Anonymous 1988; Schley and Roper 2003).

Our data suggest that in Luxembourg, damage seems to be more severe than in other parts of Europe. A mean value of 396 EUR per case is higher than in other studies. Linderoth and Elliger (2002) investigated 808 cases of wild

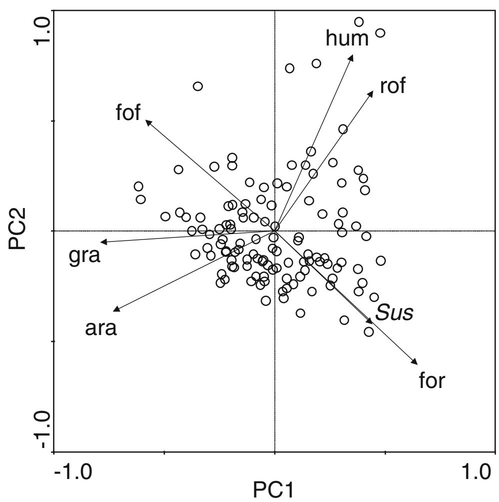


**Fig. 5** Plot of samples and of the seven predictors on the two first axes of PCA. *Sus* wild boar shot, *hum* human density, *gra* grassland cover, *ara* arable cover, *for* forest cover, *fof* forest fragmentation, *rof* road density (see "Data collection and analysis" for details)

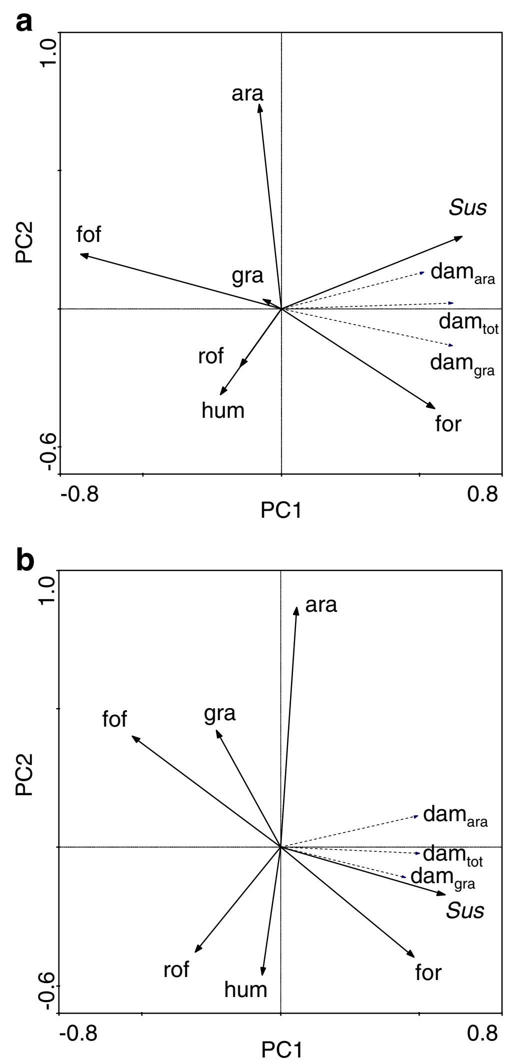


**Fig. 6** Plot of the two first axes of RDA showing the relationships between the three damage variables and the seven predictors (**a**) with spatial autocorrelation expressed by geographic coordinates ($X$, $Y$) and their combinations ($X^2$, $Y^2$, $X{\cdot}Y$) and (**b**) without spatial autocorrelation. *Sus* wild boar shot, *hum* human density, *gra* grassland cover, *ara* arable cover, *for* forest cover, *fof* forest fragmentation, *rof* road density (see "Data collection and analysis" for details), $dam_{tot}$ total damage, $dam_{gra}$ grassland damage, $dam_{ara}$ arable damage

boar damage in the German region of Baden-Württemberg and found a mean of 328 EUR per case, whereas Geisser (2000) reported an equivalent of about 145 EUR per case from Switzerland. Geisser (2000) also showed that in Switzerland, only 15% of cases related to damaged areas above 0.10 ha, whereas in Luxembourg, in 63% of cases, the damaged area was larger than 0.10 ha. In Luxembourg, the total agricultural land that was damaged amounted to 0.31% per year. The only other study giving such a value reported 0.14% from Italy (Macchi et al. 1992), less than half than that from Luxembourg.

Types of crops damaged

Overall, our results are in line with those from other countries (Łabudzki and Wlazełko 1991; Macchi et al. 1992; Geisser 2000; Linderoth and Elliger 2002). In France, damage to grassland (23%) was in second place with other cereals (23%), behind maize (43%; Klein et al. 2007). Wherever maize is grown, it is almost always the most damaged annual crop, followed by wheat and other cereals (e.g. Ballon and Bouldoire 1983; Macchi et al. 1992; Vassant 1997; Geisser 2000; but see also Wlazełko and Łabudzki 1992). Briedermann (1976) suggests that consumption of fresh maize as an important diet component is not even displaced by mast, usually considered the staple food of wild boar (Schley and Roper 2003).

Damage to grassland, however, is in some respect more problematic, as it is the only type of damage that is made to permanent crops. The reasons for high levels of grassland damage could be related to wild boar nutrition. W. Hartfiel (cited in Duderstaedt 1995) reports that damage to grassland is increased if wild boar are supplemented with grain maize because maize has low protein content and lacks essential amino acids. Similarly, Barrett (1978) suggests that consumption of carbohydrate-rich food leads to increases in damage to grassland because carbohydrate-rich food increases the need for animal protein (see also Baubet et al. 2004). It could be argued, however, that the natural staple food, namely oak and beech mast, are also rich in carbohydrates so that wild boar would still require animal protein. Therefore, feeding wild boar with grain maize should not have an impact on the levels of grassland damage. However, mast is always distributed over large areas, namely the areas covered with beech and oak forests, and is not available in massive quantities at point locations as is supplementary food. Although worms may be less frequent under forest than under grassland, we speculate that wild boar feeding on mast over large areas will, in the process, largely satiate their need for animal protein and will not require searching specifically for high densities of invertebrate prey in grassland. However, this idea requires further testing.

Damage versus availability of crops

Our data suggest that maize was clearly actively selected by wild boar, whereas barley was negatively selected (see also Briedermann 1976; Geisser 2000; Herrero et al. 2006). Again, this result is in line with most other studies. For example, all damaged fields in a small study area in Italy were wheat crop: Not a single barley field was damaged (Meriggi and Sacchi 1992). Herrero et al. (2006) reported that wild boar actively selected maize crops, consumed wheat according to availability and negatively selected barley. The dislike for barley and other trichomatous cereals could have important implications for management and damage prevention (see below).

The fact that maize is damaged more frequently and more severely than wheat, barley and other cereals may not necessarily be due only to preferential consumption. Another reason may be that the animals spend more time in maize fields because maize plants are higher and therefore provide better cover during the day, approximately from mid-June onwards, than other cereals (see also Geisser 2000). The resulting damage is higher not only due to consumption but mainly due to trampling. This has also been suggested by Kristiansson (1985) who estimated that only 5–10% of crop destruction by wild boar was a consequence of actual consumption, the rest being due to trampling. Similarly, Bouldoire and Havet (1981) stated that only 10–20% of maize cobs on the ground had been consumed in their study area in France.

Seasonal variation

Damage to maize and to cereals occurred just after planting and from the moment seeds were present, which is in line with results reported from Spain (Herrero et al. 2006), Croatia (Łabudzki and Wlazełko 1991) and Switzerland (Geisser 2000), but not Italy (Macchi et al. 1992). As regards damage to grassland, most requests for compensation in Italy concerned damage in autumn (Macchi et al. 1992), whereas in Luxembourg and in the UK, this type of damage occurred almost exclusively in winter (January to March; Wilson 2004; this study).

Temporal and spatial variation

Both the total number of wild boar shot per year and the total amount of damage per year have increased significantly since 1971, and the two sets of data were strongly correlated, suggesting that the amount of damage is related to the population density of wild boar. Moreover, there have been only very minor changes in land use throughout this period (see Harperath and Schmitz 2005), seemingly ruling out the possibility that changes in land use might have caused the observed increase in conflict. A virtually identical trend has been reported from France (Klein et al. 2007) and Switzerland (Geisser 2000). Equally, the non-uniform spatial distribution was highly correlated wild boar population density, and results of spatial analysis indicate that amongst the predictors included, wild boar density was by far the most important one. Overall, these results suggest that wild boar densities are indeed a very important factor in determining damage severity. This relationship between damage and population density has been reported in other studies (e.g. Bouldoire and Havet 1981; Goryńska 1981; Baettig 1988; Łabudzki and Wlazełko 1991; Spitz and Lek 1999).

However, apart from wild boar density, there are bound to be other factors that determine the probability of a particular field to be damaged or not. For the present study, such potential parameters were not available. Factors mentioned in this context include the proximity of agricultural fields to dense protective cover or forest (Baettig 1988; Janeau and Gallo Orsi 1992; Meriggi and Sacchi 1992; Spitz and Lek 1999; Wilson 2004; Linkie et al. 2007); the age and social structure of wild boar populations (Kristiansson 1985); the proportion of agricultural land and the type of agriculture (Łabudzki and Wlazełko 1991); the types of crops planted in vulnerable areas (Bouldoire and Havet 1981) and, finally, the intensity of supplementary feeding (Geisser 2000, see also Baubet 1998).

## Management recommendations

Wild boar density seems to be the most important predictor of damage. Reducing populations through increased hunting pressure would seem a useful management action (see also Bieber and Ruf 2005; Servanty et al. 2008, Vassant 1997), especially as hunting of wild boar is allowed all year round and there are thus no potential limitations. Moreover, it follows from there that all factors contributing to the increase in wild boar populations are also likely to contribute, indirectly, to an increase in agricultural damage. In this context, supplementary feeding should be critically examined, which has been put forward as an important factor responsible for the observed population increase of the wild boar in Europe (e.g. Groot Bruinderink et al. 1994; Hahn and Eisfeld 1998; Kaberghs 2004; Arnold 2005; Bieber and Ruf 2005), and thereby, indirectly, for higher damage thereafter (Arnold 2005; Bieber and Ruf 2005). Only in some rare cases has supplementary feeding as a dissuasive tool actually been shown to reduce damage to annual crops (Vassant and Breton 1986; Calenge et al. 2004), but only under four conditions: (1) wild boar densities are lower than 15 individuals per 1,000 ha forest (Jullien et al. 1988), (2) food is supplied only during the critical period (Vassant 1994a), (3) the food supplied is spread out over large areas (Vassant 1997; Calenge et al. 2004), (4) food is supplied in the forest at least 1 km from the forest edge (Vassant 1997; Geisser 2000; Calenge et al. 2004). In Luxembourg, these criteria are not fulfilled: The numbers of wild boar shot alone have reached nearly 50 animals per 1,000 ha of forest, supplementary feeding is done year-round and at point locations (Cellina 2008), and forests are generally fragmented and present in patches with a radius smaller than 1 km (Rondeux 2006). We therefore recommend to stop supplementary feeding altogether, as has also been generally suggested elsewhere (Schley 2000; Bieber and Ruf 2002; Arnold 2005; Bieber and Ruf 2005; Gortázar et al. 2006).

The fact that 22 communes consumed 50% of the compensation paid also has implications for management. If mean damage levels had been the same in these communes as in the rest of the country, the damage compensation paid out over the period 1997–2006 would have been lowered by 200,000 € per annum, thus by more than a third. Therefore, in view of the influence of wild boar population size on damage levels, a substantial reduction of wild boar populations in these 22 communes would seem to be a priority of wild boar management in Luxembourg. Additionally, other actions aiming at reducing damage should be mainly applied in these 22 communes, although what such actions can be is not clear. Whilst deterrents such as visual, chemical or acoustic repulsive substances do not seem to work (Vassant et al. 1987), the utility of electric fencing is controversially discussed: Vassant and Boisaubert (1984) present it as a useful tool, whereas Geisser (2000) seems less convinced.

Moreover, our study shows that actions for preventing or reducing damage (especially to maize and cereals), such as electric fences, need only be applied during a short period in time, namely after sowing and especially as soon as the crops are in milk. Outside this period, such measures would only consume resources without contributing much towards damage reduction.

Our study also confirmed a further aspect which was already known about damage to cereals, namely that trichomatous cereals are disliked and negatively selected, especially barley (Bouldoire and Havet 1981; Vassant and Breton 1986; Vassant 1997). The management implication is that trichomatous cereals should be preferentially planted close to forests, whereas annual crops preferred by wild boar such as maize and non-trichomatous cereals should ideally be planted further away from forests, as has also been recommended by Bouldoire and Havet (1981) and Vassant (1994b). This would have the additional advantage that by the time maize is in milk and thus attractive to wild boar, other cereals would long have been harvested, and the animals would have to cross longer distances without protective cover, which they tend to avoid (e.g. Janeau and Gallo Orsi 1992).

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