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Influence of seasonality, environmental and anthropic factors on crop damage by wild boar *Sus scrofa*

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Abstract. In recent decades, wild boar *Sus scrofa* populations have increased both in number and distribution in Italy, thus enhancing problems of cohabitation with humans. Crop damage represents one of the main sources of conflict; understanding the spatiotemporal variation of damage events and which factors increase the risk of damage is crucial to the development of effective management strategies. The aims of this study were to determine the impact of wild boar on croplands in the Special Protection Area "Risaie della Lomellina" (western Po Plain, northern Italy) and to formulate a risk prediction model through a binary logistic regression analysis. Damage events almost exclusively involved maize, and were concentrated in spring and summer. Sporadic cases of damage concerned rice, soybean and sorghum fields. The risk of damage was higher in fields close to forests, far from main roads, urban areas and continuous hedgerows, and in areas with low human population densities.

Key words: human-wildlife conflict, Italy, maize, Special Protection Areas, ungulates

Introduction

In recent decades, an expansion and increase in ungulate populations has been observed across Europe (Apollonio et al. 2010), with several species even colonising agricultural and urban areas (Cahill et al. 2012, Duarte et al. 2015, Sönnichsen et al. 2017), thus increasing problems of cohabitation with humans. In particular, the wild boar *Sus scrofa* often comes into conflict with humans, the main problems being the transmission of diseases to domestic animals and humans, collisions with vehicles, disturbance or threat to citizens and damage to gardens, public parks, pasture and agriculture (Meng et al. 2009, Putman et al. 2011, Barrios-García & Ballari 2012).

Wild boar damage to croplands is expressed in different ways: direct consumption of crops, rooting in search of bulbs, invertebrates or tubers, seed removal, trampling and damage to agricultural infrastructure (Barrios-García & Ballari 2012, Bengsen et al. 2014). Numerous methods can be employed to mitigate the negative impact of wild boars: odour repellents, solar blinkers, diversionary feeding, fertility control, crop guarding, fencing, translocation, poisoning, trapping and shooting (see review in Massei et al. 2011). However, these methods are often inadequate or expensive, and the limited funds available to public administrations often do not allow the implementation of preventative measures in all circumstances. Therefore, to act appropriately in the most critical situations, it is important to identify which factors increase the probability of damage. Wild boar damage is mainly affected by safety and forage-related factors. Safety factors comprise human presence and the distance to the edge of the nearest forests, roads, and rivers (Saito et al. 2011, Li et al. 2013, Lombardini et al. 2017), while forage-related factors include type, availability and maturation time of agricultural crops (Herrero et al. 2006, Schley et al. 2008, Gross et al. 2018), as well as the production of seeds in deciduous forests (Genov et al. 1995).

The literature relating to the impact of wild boar on agricultural land is abundant (Barrios-García & Ballari 2012, Bengsen et al. 2014), but few studies concern highly human-dominated areas (e.g. Herrero et al. 2006). The Po River Plain (northern Italy) is one of the most settled regions of Europe. After the Second World War, this region underwent substantial transformation as a consequence of major industrial development and changes in the rural economy, which today are reflected by the intensive agricultural matrix characterizing the

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entire area (Falcucci et al. 2007). In recent decades, the wild boar has colonized the Po River Plain, where it has established a permanent presence (Ferri et al. 2014, Bon 2017, Canova & Balestrieri 2019), mainly favoured by releases of individuals and the abundance of food sources provided by agroecosystems (Carnevali et al. 2009).

Despite the wide distribution of the wild boar in the Po River Plain, to our knowledge no studies have analysed its negative impacts on the agricultural activity of the area. In this study, we examined wild boar damage to croplands in the Special Protection Area (hereafter: SPA) "Risaie della Lomellina", an intensively cultivated area of the western Po Plain, to investigate (1) the severity of damage; (2) monthly variation in the distribution of damage; (3) whether different crops are damaged according to their availability; and (4) which environmental and anthropic factors influence the presence of damage, through the formulation of a risk prediction model. Finally, on the basis of our results, we give recommendations for the management of wild boar in the region.

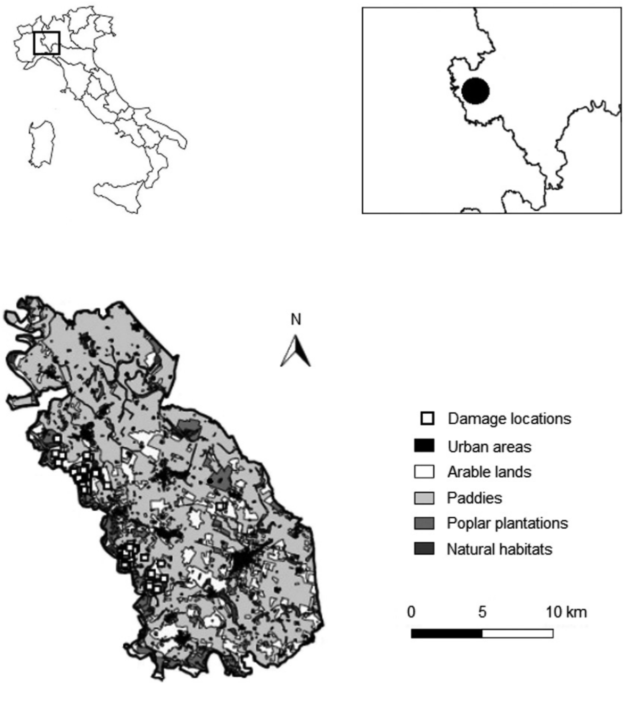

Fig. 1. Location and land use of the study area (SPA "Risaie della Lomellina", western Po Plain, northern Italy).

Study area

This study was conducted in the SPA "Risaie della Lomellina", located in the south-western sector of Lombardy (northern Italy), in the western Po Plain (Fig. 1). This is the largest SPA in Po River Plain, covering 309 km^2 at an average altitude of 95 m above sea level (range: 75-115 m). The Sesia, Po and Ticino Rivers define its western, southern and eastern borders, respectively, while the northern limit coincides with the administrative boundary separating Lombardy from Piedmont. The climate is temperate-subcontinental, with cold winters and hot summers, and a constant, high level of humidity, which facilitates the formation of fog, especially in autumn and winter. The study area is highly settled; intensively cultivated areas represent 90.6 % of the total surface, and are dominated by paddies (74.4%), followed by poplar plantations (9.7%) and arable lands (6.5%), mainly represented by maize (Carlini et al. 2010) (Fig. 1). Residual patches of natural vegetation characterize 4.3 % of the study area, and are constituted by lowland forests (2.7%, with the main species being *Alnus glutinosa*, *Carpinus betulus*, *Fraxinus* spp., *Populus* spp., *Quercus robur*, *Salix alba* and *Ulmus minor*), marsh vegetation (0.8 %) and scrublands (0.8 %) (Carlini et al. 2010). Natural areas are important chiefly for the conservation of numerous heron colonies (Fasola et al. 2011, Longoni et al. 2011), but the SPA has also been recognized as an important area for the conservation of lichens, flora, invertebrates and mammals (Bogliani et al. 2007). Urban settlements represent 3.8% of the study area. The presence of wild boar in the area is due to escapes, illegal releases and natural immigration from surrounding areas (primarily riparian habitats bordering the Rivers Sesia and Po). At present, density data and estimates of population size are not available.

Table 1. Number of cases and compensation payments (in Euros) for each type of crop damaged by wild boar in the SPA "Risaie della Lomellina" from 2013 to 2015.

Year	Maize	Rice	Soybean	Sorghum	Total
2013	9 (2, 960 €)	1 (643 €)	-	-	10 (3, 603 €)
2014	6 (4, 255 €)	1 (0 €)	-	1 (0 €)	8 (4, 255 €)
2015	5 (895 €)	3 (130 €)	2 (400 €)	-	10 (1, 425 €)
Total	20 (8, 110 €)	5 (773 €)	2 (400 €)	1 (0 €)	28 (9, 283 €)
Mean per event (€)	405	155	200	0	332

Material and Methods

Wild boar damage to croplands

To describe damage to croplands, we acquired data from the Wildlife Service of the Province of Pavia. These data include requests for reimbursement officially formulated by farmers to the provincial administration from 2013 to 2015, and consist of date, type of crop damaged and amount of compensation paid (in Euros) for each damage event. A chi-square goodness-of-fit test was used to evaluate the existence of monthly differences in the number of events (Schley et al. 2008, Lombardini et al. 2017), without separating different crops because of low sample size (see Results section).

As these data did not include detailed information regarding the geographic location of damage events, we integrated our dataset through direct interviews with local farmers. Interviews took place in 2015, according to the willingness of farmers who, in cases of damage, escorted us to their farmlands and allowed us to inspect damaged fields. With these surveys, we sampled a total of 61 fields with damage attributable to wild boar (Fig. 1), for which we were able to define geographic coordinates, the type of crop damaged and the spatial extent of damage. All this information was included in an electronic database and georeferenced with QGIS 2.4.0 software (QGIS Development Team 2015).

To investigate whether different types of crops were damaged in proportion to their availability, we calculated from the Agricultural Information System of Lombardy (https://www.siarl.regione.lombardia.it/index.htm) the area occupied by paddy, maize and other crops in the study area. Other crops (soybean, wheat, sorghum and peas) were combined into a single group as each accounted for only a small proportion of the total agricultural area. We compared the overall availability of paddy, maize and other crops with the proportion of damaged area and damage frequency using a chi-square goodness-of-fit test (Neu et al. 1974, Herrero et al. 2006). Damage frequency was extrapolated from requests for reimbursement together with interviews with farmers. In the case of significant chi-square values ($P < 0.05$), we calculated Bonferroni confidence intervals to determine whether the wild boar selected, avoided or used different crops according to their availability (Neu et al. 1974, Herrero et al. 2006). All analyses were performed with the statistical software R 3.2.3 (R Development Core Team 2015).

Factors influencing damage distribution

Data for the geographic location of damaged fields were used to build a risk prediction model, following a use-versus-availability approach and executing a binary logistic regression analysis (Boyce et al. 2002, Johnson et al. 2006). "Damage" was set as the binary dependent variable; damaged fields assumed a value = 1, whereas a value = 0 was assigned to an equal number of fields (i.e. pseudo-absences) randomly chosen with the "random points generator" function implemented in QGIS 2.4.0 (Barbet-Massin et al. 2012). In the model we included 12 continuous variables: area, perimeter and fractal dimension of fields, distance from rivers (m), distance from forest patches (m), distance from continuous hedgerows (m), distance from discontinuous hedgerows (m), distance from urban areas (m), distance from main roads (m), distance from secondary roads (m), distance from railways (m) and population density (no. of people km^{-2}). Area, perimeter and fractal dimension of fields were calculated with QGIS 2.4.0, population density was obtained from the Italian National Institute of Statistics website (http://www.istat.it/it/archivio/156224), whereas all other variables were extracted from land use maps of Lombardy and Piedmont. Collinearity among variables was verified by calculating the Variance Inflation Factor (VIF), using VIF = 3 as a threshold value (Zuur et al. 2010). The variable "perimeter of fields" showed a VIF value of 9.46, and was removed from the model.

Model selection was undertaken using the Akaike Information Criterion corrected for small sample size (AICc) and Akaike weights (ωi) (Akaike 1973, Symonds & Moussalli 2011). The relative importance of predictor variables (ω) was measured by the sum of Akaike weights of the models in which each variable appeared (Symonds & Moussalli 2011), and the model containing all the variables with a ω value ≥ 0.50 was considered the best fitting (Barbieri & Berger 2004).

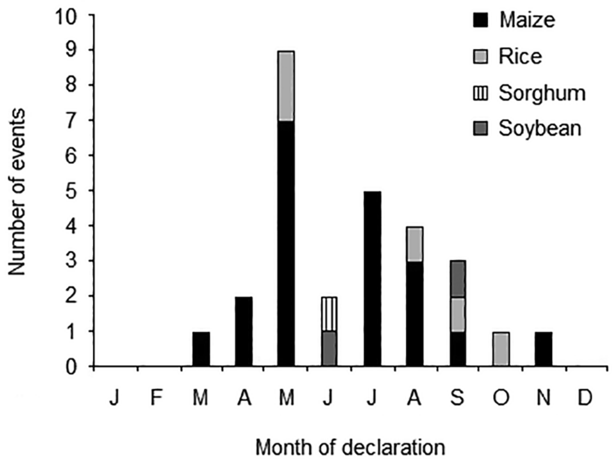

Fig. 2. Monthly distribution of wild boar damage in the SPA "Risaie della Lomellina".

Table 2. Crop selection by wild boar in the SPA "Risaie della Lomellina". In brackets: Bonferroni intervals. "Others" are other crops grouped together (see Material and Methods for explanation). *Significant selection or avoidance.

Crop	Availability	Use (damage frequency – requests of reimbursement)	Use (damage frequency – interviews)	Use (damage area)
Maize	0.14	0.71 (0.49-0.96)*	0.95 (0.89-1.00)*	0.97 (0.94-1.00)*
Paddies	0.69	0.18 (0.01-0.35)*	0.03 (0.00-0-09)*	0.01 (0.00-0.04)*
Others	0.17	0.11 (0.00-0.25)	0.02 (0.00-0.06)*	0.02 (0.00-0.04)*

Table 3. Importance of predictors describing the occurrence of wild boar damage in the SPA "Risaie della Lomellina" measured by the sum of Akaike weights (ω).

Predictors	ω
Distance from main roads	1.00
Population density	0.99
Distance from forest patches	0.98
Distance from continuous hedgerows	0.91
Distance from urban areas	0.79
Fractal dimension of fields	0.59
Distance from railways	0.41
Distance from discontinuous hedgerows	0.31
Distance from rivers	0.31
Area of fields	0.30
Distance from secondary roads	0.27

Model performance was evaluated by the area under the ROC (receiver operating characteristics) curve (AUC), which can assume values ranging from 0.50 (random prediction) to 1.00 (perfect prediction). Model discrimination ability was categorised as excellent for AUC > 0.90, good for 0.80 < AUC < 0.90, acceptable for 0.70 < AUC < 0.80, bad for 0.60 < AUC < 0.70 and null for 0.50 < AUC < 0.60 (Swets 1988).

A binary logistic regression analysis was implemented with the statistical software R 3.2.3 (R Development Core Team 2015), using the function glm (family = binomial) and "ROCR", "car", "MuMIn" and "verification" packages (Sing et al. 2005, Fox & Weisberg 2011, Bartoń 2013, NCAR 2015).

Results

Wild boar damage to croplands

Between 2013 and 2015 the Wildlife Service of the Province of Pavia recorded and ascribed to wild boar 28 cases of damage to crops (Table 1). Compensation payments amounted to 9283 Euros; on average, 332 Euros were paid for individual claims (range: 0-1400 Euros). Damage occurred in maize (*Zea mays*), rice (*Oryza sativa*), soybean (*Glycine max*) and sorghum (*Sorghum vulgare*) fields, but 71% of events and 87% of compensation payments related to maize crops (Table 1). The number of claims was similar among years, with a peak of refunds paid in 2014 (mean per event: 532 Euros, range: 0-1400 Euros), followed by 2013 (mean per event: 360 Euros, range: 0-977 Euros) and 2015 (mean per event: 142 Euros, range: 0-400 Euros) (Table 1). There were strong monthly differences in the distribution of damage events (chi-square = 32.86, df = 11, $P < 0.001$); damage was almost entirely concentrated between April and September, with two peaks recorded in May and in summer (July-August), respectively. From October to March, only three events were documented (Fig. 2). Damage events involving maize showed a peak in May (35% of events) and an absence of events from December to February, damage to rice fields was recorded in spring, late summer and early autumn, and damage to soybean fields occurred in June and in September. The only events concerning sorghum occurred in June (Fig. 2).

Table 4. Coefficients of predictors of the model examining the occurrence of wild boar damage in the SPA "Risaie della Lomellina". Only predictors with ω ≥ 0.50 are included in the model. SE: standard error. CI: confidence intervals. Predictors have a significant effect when the 95 % confidence intervals do not include zero.

Predictors	Coefficients	SE	95 % CI
Intercept	20.85	12.76	–4.15, 45.86
Distance from main roads	0.002	0.001	0.001, 0.003
Population density	–0.036	0.013	–0.062, –0.010
Distance from forest patches	–0.010	0.004	–0.018, –0.003
Distance from continuous hedgerows	0.003	0.001	0.001, 0.006
Distance from urban areas	0.002	0.001	0.0002, 0.003
Fractal dimension of fields	–18.23	9.96	–37.76, 1.30

Interviews with farmers confirmed maize fields as the main target of wild boar raids (n = 58 events), with rice paddy (n = 2) and other crops (n = 1) involved marginally in damage incidents. We surveyed a total of 131.1 hectares damaged by wild boar: maize (127.7 hectares) was the most affected crop, followed by other crops (2.0 hectares) and paddy (1.4 hectares). The percentage of observed damage frequency and damage area for paddy, maize and other crops differed significantly from the percentage of their respective availability (damage frequency from requests of reimbursement: $\chi^2 = 75.14$, df = 2, $P < 0.001$; damage frequency from interviews: $\chi^2 = 324.84$, df = 2, $P < 0.001$; damage area: $\chi^2 = 739.35$, df = 2, $P < 0.001$). Maize was damaged more than expected, whereas paddy and other crops were avoided. Other crops were damaged proportionally to their availability only when considering requests of reimbursement (Table 2).

Factors influencing damage distribution

The best fitting model that explained the occurrence of wild boar damage included six predictors with a cumulative weight (ω) ≥ 0.50 (Tables 3, 4). The risk of damage to fields increased positively as a function of distance from main roads, distance from continuous hedgerows and distance from urban areas. Risk of damage was negatively related to human population density, and distance from forest patches. The risk of damage was not explained by the fractal dimension of fields (Table 4). The ROC curve analysis showed the model had excellent predictive power, the area under the curve being 0.96.

Discussion

In recent years, wild boar damage in the SPA "Risaie della Lomellina" has become an important issue for the local public administration. In this area, rice is the most important crop. Maize is the second most important crop and is the main target of wild boar raids, and usually represents the most damaged type of crop, also being consumed in a higher proportion than its availability (Nores et al. 1999, Herrero et al. 2006, Schley et al. 2008). Though wild boar consume a wide variety of plant species, their diet always includes at least one energy-rich plant food: acorns, beechnuts, chestnuts, olives or cereals, depending on the area (Schley & Roper 2003). In our study area, the scarcity of woodland forces boar to feed on high-energetic agricultural products (i.e. maize), inevitably resulting in conflict with humans.

The average reimbursement paid amounted to 332 Euros per event, which is lower than elsewhere in Italy (Amici et al. 2012, Lombardini et al. 2017), but comparable with studies conducted in other European countries (Linderoth & Elliger 2002, Schley et al. 2008, Bobek et al. 2017). Damage is mainly concentrated in spring and summer. Spring is the sowing season for maize, during which time wild boars unearth and consume seeds, obliging farmers to restore maize fields and causing a consequent delay in plant growth. Meanwhile, summer coincides with the milk stage of maturity in maize, which attracts wild boar because corncobs represent an important source of food at this time of year and maize plants also provide good cover in daylight hours (Wilson 2004, Schley et al. 2008, Bleier et al. 2017).

The logistic model had high predictive power, as highlighted by ROC curve analysis, and stressed the importance of cover and human disturbance in determining the risk of damage. Fields close to woodlands are commonly exploited by wild boar throughout their range (Saito et al. 2011, Li et al. 2013, Bleier et al. 2017, Lombardini et al. 2017), because forest patches provide areas to thermoregulate, a source of food when other agricultural crops are not available, and shelter from predators and human disturbance (Choquenot & Ruscoe 2003, Theuerkauf & Rouys 2008, Merta et al. 2014). The avoidance of human activities is further confirmed by the negative relationship of damage risk with distance to urban areas, human population density and main roads. Although present in many European metropolitan areas (Cahill et al. 2012), wild boar are not well suited to the urban environment, preferring to live in woodlands or in agro-forested areas (Merli & Meriggi 2006, Hebeisen et al. 2008, Amendolia et al. 2019). The model showed an unexpected increase in risk of damage with distance from continuous hedgerows. Generally, small landscape elements (such as hedgerows) are considered important ecological corridors for wildlife, representing typical passage and movement zones for many species, especially in highly human-altered landscapes (Dondina et al. 2019). However, in our study area small landscape elements are almost exclusively represented by rows of trees, with shrub vegetation relatively rare. Thus, these landscape features cannot provide adequate protection to wild boar from human disturbance. Field characteristics did not have a significant effect on the occurrence of damage, probably because of the high homogeneity of fields; indeed, the modernization of agricultural practices, particularly notable in this area, has resulted in simplification of field shape, which is increasingly large and regular, to facilitate planting, maintenance and harvesting operations by farmers.

The SPA "Risaie della Lomellina" is a highly human-impacted area, where wild boar have been able to establish a permanent presence, with a consequent increase in conflict with humans. Hitherto, wild boar management in the area has been based on conjecture rather than rigorous data collection and analysis. This study represent a baseline to define adequate management strategies, which take account of the characteristics of the area, with its high level of human influence, the presence of species of conservation concern (e.g. *Emys orbicularis*, *Rana latastei*, *Lycaena dispar*; Bogliani et al. 2007, Sindaco et al. 2009) and the economic costs of damage, and demonstrating the need for a compromise among the preservation of human activities, biodiversity conservation and cost-effective preventative actions. Nevertheless, a caveat to our results is that, given the data in this study were based on reported damage claims, it is possible that low-level damage by wild boar went unreported. If this is the case, our analyses may be biased towards more serious cases of crop damage than more trivial instances.

Globally a variety of methods have successfully been used to reduce wild boar damage, such as fencing (Saito et al. 2011), diversionary feeding (Calenge et al. 2004), crop guarding (Thapa 2010), hunting (Geisser & Reyer 2004) and trapping (McCann & Garcelon 2008). However, the size of fields in our study area mitigates against the use of fencing due of high set-up and maintenance costs, as well as an increasing damage risk in adjacent areas (Geisser & Reyer 2004, Massei et al. 2011). Diversionary feeding can increase wild boar reproductive output, carrying capacity and hence population size (Calenge et al. 2004, Geisser & Reyer 2004, Ježek et al. 2016, González-Crespo et al. 2018). Crop guarding, despite the low capital investment, is an intensive and time-consuming practice (Wang et al. 2006, Thapa 2010). Hunting is difficult to implement in residential areas, may cause social objections, and could impact non-target species (Treves & Naughton-Treves 2005, Liordos et al. 2017, Stillfried et al. 2017). Considering all these approaches, we suggest the use of trapping as the main method for controlling wild boar in the SPA "Risaie della Lomellina". Trapping can be used to selectively remove large numbers of animals, particularly at high densities, with a low level of disturbance to people and other wildlife, which makes it particularly suitable in densely occupied areas, where other methods are difficult or unfeasible (Campbell & Long 2009, Massei et al. 2011). The analysis of the monthly distribution of events and the risk prediction model formulated represent important tools to focus economic investment in the areas and seasons where the risk of boar damage is greatest. Based on our results, trapping sessions should be carried out before the sowing period and the milk stage of maize maturity, giving priority to fields close to forests, and at distance from main roads and urban settlements.

More research is needed to expand our understanding of wild boar ecology and biology in this region, including population density, behaviour, feeding habits, productivity, and a thorough understanding of these features of wild boar populations in the region would further enhance the effectiveness of management strategies and preventative actions (Beasley et al. 2018).

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