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Factors influencing wild boar damage to agricultural crops in Sardinia (Italy)

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Abstract

Crop damage by wildlife is a frequent source of human–wildlife conflict. Understanding which factors increase the risk of damage is crucial to the development of effective management strategies. The aims of this study were to provide a general description of agricultural damage caused by wild boar *Sus scrofa meridionalis* over a 7-year period in North-eastern Sardinia (Mediterranean Italy), and to formulate a predictive model of damage risk. We recorded a total of 221 cases of wild boar damage, with economic losses amounting to 483,982 Euros. Damage events mostly involved vineyards, meadows and oat fields, and were characterized by a peak incidence in summer and early autumn, and a minimum in spring. Damaged fields were characterized by an increasing presence of permanent crops, a decreasing presence of woodlands, maquis and urban areas, and a reduced distance from shelter areas (forests and shrublands). The analysis of spatiotemporal variation of boar-induced damage and the identification of factors that augment the risk of damage provides essential information for contributing to the development of a more effective plan for managing wild boar populations.

Key words: Human–wildlife conflict, *Sus scrofa meridionalis*, risk modelling, landscape structure, wild boar management.

Conflicts between humans and wildlife have been reported from all over the world and include problems such as attacks by predators on livestock, transmission of diseases from wild populations to domestic animals and humans, agricultural damage, and collisions with vehicles (Kaczensky 1999; Frölich et al. 2002; Pimentel et al. 2005; Sáenz-de-Santa-María and Tellería 2015). One species that often comes into conflict with humans is the wild boar *Sus scrofa* (Barrios-García and Ballari 2012; Bengsen et al. 2014). Wild boar populations have dramatically increased in size and overall range across Europe in the past decades, owing to species-specific biological factors (e.g., very high reproductive output and dispersal potential), deliberate releases for hunting purposes, the extensive recovery of natural woodlands, and the great adaptability of the species to a wide range of environmental conditions (Apollonio et al. 2010; Massei et al. 2015). These factors, together with human population growth and the intensification of agricultural activities, have resulted in the escalation of human-wild boar conflicts. Damage to croplands is particularly intense, causing significant economic losses, which amount to hundreds of thousands of Euros per year in several European countries (Schley et al. 2008; Novosel et al. 2012; Frackowiak et al. 2012; Laznik and Trdan 2014).

Even in Italy, the wild boar has quickly expanded its range in the last 50 years (Apollonio et al. 1988, 2010). At the beginning of the 1950s, wild boars were reduced to a few fragmented, small populations. From the 1960s onwards, the species occupied the hilly and mountainous areas of the Italian peninsula, and recently it has also been observed in several zones of the Alps and in intensively cultivated plains (Monaco et al. 2006; Carnevali et al. 2009). Concurrently, the Italian population has grown to roughly 600,000 individuals, and conflicts with human activities have increased dramatically (Carnevali et al. 2009; Riga et al. 2011). At present, compensation payments for wild boar damage to croplands amount to about nine million Euros per year (Riga et al. 2011). In Italy, farmers who discover damage by wild boar (or other game species) in their fields are required by law to declare the damage promptly. Verification of damage in the field, with identification of the presumptive culprit species and assessment of the extent of damage, is carried out by qualified technicians, who assess the economic loss and, consequently, the amount of compensation paid (more details can be found in Riga et al. 2011).

On the Mediterranean island of Sardinia the wild boar is present as an endemic subspecies *Sus scrofa meridionalis* (Iacolina et al. 2016). The Sardinian population probably originated in the early Neolithic, when pigs escaped from human control and became feral; evolution in isolation led them to diverge from continental populations, both morphologically and genetically (Albarella et al. 2009; Scandura et al. 2011; Iacolina et al. 2016). Today, the Sardinian wild boar is common and widespread across the entire island, occupying different habitats including woodlands, low Mediterranean maquis, garrigue, untilled lands, pastures, and cultivated areas (Apollonio et al. 2012). Despite the abundance and the wide distribution of the wild boar, very few studies analyzing its negative impact on human activities and biodiversity have been performed in Sardinia (Onida et al. 1995; Pisanu et al. 2012). Onida et al. (1995) focused on damage caused to croplands by the wild boar, but they provided only a general description of damage, which did not allow them to suggest any management strategies.

Facing increasing negative impact attributable to wild boar, scientists and wildlife managers are searching for effective prevention and/or mitigation methods (Calenge et al. 2004; Geisser and Reyer 2004; Cai et al. 2008; Schlageter and Haag-Wackernagel 2012). To improve the effectiveness of preventative actions, it is important to identify which factors increase the risk 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 (Calenge et al. 2004; Cocca et al. 2007; Honda and Sugita 2007; Cai et al. 2008; Thurfjell et al. 2009), while forage-related factors include type, abundance, maturation time and availability of agricultural crops (Herrero et al. 2006; Schley et al. 2008; Li et al. 2013), and the production of seeds by deciduous forests (Cutini et al. 2013).

Species distribution models represent a powerful tool to identify the areas with the highest likelihood for the presence of a species, and its relationships with environmental factors (e.g., land use, topography, landscape features, climate) (Guisan and Zimmermann 2000; Elith and Leathwick 2009). Recent studies have shown, however, that these tools could have a wider application, such as the assessment of damage risk by target species (e.g., Ficetola et al. 2014; Dondina et al. 2015; Sorensen et al. 2015; Meriggi et al. 2016). In this study, we first provide a general description of wild boar damage to croplands in North-eastern Sardinia (Mediterranean Italy). We then used these data to build a distribution model, to identify which factors determine the distribution of damage and to define the areas where the risk of damage is highest.

Materials and Methods

Study area

The study was located in the province of Olbia-Tempio (NE Sardinia, Central Italy) (Figure 1), which extends over 3,404 km^2 with altitude ranging from sea level to 1,359 m a.s.l. (Mount Limbara). The climate is Mediterranean, with a mean yearly temperature of 14.7 °C (minimum 6.8 °C in December, maximum 22.8 °C in July) and a mean yearly precipitation of 832 mm (minimum 8 mm in July, maximum 126 mm in December) (Meriggi et al. 2012). Vegetation is typically Mediterranean; the area is dominated by garrigue and low maquis (with *Phillyrea* sp., lentisk *Pistacia lentiscus*, cistus *Cistus* spp., and heather *Erica arborea*), and broadleaved forests, mostly including oaks (*Quercus ilex, Q. suber*). Agricultural areas represent about 15% of the total land area, and are dominated by meadows, partly used for grazing and partly as fodder crops. Additional cultivars include cereals, vineyards, orchards, and olive groves. In the study area, the wild boar is widespread and abundant. In 2011–2012, a density of 14.4 individuals per 100 ha was estimated (Meriggi et al. 2013).

General description of wild boar damage

Wild boar damage data were collected over a period of 7 years, from January 2006 to December 2012. In the analyses, we included only cases of crop damage for which compensation was paid out, because data were available only for such cases. Each case was georeferenced in an IGM map (produced by the Italian Military Geographic Institute) at a scale of 1:25,000 with ArcMap v9.3 GIS software (ESRI, Redlands, USA), and the amount of damage (estimated economic loss) and the type of crop damaged were recorded.

To evaluate the general trend of damage events and economic losses during the study period, two regression analyses were performed, using damage variables (the number of events per year and economic losses per year) as dependent variables and time as an independent variable. To evaluate the existence of monthly differences in the number of events, a Chi-square goodness-of-fit test was performed. All the analyses were carried out using PAST version 2.17c (Hammer et al. 2001).

Factors influencing damage distribution

We analyzed the relationship between damage and vegetation, topography, and human disturbance factors (Table 1). Vegetation variables were extracted from the Corine Land Cover database (scale 1:25,000) (European Environment Agency, Copenhagen. http://www.eea.europa.eu), and the original categories were reclassified to obtain five predictors: "forests and shrublands", "arable land", "permanent crops", "agro-forestry areas" and "urban areas" (Table 1). The proportions of these variables were measured within a radius of 1.325 km from each damage location, according to the mean home range size of the wild boar in Mediterranean Europe (551 ha) (Barasona et al. 2014). Then, the distance between each damage site and the edge of the nearest patch of forest/shrubland was measured, as wild boar uses forests and shrublands as shelter areas (Honda and Sugita, 2007; Thurfjell et al. 2009). Besides the land cover dataset, in the analyses we included altitude and three "human disturbance" variables (Table 1): distance from protected areas, to evaluate the existence of a "refuge effect" (Amici et al. 2012), distance from primary roads, and human population density. Altitude was derived from a digital terrain model (DTM; cell size 75 m) produced by the Italian Military Geographic Institute, while human population density was obtained from the Italian National Institute of Statistics website (http://www.istat.it/it/archivio/156224). We considered potential multicollinearity among predictors using the Pearson's coefficient and the Variance Inflation Factor (VIF). We retained $r = 0.7$ and VIF = 3 as threshold values to diagnose collinearity among variables (Zuur et al. 2010; Dormann et al. 2013). The variable "arable land" had a VIF value of 4.9, therefore we excluded it from our analyses. For modeling, we randomly selected the same number of pseudo-absences as there were presences. The model was built following a use-versus-availability approach, with a Binary Logistic Regression Analysis (Cumming 2000; Boyce et al. 2002). "Damage" was set as the binary dependent variable (damage locations = 1,

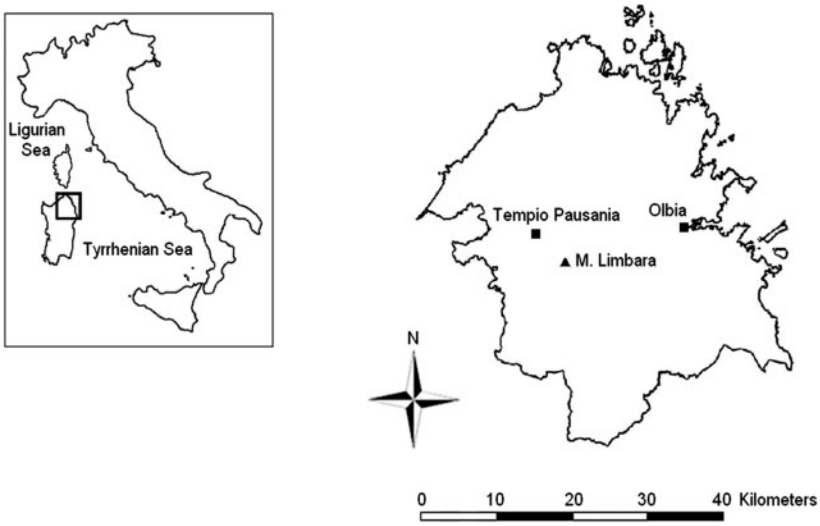

Figure 1. Location of the study area (Province of Olbia-Tempio, NE Sardinia, Central Italy).

Table 1. Variables used in the analyses

Name	Type	Description	Corine Land Cover codes
Forests and shrublands	Vegetation	Deciduous, conifer and mixed woods. Vegetation dominated by bushes and shrubs. Includes maquis, garrigue, and transitional woodland/shrub	311 312 313 322 323 324
Arable land	Vegetation	Cultivated areas regularly ploughed and generally under a rotation system. Includes cereals, legumes, fodder crops, root crops, and fallow land	211 212
Permanent crops	Vegetation	Vineyards, fruit trees, berry plantations, and olive groves	221 222 223
Agro-forestry areas	Vegetation	Annual crops or grazing land under the wooded cover of forestry species	244
Urban areas	Vegetation	All artificial surfaces	1
Distance from forests and shrublands	Vegetation	near, 0–280 m; far, > 280 m	
Altitude	Topography		
Human population density	Human disturbance		
Distance from primary roads	Human disturbance	near, 0–280 m; far, > 280 m	
Distance from protected areas	Human disturbance	near, 0–280 m; far, > 280 m	

random locations = 0), and landscape variables previously described were set as predictors. Vegetation variables, altitude, and human population density were considered as continuous variables, whereas distances from forests and shrublands, protected areas and primary roads were retained as categorical variables (near, 0–280 m; far, > 280 m. We chose this resolution because it is comparable to the mean daily home range size of the wild boar in Mediterranean Italy) (25 ha; Russo et al. 1997).

The response variable was modeled for dependence on predictor variables using the model selection procedure based on the Akaike Information Criterion corrected for small sample size (AICc) (Akaike 1973). We ranked and scaled models by the differences with minimum AICc (ΔAICc) and by Akaike weights (ωi) for each i-model (Burnham and Anderson 2002; Symonds and Moussalli 2011). Models with ΔAICc ≤ 2 were considered the best ones and used to develop model averaging (Burnham and Anderson 2002). To obtain the relative importance of predictor variables (ω), we summed Akaike weights across all the models where individual variables occurred.

These analyses were conducted in R 3.2.3 (R Development Core Team 2015), using the "glm" function (family = binomial) and the packages "MuMIn" (Bartoń 2013) and "car" (Fox and Weisberg 2011). Significance was assumed when $P < 0.05$.

Results

General description of wild boar damage

From 2006 to 2012, 221 cases of damage to croplands were recorded and ascribed to the wild boar (mean per year ± standard error: 31.6 ± 4.2 events; range 21–51) (Figure 2). The number of events increased linearly from 2006 to 2012, but the trend was not statistically significant (linear model: $y = 5.174\ x + 10.873$; $r^2 = 0.45$; $P = 0.099$) (Figure 2).

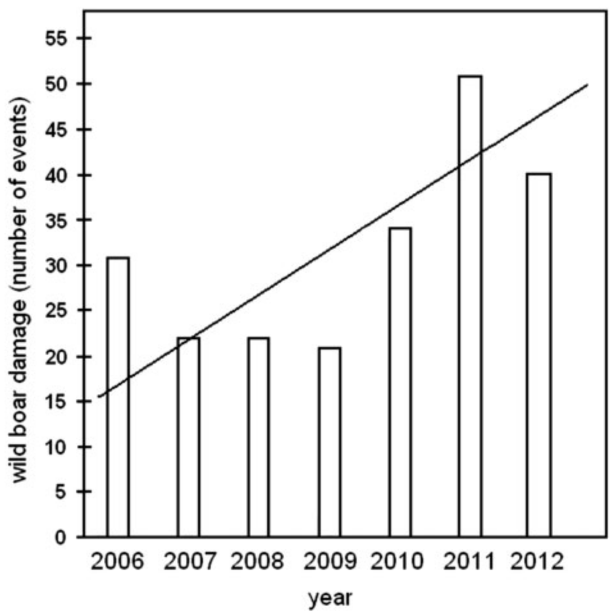

Figure 2. Wild boar damage (Number of events) plotted against time (black line indicates linear regression: $r^2 = 0.45$).

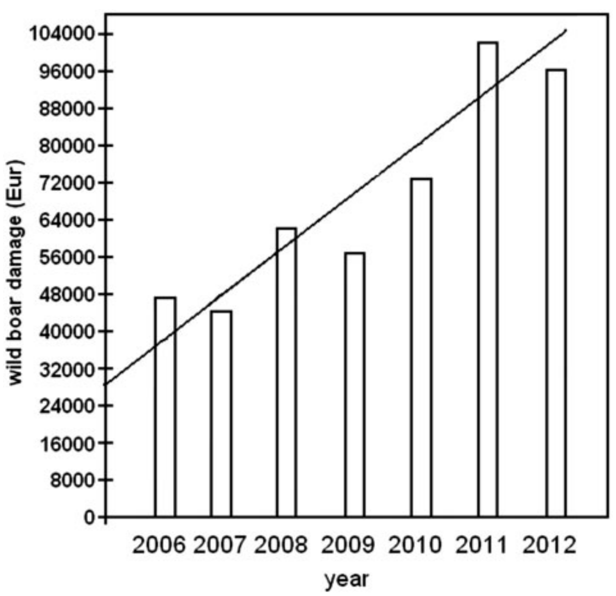

Figure 3. Wild boar damage (Euros) plotted against time (black line indicates linear regression: $r^2 = 0.84$).

Total economic loss attributed to damage by wild boar amounted to 483,982 Euros (mean per year ± standard error: 69,197 ± 8,596 Euros; range 45,144–102,918) (Figure 3), with an average of 2,190 Euros for individual claims. Economic losses increased linearly and significantly in the study area over the study period (linear model: $y = 10{,}528\ x + 27{,}085$; $r^2 = 0.84$; $P = 0.003$) (Figure 3).

Vineyards, meadows, and oat fields had the highest number of damage events, with 73, 55, and 32 records, respectively. All the other types of crops (alfalfa, barley, clover, wheat, rye, sorghum, maize, olive groves, orchards, watermelons, artichokes, and

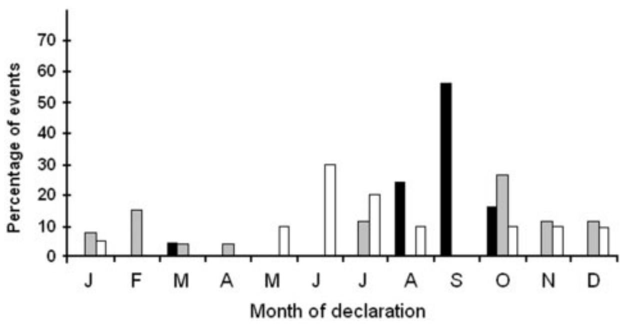

Figure 4. Seasonal distribution of wild boar damage to vineyards (black bars), meadows (grey bars), and oat fields (white bars).

reforestations) were affected by less than 10 events each during the entire study period.

In terms of economic loss, the highest mean amount per case was reported for damage to maize (3,902 Euros), followed by artichokes (3,534 Euros) meadows (2,751 Euros), sorghum (2,650 Euros), vineyards (2,631 Euros), watermelons (2,376 Euros), oat fields (1,893 Euros), alfalfa (1,870 Euros), wheat (1,440 Euros), reforestations (1,369 Euros), rye (1,276 Euros), olive groves (1,143 Euros), clover (840 Euros), and orchards (212 Euros).

There were strong monthly differences in the distribution of damage events ($\chi^2 = 40.13$; $df = 11$; $P < 0.001$), with a peak recorded in September (21% of events) and a minimum in April (1% of events). Damage to vineyards almost exclusively occurred from August to October, damage to meadows was concentrated mainly from October to February, whereas oat damage was recorded throughout the year, with a peak in June and July and a lack of damage only in late winter and early spring (Figure 4). Monthly differences were significant for vineyards ($\chi^2 = 94.52$, $df = 11$, $P < 0.001$), meadows ($\chi^2 = 25.00$, $df = 11$, $P = 0.009$), and oat fields ($\chi^2 = 20.71$, $df = 11$, $P = 0.036$).

Factors influencing damage distribution

There were five plausible models (with $\Delta AICc \leq 2$) used to develop model averaging, with eight predictors included in the best models (Table 2). The cover of permanent crops, urban areas, forests and shrublands, and the distance from shelter areas were the most important variables explaining the presence of damage, in that those same factors were present in all the models with $\Delta AICc \leq 2$ ($\omega = 1.00$) (Tables 2 and 3). The risk of damage was higher with an increasing presence of permanent crops, a decreasing presence of urban areas, forests and shrublands, and a lesser distance from shelter areas (Table 3). All of these predictors were significant, whereas the distance from protected areas, population density, altitude, and the distance from primary roads had lower importance and an uncertain effect (Table 3).

Discussion

Wild boar damage to croplands has quickly increased in North-eastern Sardinia since 2006, though the incidence of reported events is small relative to that reported for other regions (Schley et al. 2008; Amici et al. 2012; Li et al. 2013). Nonetheless, the 2-fold increase observed in a few years raises concern for future.

The peak observed in 2011, with 51 damage events recorded and economic losses amounting to about 103,000 Euros, was attributable to peak damage to meadows (14 events and 38,532 Euros), which

Table 2. Ranking of models describing the occurrence of wild boar damage in sardinia (italy) Model selection was based on the corrected Akaike's information criterion (AICc) (only models with ΔAICc ≤ 2 are shown).

Model	AICc	ΔAICc	ωi
Forests and shrublands, Permanent crops, Urban areas, Distance from forests and shrublands	327.77	0.00	0.35
Forests and shrublands, Permanent crops, Urban areas, Distance from forests and shrublands, Population density	328.72	0.95	0.21
Forests and shrublands, Permanent crops, Urban areas, Distance from forests and shrublands, distance from primary roads	329.11	1.34	0.17
Forests and shrublands, Permanent crops, Urban areas, Distance from forests and shrublands, distance from protected areas	329.48	1.71	0.14
Forests and shrublands, Permanent crops, Urban areas, Distance from forests and shrublands, Altitude	329.72	1.95	0.13

Table 3. Coefficients of model predictors, after model averaging of the top candidate models (*SE*: standard error; ω: predictor weights)

Predictors	Coefficients	SE	95% Confidence Intervals	ω
Intercept	1.861	0.587	0.711; 3.012	–
Forests and shrublands	–0.028	0.008	–0.044; –0.013	1.00
Urban areas	–0.116	0.044	–0.202; –0.029	1.00
Permanent crops	0.080	0.040	0.001; 0.158	1.00
Distance from forests and shrublands	–1.544	0.784	–3.081; –0.007	1.00
Population density	–0.001	0.003	–0.006; 0.004	0.21
Distance from primary roads	–0.053	0.185	–0.416; 0.310	0.17
Distance from protected areas	–0.045	0.218	–0.472; 0.382	0.14
Altitude	–0.0002	0.002	–0.0004; 0.0005	0.13

Predictors have a significant effect when the 95% confidence intervals do not include zero.

were presumably more abundant in 2011 because of crop rotation. Crop rotation may determine differences in the availability of agricultural products each year. Wild boars, thanks to their ability to modify their diet according to food availability (Herrero et al. 2006; Ballari and Barrios-García 2014), likely took advantage of the higher availability of meadows, thus increasing the amount of damage.

Our data suggest that in Sardinia damage seems to be more severe than in other parts of Europe, with a mean value of 2,190 Euros per event. Novosel et al. (2012) reported a mean of 477 Euros per event in Croatia, Schley et al. (2008) reported an equivalent of 396 Euros per event in Luxemburg, while Linderoth and Elliger (2002) reported a mean of 328 Euros per event in Baden-Württemberg (Germany). These data, however, unlike ours, refer to compensation payments, not to economic losses. In Sardinia, economic losses are refunded to farmers concurrently with the annual allocation of funds by “Regione Sardegna”. During the study period, in our study area, 53–75% of economic losses were refunded (Azzena et al. 2010), therefore, we can say that, even considering the amount of compensation, damage in Sardinia is more severe than elsewhere in Europe. Only in the study of Amici et al. (2012), carried out in Central Italy, was the amount of compensation per claim (729–5,469 Euros) comparable with our results.

Vineyards were the most frequently damaged crops, with events occurring almost exclusively in August, September, and October, in correspondence with the ripening of grapes. In the Mediterranean region, the problem of damage to vineyards is particularly pronounced in summer (Calenge et al. 2004; Meriggi et al. 2016); in this part of the year, acorns produced by the holm-oaks *Quercus ilex*, which commonly represent the main source of food from September to June for wild boars (Fournier-Chambrillon et al. 1995; Calenge et al. 2004; Pinna et al. 2007), are not available. Furthermore, other natural foods are also limited, and grapes are often the only edible material present in large quantities (Fournier-Chambrillon et al. 1995). As regards damage to meadows, most requests for compensation payments came about in autumn and winter. These results agree with other European studies, in which damage to meadows occurs mainly in autumn and in winter (Brangi and Meriggi 2003; Wilson 2004; Schley et al. 2008; Amici et al. 2012). Wild boar damage is caused by direct consumption and by rooting activity linked to the search for invertebrates (Bueno et al. 2009; Barrios-García and Ballari 2012). Grasses and invertebrates are important components of the diet of the wild boar; acorns and maize, in fact, are higher in carbohydrates and fats, but have lower crude protein content than grasslands and arthropods (Massei et al. 1996; Schley and Roper 2003; Ballari and Barrios-García 2014), so wild boars could have to complement their diet with animal foods and graminoids. Oats were the most important type of cereal affected by wild boar damage. Wild boar damage to cereals is caused by direct consumption, by trampling and removing the grains, and by wallowing in croplands (Schley et al. 2008; Amici et al. 2012). Damage to oats was recorded throughout the year, but chiefly in summer and in autumn, in conjunction with the milky stage of maturity for cereals.

Our model identified landscape features that increase the risk of crop damage: the risk was highest in areas close to the edges of forest and shrublands, with a high presence of permanent crops and a low presence of urban areas. The importance of permanent crops on wild boar damage distribution in our study area is probably linked to forage requirements; anthropogenic foods have a rich energetic content, and are often consumed by boars in large proportion (Schley and Roper 2003; Herrero et al. 2006; Ballari and Barrios-García 2014; Gentle et al. 2015). The exploitation of fields close to forests and bushy areas is quite common throughout the overall range of the wild boar (Meriggi and Sacchi 1991; Calenge et al. 2004; Wilson 2004; Honda and Sugita 2007; Cai et al. 2008; Thurfjell et al. 2009), and suggests that the distance to potential cover is important in influencing its foraging behavior. Different reasons may induce wild boars to forage close to edges; an easier escape in case of threat, probably linked to the avoidance of predators and human interference (primarily hunting) (Lima and Dill 1990; Tolon et al. 2009; Thurfjell et al. 2013; Morelle and Lejeune 2015), or the need to access thermal refuges (represented by forests and shrub associations) (Choquenot and Ruscoe 2003), which are particularly limiting in the Mediterranean Basin especially in summer, with high temperatures and scarce rainfalls.

However, our findings also indicate that an excessive presence of woods and Mediterranean maquis lowers the risk of damage. Therefore, we can hypothesize that wild boars preferentially exploit fragmented habitats and adopt a strategy of compromise, which optimizes the trade-off between the need for shelter (provided by woodlands and shrublands) and the need for access to energy-rich food resources (provided by permanent crops).

The frequency of damage also increased with a decreasing presence of urban areas. Although the wild boar is able to adjust its spatiotemporal behavior and food habits, as demonstrated by its presence in several European metropolitan areas (e.g., Cahill and Llimona 2004; Jansen et al. 2007; Podgórski et al. 2013), urban areas do not represent an ideal habitat for the wild boar, for which woodlands and shrublands commonly represent optimal habitats (Abaigar et al. 1994; Merli and Meriggi 2006). Furthermore, the presence of agricultural fields becomes rarer in the presence of cities and denser human settlements.

The analysis of spatiotemporal variation in boar-induced damage, together with the identification of factors that increase the risk of damage, can provide information contributing to the more effective management of wild boar populations, which could prove important in reducing damage to crops, but also reduce any adverse effect that wild boars have on the physical and biological components of ecosystems (Barrios-García and Ballari 2012; Bengsen et al. 2014). At present, in North-eastern Sardinia there is not a well-defined management strategy for the wild boar. The adoption of preventive measures and control activity are all but absent. Hunting is performed from November to January by drives with hunting dogs, wherein hunted animals are selected at random. Targeting particular classes of individuals should reduce the negative impact of the wild boar. In particular, it would appear advisable to increase the hunting pressure on medium- to large-sized females, which contribute disproportionately to population growth (Gamelon et al. 2012; Meriggi et al. 2016), and on yearlings, which disperse more widely than family groups, thus increasing the risk of damage (Keuling et al. 2008). It is also necessary to plan control activities both spatially, acting primarily in the areas most at risk, and temporally, concentrating control activities before the ripening period of grapes and the milky stage of maturity for cereals. In Sardinia, however, management strategies should also include the conservation of the endemic subspecies *Sus scrofa meridionalis*. Therefore, the adoption of preventative measures, such as the erection of electrified fencing around croplands, may prove the most effective tool in reducing crop damage while maintaining a viable population of this endemic boar subspecies.

To better explain the impact of the species on croplands and natural ecosystems, an analysis of the foraging behaviour of the wild boar and of the yearly availability of natural food resources (i.e., acorns and chestnuts) should be performed. Mast availability, in fact, has been repeatedly implicated as a factor influencing wild boar population dynamics and crop damage (Bieber and Ruf 2005; Servanty et al. 2009; Cutini et al. 2013).

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