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Original Paper

Impacts of Wildlife on Agriculture: A Spatial-Based Analysis and Economic Assessment for Reducing Damage

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Over the last few years, the impacts of wildlife on agriculture have constantly been growing, in particular in areas close to woodland and in hunting ban zones (‘‘refuge effect’’). Public administrations have difficulty in meeting the growing requests for crop damage compensation. The development of appropriate measures to control this trend—starting from the understanding of the dynamics concerned—is crucial. The aim of this study was, therefore, to analyze damage at regional scale and define common local actions. In particular, the study involved different steps that define a spatial-based classification of risk levels, integrating statistical methods (principal component analysis and receiver operating characteristic) with multi-criteria evaluation (MCE) in a geographic information system (GIS). It turns out that, in the study area, the very high-risk zones affect 8.83% of used agricultural areas; about 97% of them concentrated in the first 400 m from the most suitable habitats. A selected cluster of 11 test areas within these zones allowed us to assess the cost-effectiveness of integrated prevention and control actions (IPCA) with respect to the compensation of the damage. The analysis shows cost of IPCA to be nearly twice the actual cost incurred by the public administration to compensate partially the damage. The comparison with the estimated damage shows the overall economic convenience of the proposed investment with significant differences depending on the areas. Thus, we suggest reaching an ‘‘agro-ecological’’ balance starting from actions on specific areas; if they produce the desired effects, they could be progressively extended to other areas with gradual investments (adaptive management).

KEY WORDS: Wild boar, Crop damage, Risk model, Integrated prevention and control actions, Adaptive management.

INTRODUCTION

Over the past decades, in Italy, as in other European countries, there has been a significant increase in spatial distribution, density and abundance of wild ungulate species, especially wild boar (Erkinaro et al. 1982; Tellerìa and Saez-Royeula1985; Feichtner 1998; Melis et al. 2006; Klein et al. 2007; Carnevali et al. 2009; Riga et al. 2011), in those areas where the species was missing for some time, causing direct and indirect impacts on natural ecosystems and man-made land (Bueno et al. 2010; Burrascano et al. 2015; Cozzi et al. 2015a). In particular, the pressure exerted on agricultural crops by wildlife has become major problem for rural area management, contributing to increase costs for public administrations to compensate damages (Gill 1992; Horsley and Stout 2003; Lombardini et al. 2016).

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However, if farmers are suffering due to damage caused to crops by wildlife, hunters should push toward the growth of wild fauna populations to have greater hunting opportunities. This has led to conflicting interests in many European (Wenum et al. 2003; Calenge et al. 2004; Geisser and Reyer 2004; Herrero et al. 2008; Thurfjell et al. 2009, Apollonio et al. 2010; Bleier et al. 2012) and Italian areas (Brangi and Meriggi 2003; Amici et al. 2012; Cozzi et al. 2015b; Riccioli et al. 2018). These issues are often due to deficient management policies responding to sectoral reasons without providing long-term strategies. Indeed, the difficulty of managing the consistency of wild ungulate species and its impact on the ecosystem also descends from a territory divided into management institutes with different purposes: institutions where hunting activities are planned and institutions where such activities are forbidden. The European experience has shown that the occurrence of wildlife damage to crops may be regarded as a ‘‘physiological fact.’’ Therefore, it is not practical to aim for the elimination of the damage. Rather, it is necessary to pursue a path to achieve and maintain a socially, economically and ecologically acceptable equilibrium (Monaco et al. 2010).

Based on a historical spatial database of damage caused by wild animals, the objective of this study is to build a geographic information system (GIS)-based risk model aimed to identify areas with very high risk of damage from wild boar, and to propose appropriate measures to reduce the trend. The model was applied to the Basilicata region (southern Italy), where agriculture plays an important role in the regional economy integrated with protected areas, which account for about 30% of the whole regional area.

Indeed, the literature proposes specific studies applied to local contexts (Boone et al. 2006; Li et al. 2013; Riccioli et al. 2018) but lacks large-scale applications. In particular, the proposed study represents an evolution of the model proposed by Cozzi et al. (2015a). We expanded the scale of detail at a regional level because we believe that a large-scale approach, as a first step, might provide a valuable framework for common land planning that could result in additional lower-level local assessments. In fact, some authors consider the mismatching of ecological process scales (such as floods, fires or, in this specific case, crop raiding by wild animals) and the actions of the institutions in charge of their management may contribute to reduce socio-ecological resilience (Cumming et al. 2006). Moreover, in the literature there is no specific study combining the risk analysis with the economic feasibility of integrated prevention actions aimed to reduce crop damage.

The contribution of the approach proposed here lies in the application of a framework, which incorporates (a) the fuzzy set theory to standardize damage predictor variables, (b) the principal component analysis (PCA) (Pearson 1901) applied to elicit weights concerning relative importance of the variables and (c) the weighted linear combination (WLC) (Carver 1991) aggregation method, to compute a map damage risk, validated by receiver operating characteristic (ROC) (Lusted 1971). The risk map was obtained by identifying a series of factors related to the occurrence of damage by wildlife to agricultural crops. These factors have been identified in the literature and validated through correlations with the damage events, during 2007–2012, recorded in a spatial database. The set of predictor variables are related to a trophic component, a territorial component and an anthropic component. Subsequently, in high-risk zones, test areas were selected in which an economic analysis was conducted in order to compare the costs of integrated prevention and control actions with respect to damage compensation ones. Figure 1 represents the scheme of the methodological procedure followed in this study.

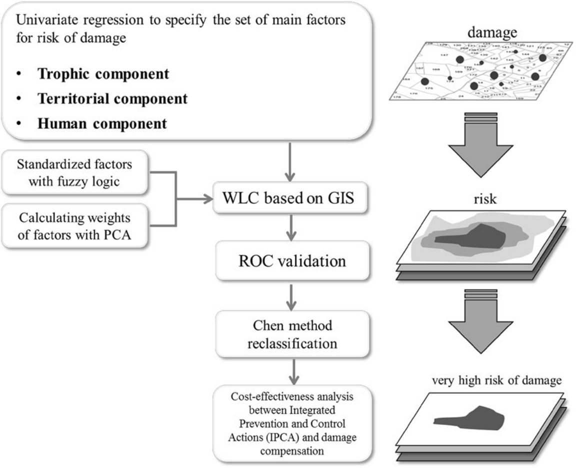

Fig. 1. Flowchart of methodological procedure.

MATERIALS AND METHODS

Study Area

The Basilicata region is located in the south of Italy (40° 30′ 14″ North, 16° 6′ 50″ East) with surface area of 9992 km^2 and population density of about 61 inhabitants per km^2. It is characterized by high geomorphological diversity (46.8% of the area is mountainous, 45.2% is hilly, and only 8% is covered by flat morphology) with rich hydrographic network. Its elevation ranges between 0 and 2267 m a.s.l.; temperatures vary from − 15°C in winter to 35°C in summer, and rainfall ranges from 500 mm to 1200–1300 mm (Fig. 2).

As in the other rural regions, agriculture plays an important role in the rural economy, due to the significant weight of employment involved in the sector and the wide range of typical and quality agri-food products (Viccaro et al. 2018). The agricultural land covers about 67% of the regional surface area. According to the last agricultural census (ISTAT 2018a, b), the utilized agricultural area (UAA) is 519,127 ha (52% of the total regional area), mostly dedicated to cereal cultivation on non-irrigated arable land (158,851 ha), followed by olive groves (31,351 ha), vegetable and orchards on permanently irrigated land (about 16,000 ha) and vineyards (5361 ha). These areas are an important source of food for wild boar, especially those close to natural environments such as forests, where the same animals find refuge. The forest area covers 354,895 ha (about 35.6%) of the total regional area, consisting mainly of mesophilic and meso-thermophile oak woods (51.8%), beech forests (10%), Mediterranean maquis (7.9%), thermophilous shrublands (6.9%) and other mesofile and meso-thermophilous broad-leaved woods (5.5%) (Corona 2006). These areas represent an ideal habitat for the wild boar, a native species that has always populated the region. However, over the years the continuous, often abusive, introduction of highly prolific non-native breeds has led to an increase in spatial distribution, density and abundance of wild boar, of which there is little knowledge. To date, in fact, there is not a complete and adequate regional framework with respect to the consistency and structure of the age and sex classes of wild boar population. Several studies highlight the increasing spread of the species to the entire regional territory and the presence, in its management, of too many institutions. In particular, on the basis of Law 394/91 and Law 157/92 there is a territory represented by a mosaic of hunting territorial areas (HTA) and hunting ban areas in various capacities (national and regional parks—L. 394/91, and protection oasis, restocking and capture areas—L. 157/92). In the territory, there are nine institutions (see Fig. 2), which have their own wildlife management regulations, that make it difficult to control the species. The result of the difficulty of management implies a considerable amount of damage to agricultural crops. This represents an element of criticality for farmers, in particular in obtaining the correct compensation for the damage received (estimated damage—ED) which is only a percentage (compensation provided—CP) of the actual amount. It is also difficult for public administrations who also have to bear a high social cost.

Data Collection and Analysis of Factors Affecting Damage

In order to understand the wild boar damage trends in the study area, a database of damages was created based on the 8600 requests submitted by farmers who endured wildlife damage in the study area from 2007 to 2012. The recorded information includes the cadastral location, the species, the damaged surface and crop type, the year, the percentage of damage, the market price of the agricultural product, and the estimated and indemnified compensations. We detected a damaged surface of about 27,000 ha, caused especially by wild boar (95% of the damage), corresponding to an ED of 5.1 million €, of which about 2.8 million € was the CP, namely 54% of the ED. Most of the damaged surface concerns cereal crops (3000 ha damaged only in 2012).

In order to enter the data drawn from the requests in a GIS, the database was further broken down so that each record corresponded to a land parcel, obtaining 24,000 records (see Fig. 2). This allowed us to create a map with the geographic distribution of damages in order to correlate these damages to different factors that may affect their occurrence. Indeed, it was found that one plot out of three was affected more than once in the six-year period. This induces us to predict a systematic or customary trend of the species to raid the same plot, probably due to the crop type and localization conditions favorable to damage. This suggested the possibility of developing a logical model (risk mod-

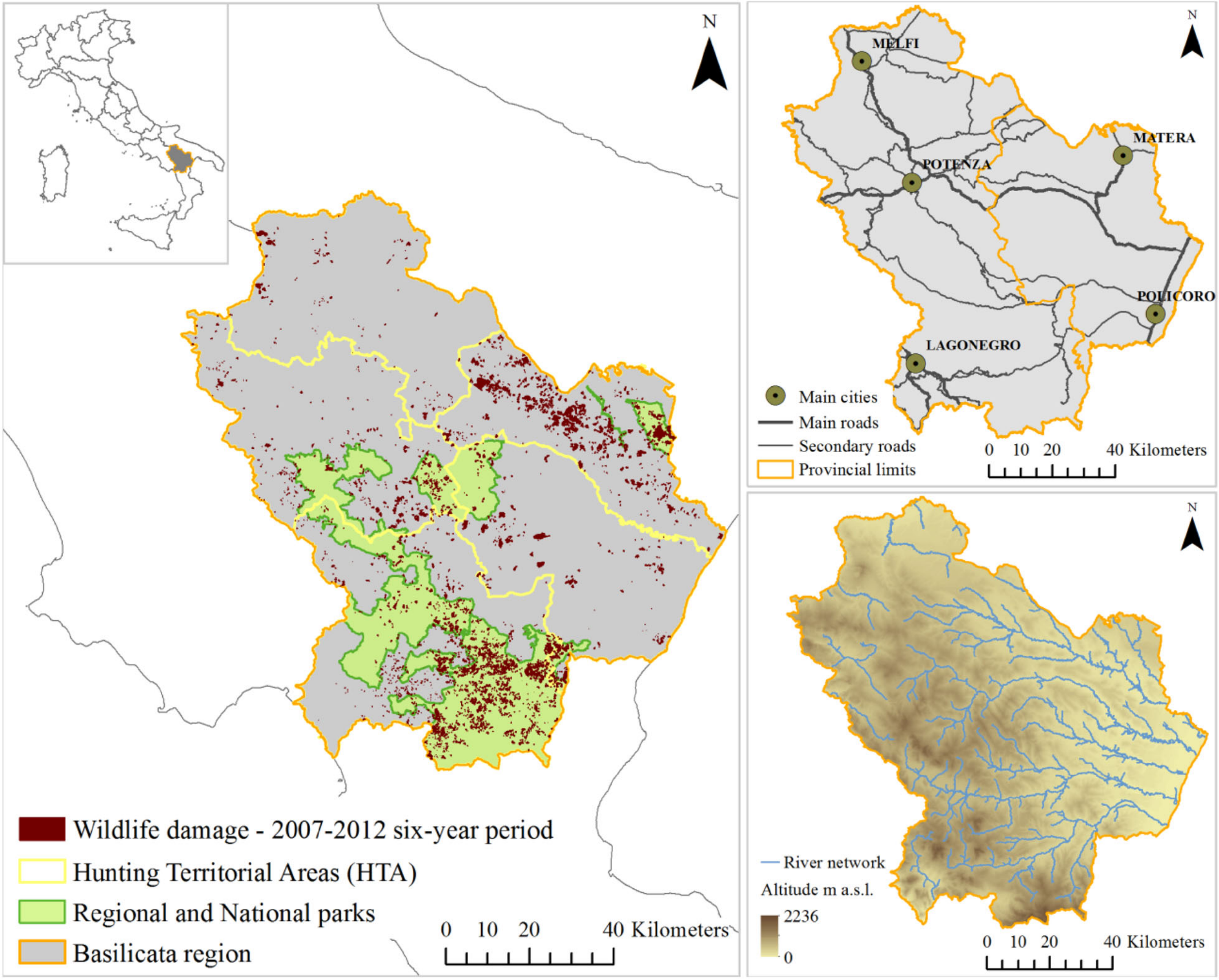

Fig. 2. Study area and wildlife damage in 2007–2012 six-year period.

el) to identify the areas having a greater propensity to damage.

A recent study (Riccioli et al. 2018) highlighted how the characteristics of an area can significantly affect the number and distribution of ungulates. In particular, it was noted that the presence of such animals does not depend solely on environmental factors (e.g., presence of ecological corridors), but also on factors related to human activities, such as the presence of farms or artificial areas. A greater presence of ungulates was recorded precisely in correspondence with the agricultural areas that are therefore more susceptible to damage.

Other studies (Calenge et al. 2004; Cocca et al. 2007; Honda and Sugita 2007; Cai et al. 2008; Herrero et al. 2008; Schley et al. 2008; Thurfjell et al. 2009; Amici et al. 2012; Cutini et al. 2013; Li et al. 2013; Ballari and Barrios-García 2014), more specifically, have focused on the analysis of the relationships between a number of factors (environmental and otherwise) and cases of wild boar damage to agricultural crops. These factors are essentially linked to the sense of safety and the presence of forage. Safety factors include the presence of humans, the distance from the edge of forests and the distance from the nearest roads and rivers (Calenge et al. 2004; Cocca et al. 2007; Honda and Sugita 2007; Cai et al. 2008; Thurfjell et al. 2009). In contrast, forage factors include type, abundance and ripening time of agricultural crops

(Herrero et al. 2008; Schley et al. 2008; Li et al. 2013; Ballari and Barrios-García 2014) and at the same time the presence of food in natural environments, such as the production of seeds in deciduous forests (Cutini et al. 2013). Other authors have suggested that crop damage is positively correlated with abundance of wild boar in an area (Schley et al. 2008) and negatively correlated with hunting. Amici et al. (2012) also highlight the importance of topographic factors (e.g., altitude) and of an often neglected factor, i.e., the legal status of the species (hunting or hunting ban). In fact, they point out that the widespread presence of hunting ban areas plays a role of "refuge," contributing to increasing the risk of damage to crops.

Considering the above-mentioned factors as well as the data available, a univariate nonlinear regression analysis was initially performed in order to define the variables linked to the damage. We used damage density (divided by year) as dependent variable, and trophic, territorial and human disturbance components as explanatory variables (Table 1). A trophic variable was extracted from the 2012 Corine Land Cover (CLC) database (scale 1:25,000) (EEA 2018) (Amici et al. 2012; Lombardini et al. 2016; Riccioli et al. 2018); according to the CLC legend, used agricultural surfaces (code 2 of the first level) were considered. Apart from the land cover dataset, we included in the territorial component distance from forests/shrublands, distance from rivers and altitude (Amici et al. 2012). Distances were calculated using the method of Euclidean distance, while altitude was derived from a digital terrain model (DTM; cell size 100 m) produced by the Italian Military Geographic Institute. Thus, the distance between each damaged site, considering its centroid, and the edge of the nearest patch of forest/shrubland was measured, as wild boar uses forests and shrublands as refuge areas (Saj et al. 2001; Calenge et al. 2004; Honda and Sugita 2007; Linkie et al. 2007; Thurfjell et al. 2009). Distance from the nearest river was measured because the flow channels provide passage for the wild boar from wooded areas to cultivated land, especially in summer (Cai et al. 2008). Four human disturbance variables include human population density (ISTAT 2018a, b) (Cai et al. 2008; Lombardini et al. 2016), distance from roads (Lombardini et al. 2016), distance from urbanized areas (Cai et al. 2008) and distance from hunting ban areas to evaluate the existence of "refuge effect" (Amici et al. 2012; Lombardini et al. 2016).

Spatial-Based Classification of Risk Levels

In order to combine the variables maps useful to define the risk-damage map, we used the WLC, one of the most widely applied multi-criteria evaluation (MCE) methods in GIS (Malczewski 2000). Although MCE-GIS techniques have been widely used in the land use suitability analysis (Carver 1991; Eastman 1997; Thill 1999; Malczewski 2004; Romano et al. 2013; Viccaro et al. 2017), in the last few years they have also been applied for risk analysis, such as soil erosion vulnerability (Zaimes et al. 2012), landslide susceptibility (Kouli et al. 2014), ecological risk assessment of wetland ecosystems (Malekmohammadi and Blouchi 2014), wildlife risk (Cozzi et al. 2015a) or fire risk (Goleiji et al. 2017). The integration of MCE with GIS techniques may be useful for managing and solving conflicting situations in spatial contexts (Janssen and Rietveld 1990; Malczewski 1996). It can be considered as a process that combines and transforms evaluation data (input maps) into a resultant decision (output maps), by a specific aggregation rule. One of the main problems in choosing the aggregation rule is the risk involved in the analysis, especially when the risk is difficult to define. For this reason, among different MCE-GIS methods, the WLC method has become one of the most widespread methods because it can be defined as a neutral-towards-risk strategy (Malczewski 2004).

The WLC approach involves the standardization of spatial variables and the definition of the weights of relative importance to the variables; then, by combining the weights (w_i) and standardized maps (μ_i), the overall score (S) of damage risk is obtained as (Malczewski 2004):

$$S = \sum w_i \mu_i \tag{1}$$

In this study, the spatial variables were standardized in a scale ranging from 0 to 1 by density function. The knowledge of experts can be used in the fuzzy classification, but in this study, damage risk was calculated by the average damage density from the six-year period (2007–2012), based on appropriate fuzzy functions. A similar approach was used by Gorsevski et al. (2006) to evaluate the risk of landslide based on categorizing predictor variables that are coded by computing landslide density and are ordered based on related significance of landslide hazard.

The attribution of weights to variables is an important process. For this purpose, PCA (Saito

Table 1. Factors statistically analyzed

Name	Units	Risk component
Type of vegetation	Classes	Trophic
Distance from woodlands and shrublands	Meters	Territorial
Distance from rivers	Meters	Territorial
Altitude	Meters a.s.l.	Territorial
Human population density	Population x square kilometer	Human disturbance
Distance from roads	Meters	Human disturbance
Distance from urbanized areas	Meters	Human disturbance
Distance from hunting ban areas	Meters	Human disturbance

et al. 2012; Jolliffe 2014; Cozzi et al. 2015b; Riccioli et al. 2016) was applied. The PCA is a multivariate statistical technique used to examine the relationships between different quantitative variables (Pearson 1901; Hotelling 1933). It first calculates a correlation matrix, so that high coefficients correspond to variables that are highly correlated with each other and are, subsequently, redundant. Therefore, the PCA measures the relative importance (weights) of the variables that are not excluded from the model. For each variable, it concerns the cumulative contribution of eigenvectors of the main components, multiplied by the eigenvalue referred to each component (Alleva and Falorsi 2009; Sanguansat 2012).

To validate the risk model, the ROC analysis was applied (Zweig and Campbell 1993; Scott et al. 2002; Amici et al. 2012) via the study of the function that links—in the model—the probability of obtaining a positive real result, in the class of presence, to the probability of obtaining a false positive result, in the class of absence. From the ROC graph, it is possible to calculate the area under the curve (AUC), which provides an indication of model performance. According to Swets classification (1988), the value of the AUC ranges from 0.5 to 1, where 0.5 is for a model with no discrimination between presence/absence and 1 for a model with perfect discriminating capacity. Differently from the Cozzi et al. (2015b) study, in our study the ROC allows us to opt for the development of a unique risk map, which permits the validation of the model through its comparisons with real data.

Cost-Effectiveness of Mitigation and/or Compensation Actions

In order to reduce the damage to agricultural crops, the cost of the actions to be taken must be lower than the value of the damage suffered or the cost of compensation. In the second case, the public entity could benefit from undertaking such actions. For this reason, the annual cost for integrated prevention and control actions (C_{IPCA}) was estimated, in order to be able to compare the value of the ED and the CP.

The C_{IPCA} was calculated as:

$$C_{\mathrm{IPCA}} = C_{a_{\mathrm{LEF}}} + C_{a_{\mathrm{TC}}} + C_{\mathrm{DF}} + C_{\mathrm{O}} \qquad (2)$$

where $C_{a_{\mathrm{LEF}}}$ is the amortization rate of the initial investment for linear electrical fencing $C_{\mathrm{inv}_{\mathrm{LEF}}}$, $C_{a_{\mathrm{TC}}}$ is the amortization rate of the initial investment for trap-cages $C_{\mathrm{inv}_{\mathrm{TC}}}$, C_{DF} is the annual cost for deterrent foraging, and C_{O} is the annual operating cost for maintenance and surveillance.

Among the preventive measures envisaged to control the damage caused by wild boar, over the last few years, protection by electrical fencing has provided excellent results in tests conducted by different authors (Boisaubert et al. 1983; Geisser and Reyer 2004). In this study, the attention was focused particularly on linear barriers—linear electrical fencing (LEF), mainly recommended for large-scale actions. Indeed, using 800 m of electrical fence, for example, it should be possible at least to protect 4 hectares (considering a square field with sides of 200 m). Using the same 800 m in linear way, it should be possible to protect up to 32 hectares (considering that protection can extend to fields up to 400 m from the fence) (Vassant 1994; Santilli and Stella 2006). Differently from Santilli and Stella (2006), we have considered more than one test area.

The purchase cost was obtained from recent tests conducted within the Rural Development Programme 2007–2013 of the Emilia Romagna region, indicating values ranging between 765 and 890 € per km, whether or not they were connected to the electricity network. The installation cost, amounting to around 736 €/km, was added to the purchase cost. The time needed to install linear fencing was drawn from an analysis conducted in France by the Office National de la Chasse (ONC 1981), whereas the cost of labor was taken from the collective bargaining agreements for the workers involved in forest, watercourse management and rural engineering work. It is important to underline that the realization of the LEF was foreseen only for the district's agricultural/natural environment interface lines. It was necessary to determine its geometry, in particular the semi-perimeter, to take into account that the barrier is not necessary in the whole area. The investment cost also includes the purchase cost of the trap-cages (TC) equal to 550 € each one for the control of the wild boar population to be placed along the barriers for a width of 15 m (Monaco et al. 2010). These systems have the advantage of having little impact on other zoocoenoses. They can in fact be placed on the edge of agricultural areas and allow selective population control. However, it should be noted that catches are not necessarily an alternative to hunting. In fact, these two withdrawal methods can be used in synergy in the same area (perhaps at different times in the annual cycle) (Monaco et al. 2010). Thus, considering a life time investment of 5 years for the LEF (n) and of 10 years for the TC (m) and a rate r equal to 2.5%, the total amortization cost, both for LEF (Eq. 3) and TC (Eq. 4), can be calculated, respectively, as:

$$C_{a_{\mathrm{LEF}}} = C_{\mathrm{inv}_{\mathrm{LEF}}} \frac{r(1+r)^n}{(1+r)^n - 1} \tag{3}$$

$$C_{a_{TC}} = C_{\mathrm{inv}_{\mathrm{TC}}} \frac{r(1+r)^m}{(1+r)^m - 1} \tag{4}$$

The value of r derives from the fixed rate for ordinary loans from the deposit and loan fund (CDP) for public funding, considering that it is an investment with a low risk.

Moreover, to prevent the population of wild boar moving to other agricultural areas, thus eliminating the effect of using fences for protection, a dissuasive feeding (DF) was also suggested. Approximately 40 kg/km of maize should be distributed every three days in the most critical months (from June to September) along barriers, covering a belt 15 m wide (Monaco et al. 2010). We considered a wholesale price of maize of 200 € per ton (Ager 2018).

The C_{O} relates to the maintenance and surveillance of fences (brush cutting, periodic maintenance, repair work). The cost for brush cutting was taken from the FIMAV (2012) rate table of mechanical agricultural work on the behalf of a third party, whereas the cost for periodic maintenance and repair work, as well as the surveillance, was quantified as 10% of $C_{a_{\mathrm{TOT}}}$(given by $C_{a_{\mathrm{LEF}}} + C_{a_{TC}}$), which was summed to the other costs.

In order to compare the annual C_{IPCA} and the values of ED and CP, an average annual value was calculated for the two latter values after being discounted considering the right inflation rate.

RESULTS AND DISCUSSION

The selected variables standardized by fuzzy membership functions based on the relation with the average damage density from the 2007–2012 six-year period are shown in Figure 3.

The most important variables selected as risk predictors are the ‘‘distance from woodlands and shrublands’’ ($R^2 = 0.99$) with a linear decreasing function and the ‘‘distance from hunting ban areas’’ with a nonlinear decreasing function ($R^2 = 0.98$) that outline a high risk in extensive farming areas, mostly cropped with cereals ($R^2 = 0.98$), and bordering woodlands (within 400 m). This risk increases in large hunting ban zones as well as in a buffer area with decreasing gradient up to 10 km (Table 2). Indeed, a crucial element that results from this study and explains the crop damage is the ‘‘refuge effect,’’ as indicated by other authors (Amici et al. 2012). This variable, which is increasingly important over time, can indirectly discriminate the possible effects derived from the presence/absence of hunters, who influence the damage distribution across the territory, as they cause imbalances in population density (Cahill et al. 2003).

Given the topography and hydrography of the area under study, characterized by rivers that run through woodlands and cultivated plains, the ‘‘distance from rivers’’ variable turned out to be an important predictor ($R^2 = 0.98$), with a concentration of damage in the first 1000 m. This is probably because rivers, especially ephemeral streams, act as ecological corridors in summer (Cai et al. 2008). The trophic aspect is important considering that code 211 of the CLC corresponds to unirrigated arable crops, which include autumn–winter cereal (durum wheat,

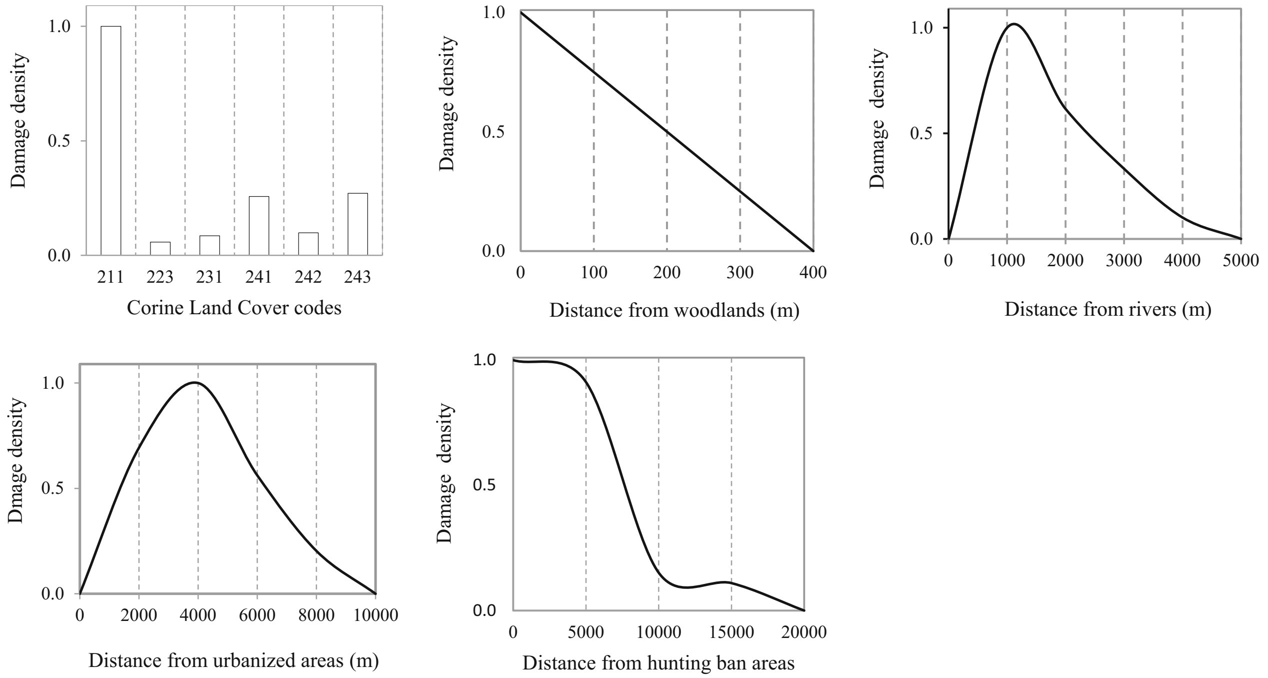

Fig. 3. Fuzzy membership functions based on the relation with damage density.

Table 2. Occurrence of damages in the six-year period (2007–2012) in large hunting ban areas and within the first 10 km

Period	Large hunting ban areas (%)	Buffer 0.5 km (%)	Buffer 10 km (%)
2007–2010	56	59	82
2011	47	51	82
2012	43	48	85

common wheat, oats and barley), and are the most common crops in the area; they have high energy value and are available in the spring–summer period when the preferred feed of wild boar (acorns, beechnuts and chestnuts) are not available in the woods. The variable ‘‘distance from urbanized areas’’ (R^2 = 0.93) has a minor contribution. However, there is more damage in the first 4,000 m that gradually declines with increasing distance. Altitude (R^2 = 0.51), distance from roads (R^2 = 0.55) and human density population (R^2 = 0.59) are not significantly related to damage density. In particular, roads can negatively affect wildlife species by creating barriers to movement (Forman et al. 2003). However, the spread of invasive species can also be facilitated by roads (Coffin 2007). Additionally, many vehicle collisions with wild pigs and other wildlife occur on roadways (Litvaitis and Tash 2008; Beasley et al. 2014; Lister et al. 2015; Thurfjell et al. 2015). Therefore, studying the effects of roads as barriers or facilitators to animal movement will continue to be a critical component of wildlife conservation and will help reduce the risk of human-wildlife conflict.

Thus, only the variables significantly related to damage density ($R^2 > 0.90$) were analyzed by PCA and, showing a low correlation (Table 3), were considered in the risk model. The results of PCA are mainly related to loadings (see Table 4), which represent the weights by which each standardized original variable should be multiplied to get the component score (S) (see Table 5).

Table 3. Correlation matrix of variables

Variables	Distance from woodlands	Distance from rivers	Distance from hunting ban areas	Distance from urbanized areas	Type of vegetation
Distance from woodlands	*1.00*	– 0.04	0.39	0.15	-0.66
Distance from rivers	– 0.04	*1.00*	0.13	– 0.00	0.06
Distance from hunting ban areas	0.39	0.13	*1.00*	0.09	– 0.33
Distance from urbanized areas	0.15	– 0.00	0.09	*1.00*	– 0.01
Type of vegetation	– 0.66	0.06	– 0.33	– 0.01	*1.00*

Table 4. Loading table

	*c*1	*c*2	*c*3	*c*4	*c*5
Distance from woodlands	0.89	0.09	0.02	0.32	0.32
Distance from rivers	0.02	0.63	0.77	0.08	0.00
Distance from hunting ban areas	0.53	0.74	0.39	0.14	0.03
Distance from urbanized areas	0.12	0.07	0.14	0.78	0.59
Type of vegetation	0.89	0.23	0.17	0.25	0.26

Table 5. Weights of selected variables

Variables	Weights (w_i)
Type of vegetation	0.236
Distance from woodlands and shrublands	0.207
Distance from rivers	0.182
Distance from urbanized areas	0.123
Distance from hunting ban areas	0.252

Applying Eq. 2, the risk mapping with a range between 0 and 1 was obtained (Fig. 4a). The AUC is 0.684, meaning that 68.4% of the time a random selection from the positive group will have a score greater than a random selection from the negative group adherent to the actual data.

To reclassify the risk map for agricultural areas, the Chen method (Chen and Hwang 1992) was used to convert verbal terms into numerical values and vice versa, using an appropriate scale of linguistic terms. It is possible to distinguish eight types of scale. These scales refer to the terms ''high'' and ''low'' with various intermediate nuances, depending on the decision problem to be analyzed. In our study, we used scale 5, for which six risk classes were identified: very low < 0.08, low between 0.08 and 0.25, relatively low between 0.25 and 0.42, relatively high between 0.42 and 0.58, high between 0.58 and 0.75 and very high > 0.75 (see Fig. 4b). In particular, the very high class covers 50,547 ha (8.83% of UUA).

By relating the reclassified risk map with the species suitability map, which was developed at a regional scale within the provincial wildlife-hunting plans (Cozzi et al. 2013), it was found that the very high-risk areas (Fig. 4c) were approximately 97% concentrated in the first 400 m from the most suitable habitats. This confirms that wild boars move from their habitat to the neighboring areas, especially in times of food scarcity.

Thus, from the reclassified risk map, 11 test areas were selected within the very high-risk class (Fig. 5a), in which large cultivated areas are interposed with highly suitable areas (Fig. 5b). The cost-effective assessment is based on the cost incurred to compensate for the damage; it was assumed that part of this amount was allocated to investments aimed at combating/preventing the phenomenon. This expenditure is expressed in terms of annual value to be compared with the ED and CP to farmers who endured damage, specifically referred to the agricultural districts involved in the planned work. Considering an annual amount of about 500,000 € spent to compensate for the damaged crops, we assumed to reinvest a share of it in integrated management work to protect crops. This share, equal to about 1/5 of the annual amount, is related to the need to have a sufficiently high sample of areas that could represent an effective tester, while maintaining a precautionary attitude in case of possible failure of actions.

The C_{IPCA}, calculated for the 11 test areas, sums to approximately 108,000 €/year, varies between a minimum of about 4500 €/year and a maximum of

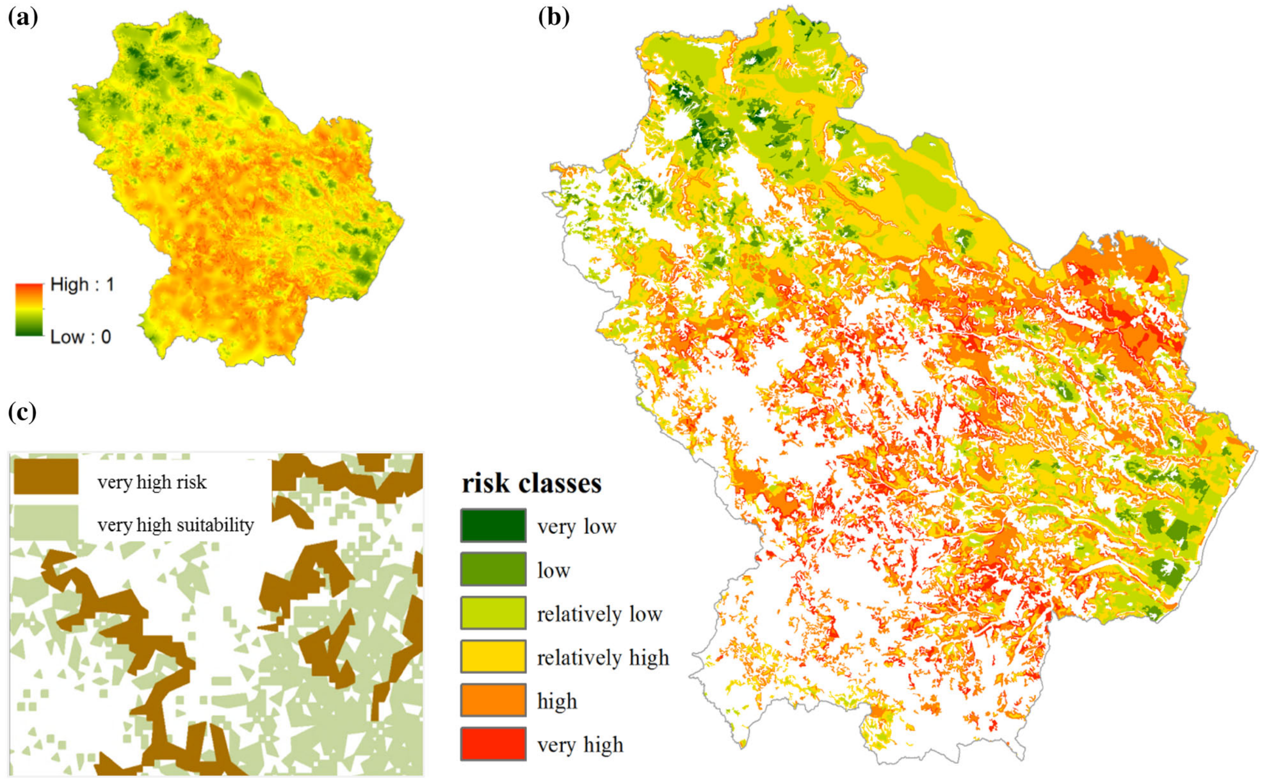

Fig. 4. (**a**) Risk map, (**b**) risk classes within agriculture areas, (**c**) detail of the relation between very high-risk class and very high suitability class.

about 21,000 €/year depending on its length. It consists of about 33,600 €/year for LEF, about 6000 €/year for TC and about 25,000 €/year for DF; the average C_{IPCA} per test area was about 9800 €/year (Table 6). The overall investment is nearly twice the actual cost incurred by the public administration to compensate damages—CP (about 57,400 €/year) of agricultural lands falling within the districts the Integrated Prevention and Control Actions (IPCA) are expected. The comparison with ED (120,000 €/year) shows, however, the overall economic convenience of the proposed investment. Thus, it can be said that using the CP as a threshold for assessing cost-effectiveness does not seem to be correct, because it does not reflect the actual amount of damage caused to farmers (the CP ranges between 20% and 80% of the ED in the test areas) and, more generally, to the agricultural system. Therefore, the proper threshold for cost-effective assessment is the ED. A more careful analysis of Table 6 for each area allows us to highlight different situations. This variability depends on the characteristics of the territory (e.g., conformation of the agricultural/natural interface, which affects the perimeter) and the economic value of the crops prevailing in the agricultural district (e.g., vineyards rather than corn). Thus, we have areas (areas No. 4, 5, 10 and 11; Fig. 5a) where the IPCA is not convenient with an investment that would cost at least twice the estimated damage. However, in the other test areas the IPCA has an equal cost to the ED (i.e., the areas No. 1, 3, 6; Fig. 5a) or less than the ED (about 1/3 compared to ED as in the areas No. 2, 8, 9; Fig. 5a). The possibility of identifying specific areas with different degrees of convenience supports the importance of adopting a spatial model.

CONCLUSIONS

The damage caused by wildlife to agriculture as well as to rural systems is a major problem for operators, particularly in less developed and productive areas. In this scenario, the public adminis-

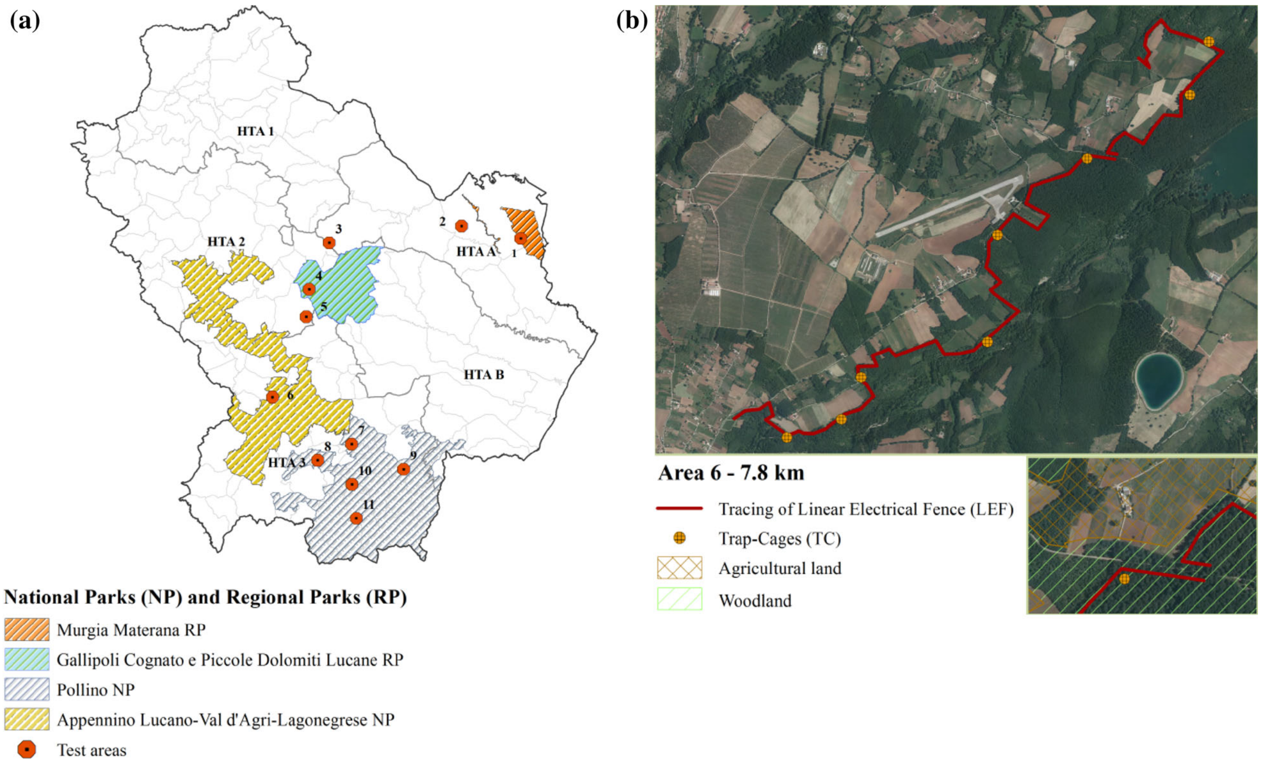

Fig. 5. (**a**) Test areas, (**b**) large cultivated areas interposed with highly suitable areas.

Table 6. Analysis of cost items

Test areas	Track barrier km	$C_{\mathrm{inv}_{\mathrm{LEF}}}$ €	$C_{\mathrm{inv}_{\mathrm{TC}}}$ €	$C_{a_{\mathrm{LEF}}}$ €/year A	$C_{a_{\mathrm{TC}}}$ €/year B	C_{DF} €/year C	C_{O} €/year D	C_{IPCA} €/year $A + B + C + D$	ED €/year	CP €/year
Area 1	8.8	15,050	5500	3239	628	2829	4302	10,999	10,653	9376
Area 2	16.1	31,113	9900	6697	1131	5152	7915	20,895	51,449	11,057
Area 3	4.0	6350	2200	1367	251	1280	1937	4835	4175	2887
Area 4	12.4	22,536	7150	4850	817	3968	6065	15,701	970	609
Area 5	5.8	10,596	3300	2281	377	1866	2852	7375	4212	860
Area 6	7.8	13,279	4400	2858	503	2496	3796	9653	8734	6338
Area 7	9.4	16,003	5500	3445	628	3008	4574	11,655	7415	5620
Area 8	3.7	5874	2200	1264	251	1184	1791	4491	13,783	8466
Area 9	3.8	6032	2200	1298	251	1216	1840	4606	11,234	6727
Area 10	6.4	10,896	2200	2345	251	2048	3115	7759	1979	1196
Area 11	10.2	18,538	6050	3990	691	3264	4989	12,935	5601	4217
Total	88.5	156,266	50,600	33,636	5781	25,046	43,175	107,639	120,204	57,403

tration should play a crucial role, acting as mediator between natural and productive components in the area. In the present study, we developed a regional analysis to assess the damage of wild boar to crops and its economic effects, improving knowledge gained by previous studies on the subject. In the same context, the lack of coordinated strategies for species management, combining hunting and protection interests, actually prevents appropriate planning and control of the impacts of wildlife on man-made activities (Monaco et al. 2010). Furthermore, the area under study is characterized by a wide range of environments that—added to the protection levels guaranteed by law of animals and plant species living in protected territories—causes a high concentration of wild animal species in particular areas, generating significant damage to the existing agricultural systems. The applied analysis draws attention to the closeness to woodlands, with special reference to large hunting ban areas, where the population of wild boar is probably higher than in hunting zones. Therefore, the ‘‘refuge effect’’ has a great influence causing an increase in damage close to sink areas, where the species is not managed or is mismanaged and tends to spread even to adjacent territories (‘‘buffer’’ areas). An important point is that the authorities involved (region, province, parkland Authorities) have failed to implement procedures for an accurate numerical estimate of the species population in the area. At present, no census data that could provide these indications exist. This is the reason why we developed a tool that uses the damage occurred as datum—based on the assumption that a greater amount of damage would correspond to a greater presence of the species—and would be able to return a probabilistic measure of the expected damage, or risk as output.

This study showed that, based on the identification of some land-based and man-made variables connected with wildlife damage, it is possible to build a damage risk map on which to focus the actions to reduce the damage. However, we need to carry out direct field surveys to check the actual effectiveness of what is proposed by the applied methodology. Nevertheless, the implemented risk model would be of high practical value if updated by a database of the annual damage occurred, acting as a valid basis to establish, year by year, the location and action priorities. Results showed that targeted actions to downsize the effects of crop damage in the long-term perspective might be envisaged. The effectiveness of the above actions also depends on other factors that need to be controlled. For example, no fences or obstacles could prevent entry if there is not sufficient feed supply in natural environments. Therefore, these controls might be successful only if integrated with additional measures (e.g., feeding in periods of natural food deficit). Therefore, the objective of the actions is to achieve an ‘‘agro-ecological’’ balance between the total social and economic cost of crop damage—in terms of refund and prevention—and a sufficient population size to maintain the ecological role of the species in the protected ecosystem (Mattioli et al. 1995). In this sense, there are no absolute indications in terms of optimal density and size; each context necessitates its own solution, which is to be sought by trial and error (adaptive management). We decided to suggest actions on specific areas where to test the effectiveness of preventive means; if the actions produce the desired effects, they could progressively be extended to other areas with gradual investments.

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