SCUOLA DI DOTTORATO
UNIVERSITÀ DEGLI STUDI DI MILANO-BICOCCA

Department of

Environmental and Earth Sciences

PhD program: *Chemical, Geological and Environmental Sciences*; Cycle: *XXXIII*

Curriculum in *Terrestrial and Marine Environmental Sciences*

Wild boar impacts on crops and nemoral flora in lowland areas of northern Italy

Surname: Cappa Name: Fabrizio

Registration number: 835775

Tutor: Prof.ssa Sandra Citterio

Supervisor: Prof. Luciano Bani; Prof. Alberto Meriggi

Coordinator: Emilio Padoa-Schioppa

ACADEMIC YEAR 2019/2020

Abstract

The growth and expansion of natural populations of ungulates in Europe have raised several questions on human and wildlife cohabitation, on the potential negative impacts on human activities and other environmental components. My thesis focuses on a particularly involved species, the wild boar (*Sus scrofa*). Understanding the habitat selection by the wild boar, which demonstrates great adaptability to different environmental conditions, represents the first fundamental step for identifying the potential criticalities related to its presence, both in natural and anthropized contexts. The habitat selection by the wild boar was studied in the Ticino Valley Regional Park (**Chapter 1**) located in Lombardy, northern Italy. The study was carried out collecting data on distribution and abundance of presence signs along 30 itineraries (average length of 8.02 km, SD = 2.97) surveyed in autumn-winter and spring. We firstly compared the use of the different habitat types with their availability by the Manly-Chesson α index. To estimate the effect of habitat composition on wild boar presence we formulated a Resource Selection Probability Function (RSPF) by Binary Logistic Regression Analysis (BLRA). To analyze the attendance of the different types of habitats by the species we carried out correlation and regression analyses between the Index of Kilometric Abundance (IKA) and the percentage of habitat types on the itineraries. Wild boar mainly selected woodland during the whole year, coniferous forests are used as availability while rice fields and urbanized areas are avoided. The meadows are mainly used during autumn and winter while in spring the presence of wild boar was higher in areas where the length of the forest edges is greater. The logistic model formulated show that high-density deciduous forests positively affected the probability of wild boar presence. Meadows and fields instead showed a negative influence. The results suggest that the most favorable habitat for wild boar is the deciduous forest while the cultivated areas represent a temporary habitat used mainly for feeding.

Crop damage represents one of the main sources of conflict; in highly anthropized contexts, characterized by high agricultural use of the land, the negative impacts of wild boar raids in the fields often lead to serious economic losses due to the destruction of crops and the consequent loss of production. Understanding the spatiotemporal variation of damage events and the factors that increase the damage risk is crucial to the development of effective management strategies. In order to assess the wild boar impacts in an area with those characteristics (**Chapter 2**), the Special Protection Area "Risaie Della Lomellina" (western Po Plain, North-western Italy) was the subject of a study that aimed to determine the impact of wild boar on croplands and to formulate a risk prediction model through 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.

The conflicts linked to the presence of the wild boar are even more evident in the lands included in protected areas, where the continuity between woods and fields favors the movement of wild boars from the refuge areas to the crops.

Protected areas located in plains, such as the Ticino Valley Natural Park, are characterized by the coexistence of important natural habitats and intensive agricultural areas (**Chapter 3**). In the Park, from 2010 to 2017, 49% of the complaints report an event of damage to maize and 43% to meadows. The total expense for reimbursements of the maize amounted to € 439,341.52, with damages concentrated in May, after the sowing period, and between August and September, during the milky stage of maize. For meadows, reimbursements amounted to € 324,768.66, with damage events concentrated in February and March. To reduce damage to crops, the Park administration carried out lethal control of the wild boar population. From 2006 to 2017, the most used control method was culling from hides. In our analysis, we did not find significant relationships between the number of shot boars and the amount of damage. The factors that determine the decrease in the probability of damage to crops are mainly related to human disturbance and the characteristics of the fields. The predictive model of damage risk built comparing damaged and undamaged fields showed a good predictive ability. The Population Viability Analyses showed that it is not possible to obtain a drastic reduction with the current harvest rate. By tripling it and focusing on the females and sub-adult a numerical reduction of 50% of the population would be achievable in 7 years and the probability of population survival would be halved in 3 years.

In protected areas, wild boar is a potentially problematic species due to the different negative impacts that its presence and activities can cause on natural plant and animal communities. Between March and August 2019 (**Chapter 4**), in the lowland forests of the Ticino Valley Natural Park (Piedmont region, Northwestern Italy), we investigated the factors influencing feeding habitat selection of the wild boar, and the impact of rooting on nemoral flora. Feeding during spring and summer seems concentrated in wooded areas characterized by fresh soils, where the thickness of the litter is greater and the mast content, especially acorns, is greater. Although we found a significant correlation between the intensity of rooting and the presence of nemoral species, it does not seem to have a significant and negative effect on the number of species present or their abundance in the sampled areas. The floristic diversity and the dominance ratios between the nemoral species are not influenced by the rooting intensity, However, the results obtained did not allow to exclude an impact of the long-term rooting activities on the nemoral flora present in the study area, although the investigation of the short-term effects seems to suggest the absence of a significant impact.

In general, the results obtained show that wild boar selects the forest as a priority habitat, the use of crops is sporadic, and it is possible to predict the risk of damage through a predictive risk model. A massive culling plan focused on reproductive females and sub-adults would be necessary to obtain a drastic reduction in the size of the population. Finally, the nemoral flora does not appear to be negatively affected by the wild boar in the short-term.

Introduction

In recent decades, the numerical growth and spatial expansion of ungulates populations have assumed an international significance (Valente et al., 2020), posing questions of public interest on the coexistence between humans and wildlife (Vallée et al., 2016). The reasons behind this growing trend are numerous and diversified, involving both species-specific biological traits and factors directly or indirectly linked to human behavior (Veličković et al., 2016). The most emblematic and involved species is certainly the wild boar (*Sus scrofa*).

Wild boar populations, in the last forty years, have benefited from various factors that have supported their growth and spread. In native distribution areas such as Europe, the lack of large predators (Massei et al., 2015), the effects of climate change (Melis et al., 2006; Pauchard et al., 2016) and the natural reforestation processes (Keuling et al., 2009; Servanty et al., 2011; Haaverstad et al., 2014), often linked to the abandonment of many human settlements located in hilly and mountain areas, have created favorable conditions for natural restocking of wild boar. Moreover, the success of this ungulate has been favored by biological and ecological characteristics such as the opportunistic omnivorous behavior (Massei et al. 1996; Fonseca 2004), high prolificacy, and adaptive plasticity (Fonseca et al. 2004; Johann et al., 2020). At least, the releases carried out for hunting purposes (Long, 2003, Rollins et al., 2007) emphasized the expansion of the species.

The great adaptability of the wild boar to different types of environments, allowed the colonization of secondary habitats such as cultivated areas and suburbs (Amendolia et al., 2019), this has increased the negative impacts on human activities both in terms of economic loss resulting from damage to crops (Linnel et al., 2020), and public health and safety, being involved in vehicles collisions and being a source of dispersion of various infectious diseases (Pisanu et al., 2012; Meier and Ryser-Degiorgis 2018). Wild boar can also have a strong influence on biodiversity. Negative impacts are generally related to trampling and feeding activities together with predation upon invertebrates, small vertebrates, and eggs of ground-nesting birds (Baubet et al., 2003; Amori et al., 2016; Senserini and Santilli 2016; Oja et al., 2017; Mori et al., 2020). Moreover, depending on the intensity of rooting, wild boar can alter soil properties (Bueno et al., 2013; Palacio et al., 2013) and damage plant communities (Brunet et al. 2016; Sondej and Kwiatkowska-Falińska 2017).

In Italy, the north-western Po Valley is an area where both protected natural environments and fragmented habitats are part of a human-dominated landscape, strongly used for agricultural production, and the conflicts related to the presence of the wild boar are expressed at different levels. In this context, my research project aimed to understand and describe the processes and factors involved in the origin of the potential negative impacts of wild boar and to provide useful elements for a better wild boar management strategy.

Understanding habitat selection processes could be the key to wild boar management and prevent its possible negative impacts. The first part of my research (**Chapter 1 - Seasonal changes of habitat use by wild boar in a protected area of the Po Plain**) is focused on the habitat selection processes by the wild boar to identify and analyze the most suitable habitat characteristics in lowland areas. As mentioned, the use of secondary habitats by wild boars is often a source of conflicts with humans, especially about the incursions of wild boars in intensely cultivated areas and the consequent damage to crops. I investigated which factors are involved in the damage that occurred in an intensively cultivated area (**Chapter 2 - Influence of seasonality, environmental and anthropic factors on crop damage by wild boar *Sus scrofa***) and formulated a risk prediction model that represents an important management tool that allows acting on the problem before the damage occurs planning field protection interventions. When damage prevention is absent or fails, it is necessary to proceed with interventions aimed at reducing the number of wild boars present in a given area. When agricultural damage occurs within a protected area, the numerical control of the wild boar population represents a source of disturbance for the other species present, therefore, it is necessary that culling is carried out in the most effective and least impactful way. Inside the Ticino and Lake Maggiore Park

(**Chapter 3 - Factors affecting the crop damage by wild boar (*Sus scrofa*) and effects of population control in the Ticino and Lake Maggiore Park**), I analyzed the damage to the crops present and the damage reduction strategy through the selective harvest of wild boar. Moreover, simulations of the population viability (PVA) were carried out under different culling rate scenarios to identify the best strategy for the future management of the wild boar numerical control in the Park.

The feeding activities of the wild boar can have negative repercussions not only concerning damage to crops, several studies have shown a negative impact on the species richness of vascular plants (Hone, 2002; Welander, 2014), damage to herbaceous cover (Howe and Bratton, 1976; Howe et al., 1981), and a negative impact in terms of composition, dominance and abundance ratios of the undergrowth flora (Burrascano et al., 2015). In the last part of my research (**Chapter 4 - Feeding habitat selection by wild boar in woodlands: can the rooting affect nemoral species?**), I investigated the factors that influence the selection of wooded areas used by wild boar for feeding and the potential effects of rooting on the most important nemoral species that characterize the undergrowth of the lowland woods present in the Ticino and Lake Maggiore Park.

Chapter 1

Seasonal changes of habitat use by wild boar in a protected area of the Po Plain (northern western Italy)

Piacentini, I., Cappa, F., Bani, L., Meriggi, A. (2020). Seasonal changes of habitat use by wild boar in a protected area of the Po Plain (northern western Italy).

Abstract

The great adaptability of the wild boar (*Sus scrofa*) to environmental conditions seems to be the basis for the increase and expansion of its populations in Europe. The selection of the wild boar habitat was studied within Ticino Valley Regional Park. The study was carried out collecting data on distribution and abundance of presence signs along itineraries (n = 30, average length 8.02 km, SD = 2.97) surveyed in autumn-winter and spring. We firstly compared the use of the different habitat types with their availability by the Manly-Chesson α index. To estimate the effect of habitat composition on wild boar presence we formulated a Resource Selection Probability Function (RSPF) by Binary Logistic Regression Analysis (BLRA). To analyze the effects of the different type of habitats we carried out correlation and regression analyses between the Index of Kilometric Abundance (IKA) and the percentage of habitat types on the itineraries. Wild boar mainly selected woodland during the whole year, coniferous forests are underutilize while rice fields and urbanized areas avoided. The meadows are mainly used during the autumn winter season and during the spring season the presence of wild boar is higher in areas where the length of the forest edges is greater.The logistic model formulated show that high-density deciduous forests positively affect the probability of wild boar presence. Meadows and fields instead showed a negative influence. The results suggest that the most favourable habitat for wild boar is the deciduous forest while the cultivated areas represent a temporary habitat used mainly for food purposes.

Introduction

The expansion of the distribution areas and the growth of the wild boar (*Sus scrofa*) populations involved both the native and the introduced ranges (Massei et al., 2015; Keuling et al., 2018). This expansion is due to several factors such as highly adaptive biological traits (Gamelon et al., 2013), a generalist diet (Herrero et al., 2006), and human-derived causes as introductions (Courchamp et al., 2003; Long 2003). The most favorable habitat for wild boar is oak woods alternated with shrubs and pastures, provided there is enough water available (Jánoska et al., 2018; Kim et al., 2019; Yokoyama et al., 2020). In the deciduous forest, the diet of wild boars includes a great variety of foods, and the fruits of the forest, especially acorns, hazelnuts, chestnuts, and other hard fruits represent the basis of the boar diet (Zeman et a., 2016; Mikulka et al., 2018). The abundance of masts is fundamental for wild boar populations and can significantly influence their productivity (Schley and Roper 2003; Cutini et al., 2013; Zeman et al., 2016; Mikulka et al., 2018). Furthermore, the productivity of the forest can alter the spatial behavior of the wild boar (Cutini et al., 2013; Bisi et al., 2018) in the wood, the wild boar can also find other minor components of its diet composed in part of a fraction of food of animal origin such as invertebrates, eggs of ground-nesting birds, amphibians, reptiles and small mammals (Amori et al., 2016; Senserini and Santilli 2016; Oja et al., 2017; Mori et al., 2020) and fungi (Piattoni et al., 2013; Livne-Luzon et al., 2017). However, the wild boar can settle stably even in secondary or less favorable habitats (Castillo-Contreras et al., 2018; Amendolia et al., 2019; Khan et al., 2019). The use of secondary habitats such as crops is often related to the foraging activities of the wild boar which, in the cultivated areas, can find a great availability of attractive crops. Among the crops most favored by wild boar, corn seems to be the favorite, but also potatoes, rice, winter cereals, and sugar beet (Schley and Roper, 2003). Meadows also provide important food supplements and are often rooted by wild boar in search of larvae, annelids, and other invertebrates (Baubet et al., 2004; Frackowiak et al., 2013). In the last two decades, the wild boar presence is recorded in 95 of the 107 Italian provinces: in 73 (68%) it is widespread and with large populations, in 19 (18%) it is present with one or more isolated but stable populations (Carnevali et al., 2009). Indeed, this ungulate increasingly uses cultivated areas, arriving to settle within suburban areas of many large Italian cities, like Rome and Genoa (Pierucci et al., 2014, 2015; Monterosso et al., 2016; Amendolia et al., 2016, 2019) and colonizing the Alps (Monaco et al., 2007). The use of secondary habitats by wild boar is often a source of conflicts with humans, especially in relation to the incursions of wild boars in intensely cultivated areas and the consequent damage to crops (Cappa et al., 2019; Leirs et al., 2019 Liu et al., 2019; Gren et al., 2020), health risks associated with zoonoses (Li et al., 2018; Fredriksson-Ahomaa, 2019, O'Neill et al., 2020) and collisions with vehicles (Bíl et al., 2019; Vrkljanet et al., 2020; Saint-Andrieux et al., 2020).The presence of wild boar in protected areas inserted in intensively cultivated and populated plain contexts, such as the Po Valley, can present considerable criticalities in the coexistence between wildlife and human activities. This study aims to identify and analyse the most suitable habitat characteristics in lowland areas. Understanding habitat selection processes could be the key to wild boar management and prevent its possible negative impacts.

Study area

The study area is a portion of 20,566 hectares of the Lombard Park of the Ticino Valley. The park, located in northern Italy (45° 3' 11.39" N, 9° 11' 23.78" E), extends for a total of 91,793 hectares, developing along the banks of the Ticino river for 110 km, from Lake Maggiore to its confluence in the Po river (Fig. 1). The park has a temperate-continental climate with temperate and dry winter and hot and humid summer. The average annual temperature is 16.4° C (the warmest month: August= 29.8° C; the coldest month: January= 4.9° C); while the average annual rainfall is 613.8 mm (Hydrological annals of the Lombardy ARPA, 2003). The total park surface is covered for 20,074 hectares by lowland forests while 49,719 hectares are used for agriculture and the urbanized areas extend to 18,918 hectares. 42.62% of the study area (8.766 ha) is covered by woods; while the anthropized areas are reduced to limited portions of the entire surface, occupying only 3.01% of the study area (619 ha). The most representative forest formations are attributable to the *Querco-Carpinetum boreoitalicum* association with the presence of *Quercus robur*. The shrub and herbaceous layers are mainly composed of hazel (*Corylus avellana*), hawthom (*Crataegus monogyna*), blackthorn (*Prunus spinosa*), bramble (*Rubus ulmifolius*), lily of the valley (*Convallaria majalis*). The forest environments are also characterized by chestnut trees (*Castanea sativa*) and mixed woods with white poplar (*Populus alba*), black poplar (*Populus nigra*), hornbeam (*Carpinus betulus*), and elm (*Ulmus minor*). The woods of the alluvial plain are composed of willow (*Salix* sp.) and black alder (*Alnus glutinosa*). The arid areas are characterized by the presence of heather (*Calluna vulgaris*), Scots pine (*Pinus sylvestris*), and birch (*Betula* sp.). The agricultural areas covered 41.84% of the study area (8.606 ha). The type of cultivation practiced depends essentially on the microclimate, on the characteristics of the soil, on the availability of water, and market trends, but the main ones are maize (*Zea mays*), rice (*Oryza sativa*), wheat (*Triticum* spp.) and soy (*Glycine max*) (Bocca & Magna, 2001). Human activities are limited to the presence of residents and farmers (there are about 1,250 farms) and, especially on weekends, to those of users (mushroom pickers, hikers, canoeists). Wild boar and roe deer (*Capreolus capreolus*) are the only ungulate species widespread in the study area. The wolf (*Canis lupus*) is irregularly present in the study area and use the woods along the Ticino river as a corridor for displacements between the Alps and the Apennines (Dondina et al., 2020). Hunting is forbidden, but numerical control of the wild boar population is carried out by culling (855 and 517 wild boars culled in 2007 and 2008 respectively).

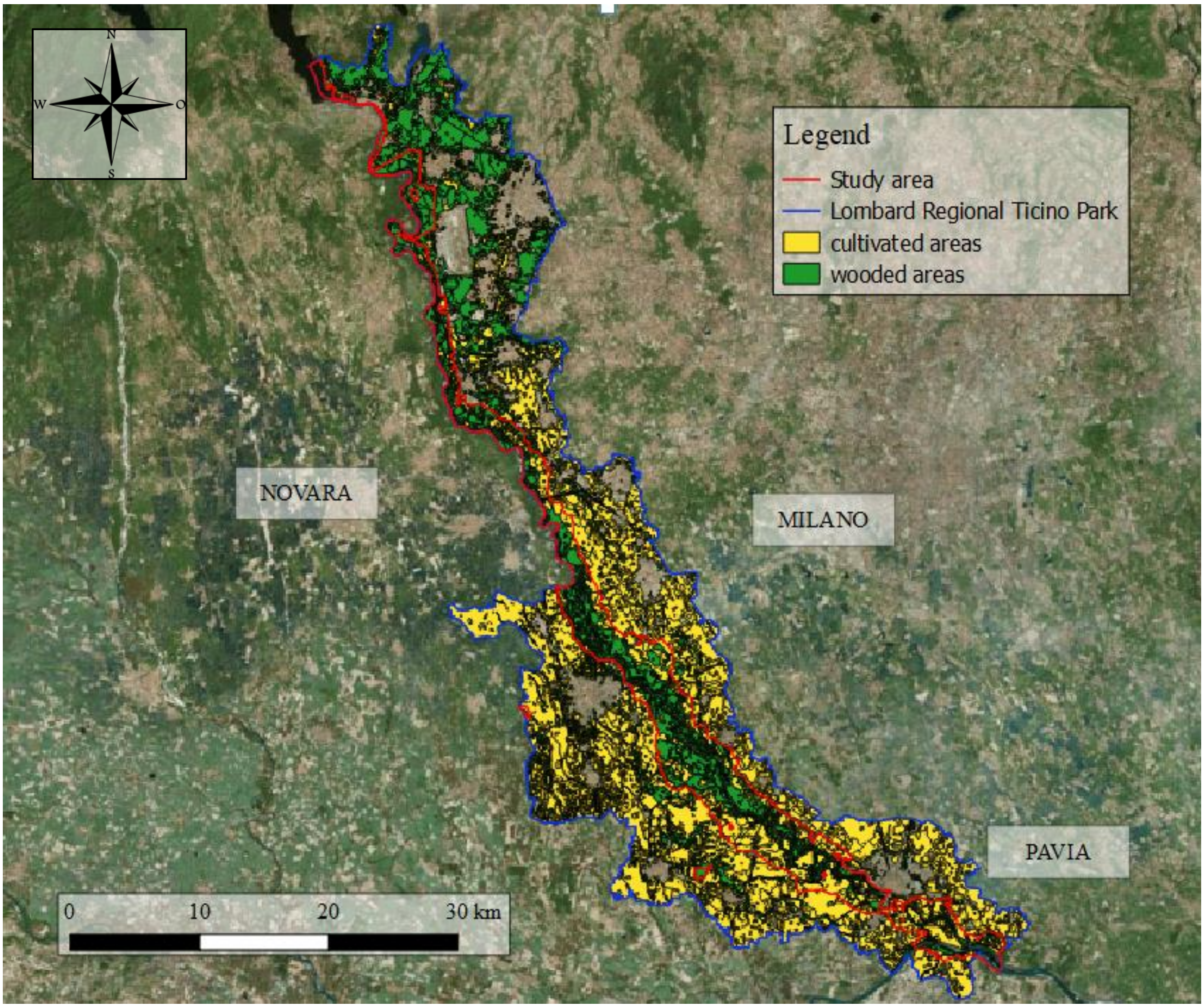


Figure 1 *Perimeter of the Lombard Regional Ticino Park, the perimeter of the study area, cultivated areas, and wooded areas.*

Materials and methods

Data collection

We recorded the signs of the presence of wild boar (footprints, feces, rubbing, wallowing, rooting, resting sites, trails) along 30 itineraries traced on footpaths for a total length of 246 km (average = 8.02, min. = 3.0, max = 14.0 km, SD = 2.97) distributed to cover the entire study area and walked in autumn-winter (October 2017 - February 2018) and spring (March - June 2018). Along the itinerary, the signs of presence were recorded at a maximum distance of 5 m on both sides. All data were geo-referenced with QGIS software 3.4.5 (Fig. 2).

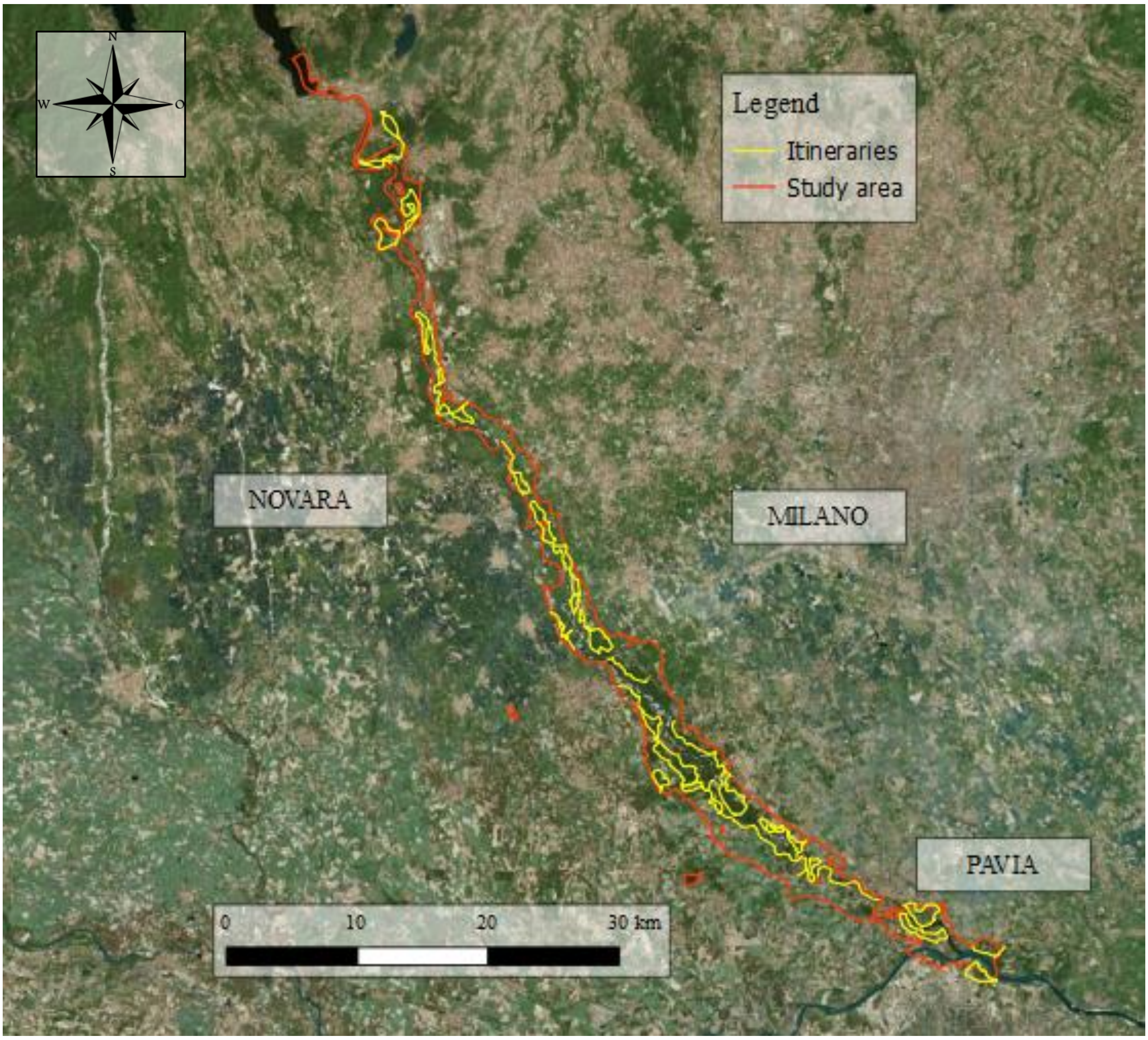


Figure 2 *Geo-reference of the 30 itineraries.*

Data analysis

To evaluate habitat selection, we used a multilevel approach (Meriggi & Sacchi, 2001). We firstly compared the use of the different habitat types with their availability by the Manly-Chesson α index. This test allows classifying the habitat types according to a hierarchical criterion of selection, taking into account their different availability (Manly et al., 2002). The use was estimated by the proportion of presence signs recorded in each habitat along the itineraries while the availability was calculated along the itineraries from a digitized map of land use (DUSAF, Lombardy Region, 2015). The original land use classes were grouped into 12 habitat types (Urban areas, Arable land, Rice fields, Arboriculture, Meadows, High-density deciduous trees, Low-density deciduous trees, Riparian woods, Conifer woods, Mixed woods, Bushes, and Riverbed). The index ranges from 0 to 1 with the value 1/n (were n = number of habitat types) indicating a use proportional to the availability. To detect significant differences in the index values from 1/n, we used the bootstrap resampling (1000 times) and calculated the 95% confidence intervals of the index; we then checked whether the value 1/n fell inside (no significant difference) or outside (significant difference) the intervals. The α index was calculated for each season separately.

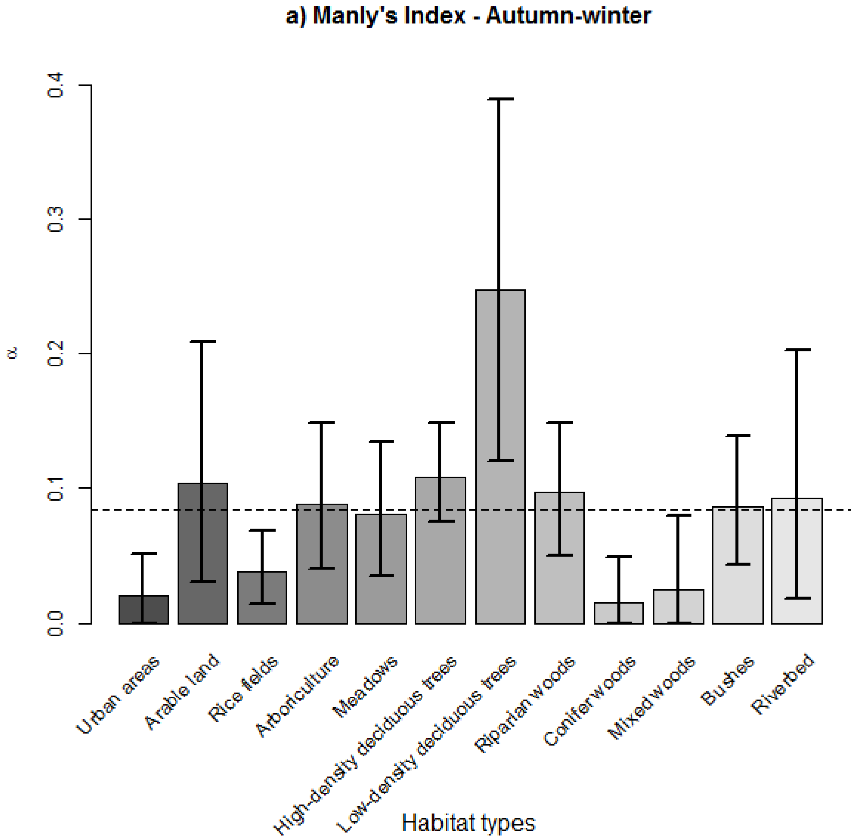
At the second level, we formulated Resource Selection Probability Functions (RSPFs) considering each season separately, considering the habitat composition, i. e. the percentages of the habitat types described above. For this we superimposed a 2-km spaced grid on the study area and selected the cells crossed by the itineraries; these were subdivided into cells of presence (those with a least 1 presence sign) and cells of absence (those without presence signs). In each cell, we then measured the percentages of the same habitat types used for the first level of analysis, with the addition of the permanent crops class (for a total of 13 classes) (for the few values of presence in the permanent crops and coniferous forests classes, the values of these have been grouped respectively into the arboriculture and mixed forests classes, always referring to the digitized land use map DUSAF, thus obtaining 11 classes), and we have also calculated a habitat diversity index (H' Shannon and Wiener diversity index), the length of forest edges and the density of hedges and trees. The size of the cells was chosen based on the daily movements that the wild canteens make to move from resting places to feeding ones. We used the Mann-Whitney test to verify the existence of significant differences in the values of habitat variables between the cells of presence and absence. Then we formulated the RSPFs using Binary Logistic Regression Analysis (BLRA). The BLRA was performed with software

IBM SPSS Statistic Desktop trial v 22.0 using the stepwise regression' method. Model performance was evaluated by using the Area Under the Receiver Operating Characteristics (ROC) Curve (AUC), which can assume values ranging from 0.50 (random prediction of the model) to 1.00 (perfect prediction of the model). Model discrimination ability was categorized 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). Finally, the deviance explained by the model (D^2) was evaluated (Yee & Mitchell, 1991; Boyce et al., 2002; Zuur et al., 2007, 2009).

At the third level, we verified the effects of habitat composition on the abundance of wild boar. We firstly calculated an Index of Kilometric Abundance (IKA, Vincent et al., 1991) as the number of signs of presence per km of itineraries for the two seasons separately. We used the Wilcoxon test for paired data to detect significant differences in the IKA between seasons. Then we performed correlations (Spearman rank correlations) and Multiple Linear Regression Analyses (MLRA) between the IKA values and the percentage of habitat variables calculated along the itineraries (Legendre & Legendre, 1998; Zuur et al., 2007). The automatic linear modeling procedure in SPSS Statistics was used (Yang, 2013; Sybertz et al., 2017). The variables in the models were selected by the best subset method, using the AICc as criteria. No automatic data preparation was used (Yang, 2013). The variance explained by the models was measured by the adjusted R^2 (Legendre & Legendre, 1998; Zuur et al., 2007), and the goodness of fit was measured by the Pearson correlation test between the observed and the fitted values (Legendre & Legendre, 1998; Zuur et al., 2007). Pearson residuals were calculated and checked for normality and spatial autocorrelation by Shapiro–Wilk and Moran I tests, respectively (Legendre & Legendre 1998; Zuur et al., 2007). Moreover, we calculated the VIF with a threshold of 3 to check for multicollinearity. The analyses were carried out by the software IBM SPSS Statistic Desktop trial v 22.0. For all statistical analyses, a value of $P = 0.05$ was used as a significance threshold.

Results

At the first level of analysis, for both seasons, considered separately, we found similar models with selection for deciduous forests and avoidance for urban areas, rice fields, and conifer woods, as well as mixed woods in autumn-winter, while the other types of habitats were used in proportion to availability (Fig. 3a and 3b).



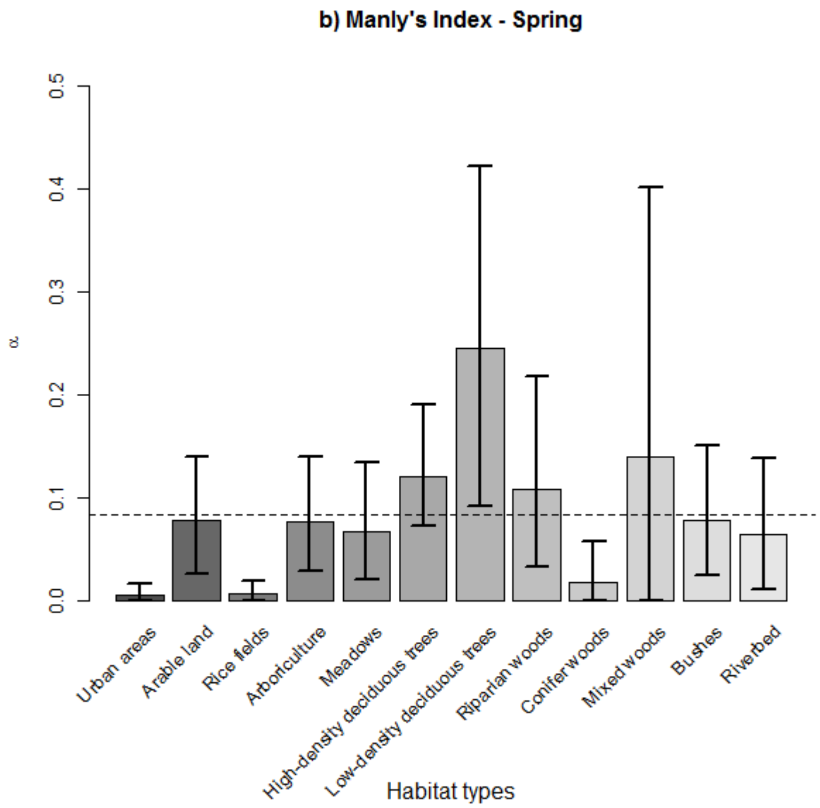


Figure 3 *Selection of habitat types by wild boar (Manly-Chesson α index; a: autumn-winter, b: spring).*

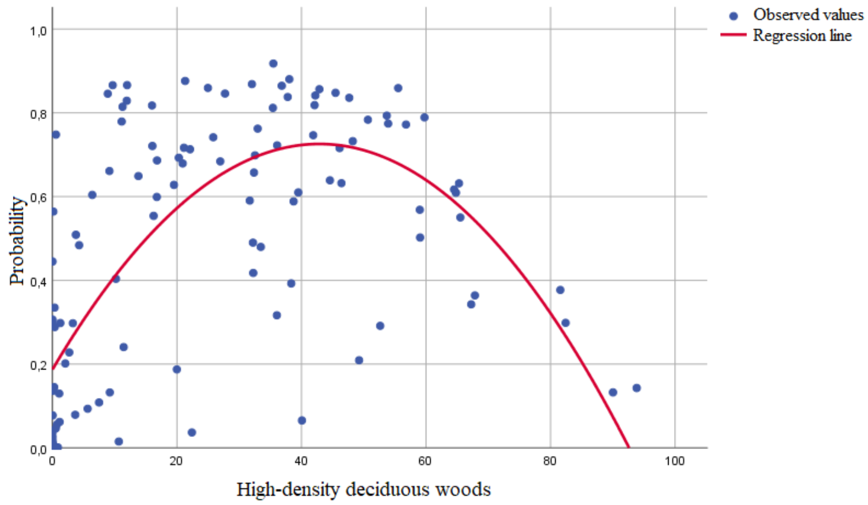
At the second level of analysis, for the autumn-winter season, we found significant differences between presence and absence cells with the percentage of arboriculture (U = 2365, P = 0.001), meadows (U = 2247, P = 0.005), high-density deciduous trees (U = 2417, P < 0.001), low-density deciduous trees (U = 2368, P < 0.001), riparian woods (U = 2382, P < 0.001), mixed woods (U = 1494, P = 0.044), bushes (U = 2393, P < 0.001), riverbed (U = 2117, P = 0.037) and habitat diversity index (U = 2766, P < 0.001) that are significantly greater in presence cells (Figure 4 – Supplementary materials).

In spring we found significant differences between presence and absence cells with the percentages of arboriculture (U = 2240, P = 0.007), high-density deciduous trees (U = 2627, P < 0.001), low-density deciduous trees (U = 2491, P < 0.001), riparian woods (U = 2394, P < 0.001), bushes (U = 2422, P < 0.001), riverbed (U = 2165.5, P = 0.021), habitat diversity index (U = 2626, P < 0.001) and length of forest edges (U = 1208, P = 0.004) that are significantly greater in presence cells (Figure 5 – Supplementary material).

The logistic model formulated considering the autumn-winter explained 77% of the variance of the dependent variable through the inclusion of two variables, both statistically significant with postivie effect: high-density deciduous trees (β = 0.045, SE = 0.012, P << 0.001) and habitat diversity index (β = 9.728, SE = 1.989, P << 0.001) (Table 1; Fig. 6).

Variables	***β***	***SE***	***P***
High-density deciduous trees	**0.045**	**0.012**	**<< 0.001**
Habitat diversity index	**9.728**	**1.989**	**<< 0.001**

Table 1 *Variables included in the logistic model formulated considering the autumn-winter.*



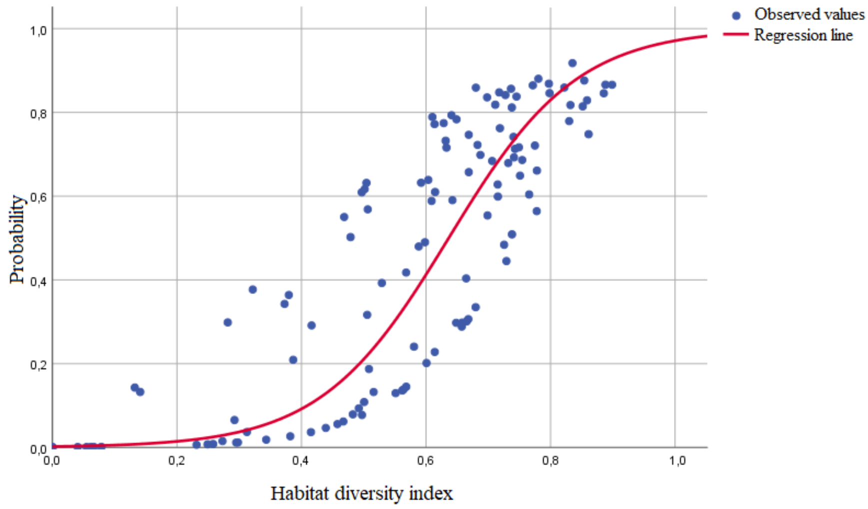
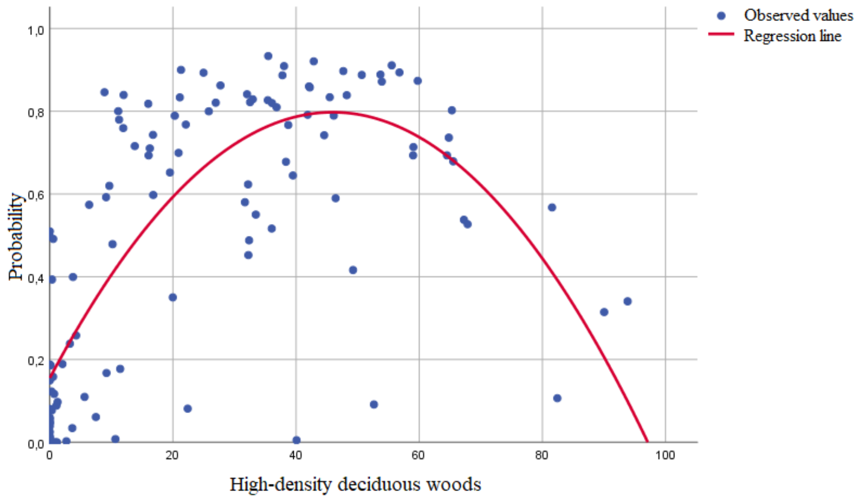


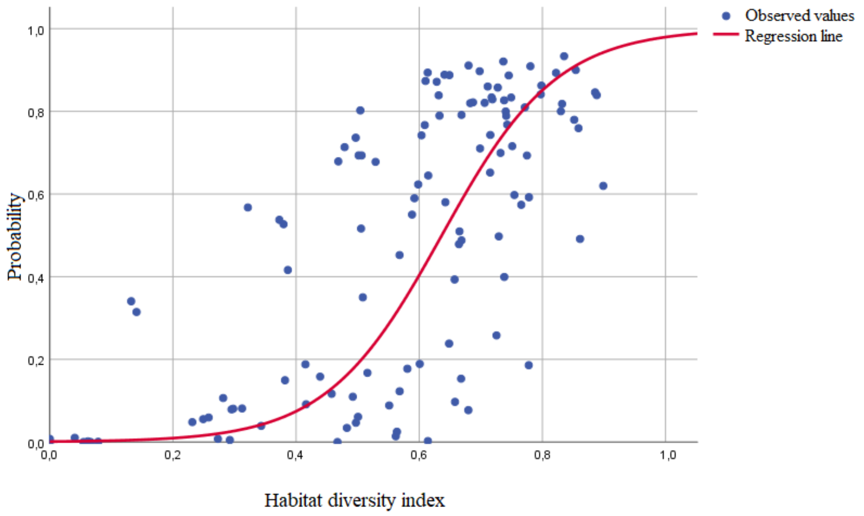
Figure 6 *Response curves of the variables included in the logistic model formulated considering the autumn-winter: High-density deciduous trees (R^2=0.506; SEE=0.219; P<0.001), Habitat diversity index (R^2=0.792; SEE=1.082; P<0.001)*

The analysis carried out using the ROC curve showed that the model has good predictive power (AUC = 0.84). The logistic model of spring explained 78% of the variance of the dependent variable with three variables all staticallly significant: high-density deciduous trees (β = 0.038, SE = 0.012, *P* = 0.002) and habitat diversity index (β = 8.271, SE = 1.747, *P* << 0.001) with positive effect and length of forest edges with negative effect (β = - 0.005, SE = 0.002, *P* = 0.016) (Table 2; Fig. 7). The analysis carried out using the ROC curve showed how the model has weak predictive power (AUC = 0.87).

Variables	*β*	*SE*	*P*
High-density deciduous trees	**0.038**	**0.012**	**0.002**
Habitat diversity index	**8.271**	**1.747**	**<< 0.001**
Length of forest edges	**-0.005**	**0.002**	**0.016**

Table 2 *Variables included in the logistic model formulated considering the spring.*


Observed values
Regression line
Probability
1,0
0,8
0,6
0,4
0,2
0,0
0
20
40
60
80
100
High-density deciduous woods


Observed values
Regression line
Probability
1,0
0,8
0,6
0,4
0,2
0,0
0,0
0,2
0,4
0,6
0,8
1,0
Habitat diversity index

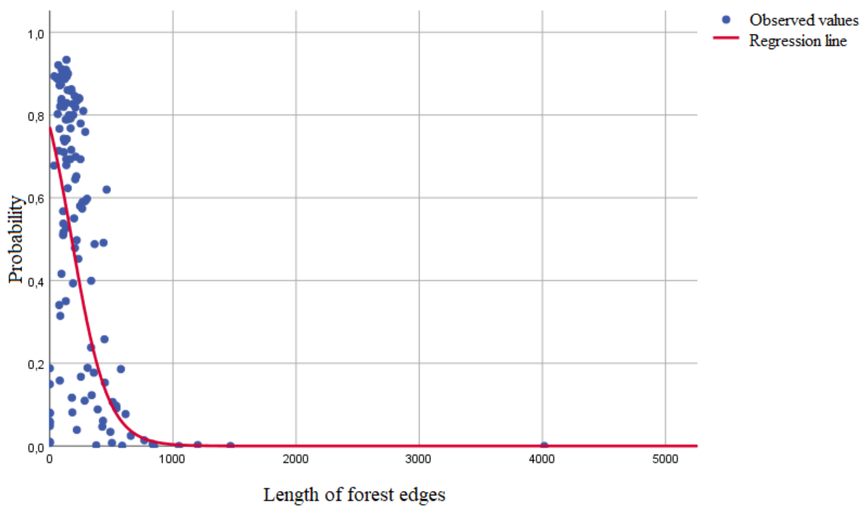

Observed values
Regression line
Probability
1,0
0,8
0,6
0,4
0,2
0,0
0
1000
2000
3000
4000
5000
Length of forest edges

Figure 7 *Response curves of the variables included in the logistic model formulated considering the spring: High-density deciduous trees (R^2=0.601; SEE=0.211; P<0.001), Habitat diversity index (R^2=0.452; SEE=2.558; P<0.001), Length of forest edges (R^2=0.700; SEE=1.892; P<0.001)*

The IKA averaged 2.7 (SD = 2.07; min. = 0; max. = 8.3) in autumn-winter, and 2.3 (SD = 1.63; min. = 0.1; max. = 6.3) in spring; the difference between seasons was not significant (Wilcoxon test: w = 477.5, *P* = 0.69). The IKA resulted positively and significantly correlated with the high density deciduous trees and negatively with arable land and meadows in the two seasons (Table 3) and also the Multiple Linear Regression Analyses (MLRA) resulted statistically significant (autumn-winter: r = 0.532 , P = 0.002; spring: r = 0.637, P < 0.001) in the two seasons (Table 4).

Variables	***Autumn-winter***		***Spring***	
	Rho	P	Rho	P
Urban areas	-0.104	0.585	-0.274	0.144
Arable lands	**-0.509**	**0.004**	**-0.549**	**0.002**
Rice fields	-0.082	0.668	-0.045	0.813
Arboriculture	-0.260	0.166	-0.180	0.340
Meadows	**-0.491**	**0.006**	**-0.505**	**0.004**
High-density deciduous trees	**0.544**	**0.002**	**0.532**	**0.002**
Low-density deciduous trees	0.037	0.848	0.089	0.640
Riparian woods	-0.092	0.629	0.065	0.732
Conifer woods	-0.077	0.687	-0.215	0.254
Mixed woods	-0.44	0.819	-0.022	0.908
Shurblands	-0.195	0.301	-0.120	0.529
Riverbed	0.108	0.570	0.125	0.510

Table 3 *Spearman rank correlations between IKA values and the percentages of habitat types on itineraries (n=30).*

Variables	*IKA-Autumn-winter*		*IKA-Spring*	
	r	P	r	P
Habitat types	**0.532**	**0.002**	**0.637**	**< 0.001**

Table 4 *The Multiple Linear Regression Analyses (MLRA) between IKA values and the percentages of habitat types on itineraries (n=30).*

Discussion and conclusions

The data collected during the research period, especially for the observation and identification of the traces, was only partially influenced by the weather and ground conditions. Although the late winter season is usually characterized by low rainfall in the Po Valley, the areas close to the river remain sufficiently humid to allow the preservation of the signs of presence on the ground. The days dedicated to data collection in the field were selected compatibly with the weather conditions, to avoid particularly cold days, in which the frozen ground would have limited the occurrence of footprints. Considering what emerged from the results, both the first and the second level of the analysis show a strong preference for deciduous forests by wild boar during the year. Furthermore, through the Mann-Whitney test, for both seasons, a particular use by the species is also highlighted of the arboriculture areas, riparian woods, mixed woods, and shrubs.

The logistic model formulated confirm the preference of deciduous forest highlighting a positive influence on the probability of the wild boar presence in both seasons. Such evidence has been observed in many studies (Meriggi & Sacchi, 2001; Fonseca 2008; Thurfjell et al., 2009; Rodrigues et al. 2016; Kim et al., 2019). The woods present in the study area, mainly characterized by oaks, chestnuts, and hazelnuts, offer a great number of the hard mast, essential in the boar diet (Zeman et a., 2016; Mikulka et al., 2018). Moreover, both the deciduous forests as well as the arboriculture areas, the riparian woods, the mixed woods, and shrubs, provide good shelters and different sources of food (acorns, hazelnuts, chestnuts, berries, mushrooms, fruit, roots, invertebrates).

The first level of analysis shows a strong underutilization of coniferous forests, urbanized areas, and rice fields by wild boars during the year. Coniferous forests are little used probably because they have a less dense shrub layer and a more limited mast production, compared to deciduous forests (Kodera et al., 2001; Fonseca 2008; Kim et al., 2019). Urbanized areas don't represent suitable habitat for the wild boar, because of the disturbance and stress deriving from human presence and activities (Merli & Meriggi 2006, Hebeisen et al., 2008; Amici et al., 2012; Amendolia et al., 2019). Finally, the rice fields, which during the year are underutilized by the wild boar, may not be suitable areas because, during the spring, paddies remain submerged to favor the growth of the plants, while, after harvesting, the remaining stubble is not high enough to give adequate cover to the animals during their foraging activities and, finally, crop residues are scarce and probably unattractive for wild boar compared to other crops such as maize.

Concerning the second level of analysis, in both seasons, the use of river beds by wild boar is highlighted. River beds can provide water resources and suitable places for a mud bath, useful for thermoregulation, and remove parasite (Mauri et al., 2019). The Mann-Whitney test also shows, in the autumn and winter months, significant use of meadows as described by several studies (Brangi & Meriggi, 2003; Schley et al., 2008; Amici et al. 2012). The wild boar diet, rich in carbohydrates due to the high presence of acorn, requires supplementary protein sources, which are offered by the invertebrates that inhabit this habitat (Massei et al., 1996; Schley & Roper, 2003; Ballari & Barrios-Garcìa, 2014). The results of the second level of analysis also show that the length of the forest edges is significant during the spring period and seems to confirm that wild boar, during the year, do not use agricultural areas as its main habitat, but their use is limited to the spring season when the forest is less productive and concentrates on palatable and easily accessible crops located in fields close to the edge of the forest (Gerard et al., 1991; Thurfjell et al. 2009).

Considering what emerged from the results of the third level of analysis, in both seasons, the positive correlation between the abundance of wild boar and deciduous forests, as previously is confirmed. The meadows and cultivated fields have shown a negative influence. The avoidance of these habitats by wild boar (Fonseca 2008; Cuevas et al., 2013; Caruso et al., 2018) is probably due to the lack of shelter because meadows and crops are often used for hunting activities (shooting from high stands). Furthermore, other studies have shown that the proximity of the fields strongly influences the probability of wild boar damage (Honda & Sugita, 2007; Cait et al., 2008; Thurfjell et al. 2009; Lombardini et al., 2016; Cappa et al., 2019).

The results obtained from this study suggest that wild boars, in intensely populated lowland areas, have a strong preference for natural forests which, as explained above, provide the best conditions for wild boar from a biological and ecological point of view (Abaigar et al., 1994; Merli & Meriggi, 2006).

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Chapter 2

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

Cappa, F., Lombardini, M., and Meriggi, A. (2019). Influence of seasonality, environmental and anthropic factors on crop damage by wild boar Sus scrofa. Folia Zoologica, 68(4), 47-54.

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. This study aimed 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 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.

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 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 a 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 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.

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.

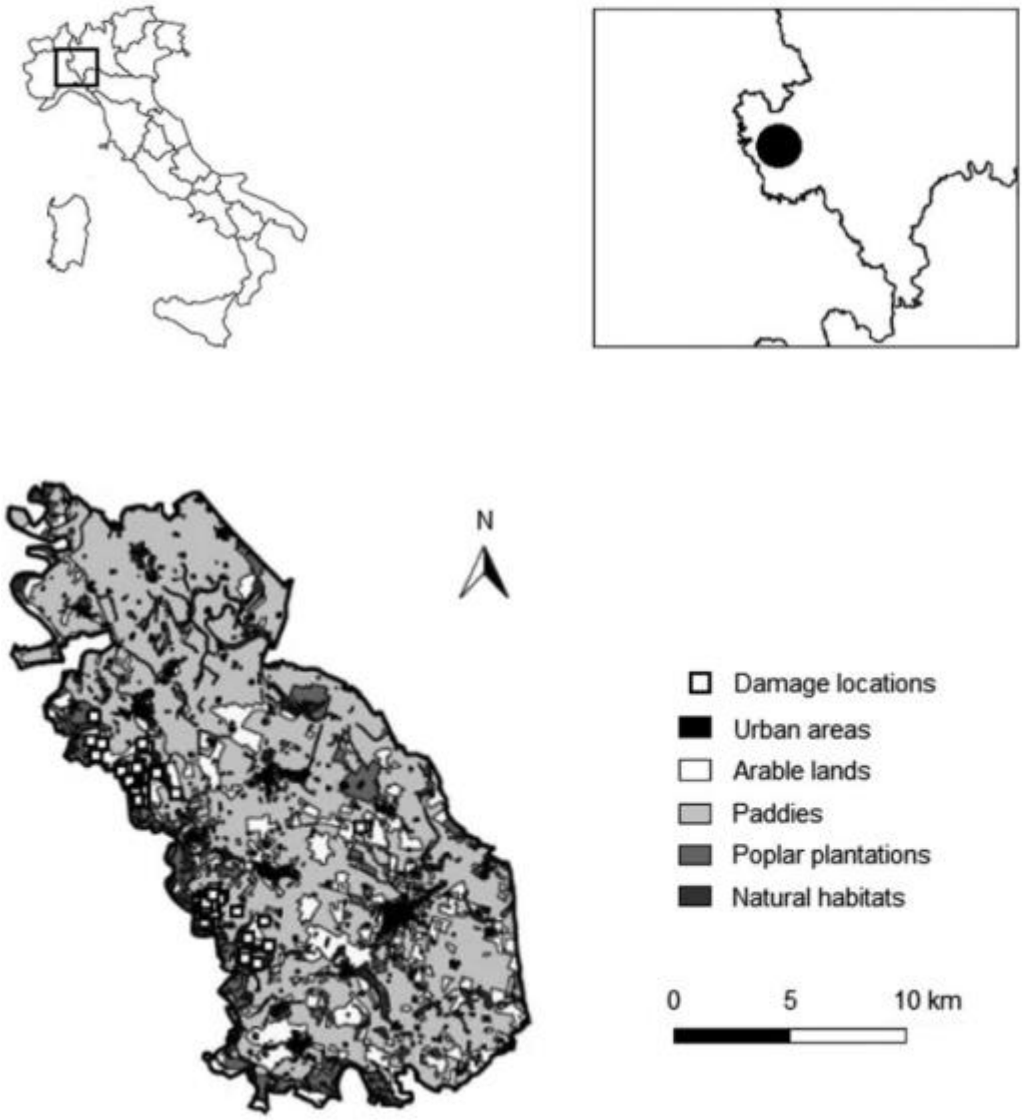

Figure 1 Location and land use of the study area (SPA "Risaie della Lomellina", western Po Plain, northern Italy).

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). 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).

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

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.

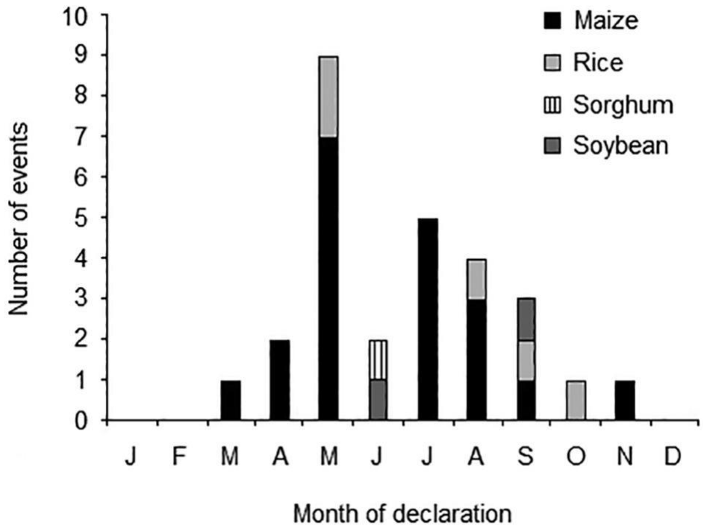

Figure 2 Monthly distribution of wild boar damage in the SPA "Risaie della Lomellina".

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: χ^2 = 75.14, df = 2, P < 0.001; damage frequency from interviews: χ^2 = 324.84, df = 2, P < 0.001; damage area: χ^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).

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 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.*

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.

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

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	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

Table 4 Coefficients of predictors of the model examining the occurrence of wild boar damage in the SPA “Risaie della Lomellina”. Only predictors with $\omega \geq 0.50$ 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.

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 consumes 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 is 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).

Acknowledgements

We are grateful to the Wildlife Service of the Province of Pavia for its help in data collection. We also wish to thank Gianpasquale Chiatante for his statistical advice, Carl Smith and two anonymous reviewers for their constructive comments on earlier versions of the manuscript and Federica Cappa, who kindly revised the English language. Finally, we thank Paolo Ghiselli, Mario Pavesi and everyone living in the SPA "Risaie della Lomellina" who participated in this study.

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Chapter 3

Factors affecting the crop damage by wild boar (*Sus scrofa*) and effects of population control in the Ticino and Lake Maggiore Park (North-western Italy)

Cappa, F., Bani, L., Meriggi, A. (2019). Factors affecting the crop damage by wild boar (*Sus scrofa*) and effects of population control in the Ticino and Lake Maggiore Park (North-western Italy). Mammalian Biology.

Abstract

Wild boar *Sus scrofa* foraging impacts the crops, pastures, and meadows causing remarkable losses to agricultural income. Protected areas located in plains, such as the Ticino Valley Natural Park, are characterized by the coexistence of important natural habitats and intensive agricultural areas. In the Park, from 2010 to 2017, 49% of the complaints report an event of damage to maize and 43% to meadows. The total expense for reimbursements of the maize amounted to € 439,341.52, with damages concentrated in May, after the sowing period, and between August and September, during the milky stage of maize. For meadows reimbursements amounted to € 324,768.66, with damage events concentrated in February and March. To reduce damage to crops, the Park administration carried out lethal control of the wild boar population. From 2006 to 2017 the most used control method was culling from hunting hides. In our analysis, we did not find significant relationships between the number of shot boars and the amount of damage. The factors that determine the decrease in the probability of damage to crops are mainly related to human disturbance and the characteristics of the fields. The predictive model of damage risk built comparing damaged and undamaged fields showed a fairly good predictive ability. The Population Viability Analyses showed that it is not possible to obtain a drastic reduction with the current harvest rate. By tripling it and focusing on the females and sub-adult a numerical reduction of 50% of the population would be achievable in 7 years and the probability of population survival would be halved in 3 years.

Introduction

The range expansion and the growing number of ungulate populations in Europe are showing increasing problems of coexistence with man. The problems are complex and vary according to species involved and the human activities. Among those species, the wild boar has shown a progressive growth of populations in Europe and worldwide. In many countries, starting from the sixties of last century, the species has re-colonized its historical range, expanding even towards many peri-urban areas (Apollonio et al., 2010; Massei et al., 2015; Stillfried et al., 2017; Castillo-Contreras et al., 2018; Gonzalez-Crespo et al., 2018; Amendolia et al., 2019). Forest expansion is one of the most important factors that favoured the expansion of the wild boar populations (Keuling et al., 2009; Servanty et al., 2011). Moreover, the releases carried out for hunting purposes emphasised the expansion of the species, thanks also to its high reproductive potential, the limited presence of natural predators in a considerable portion of its range, and its high ability to adapt to very different habitats (Brangi and Meriggi, 2003; Bieber and Ruf, 2005; Sales et al., 2017; Johann et al., 2020). Wild boar can be a problem for the preservation of health of reared pigs, since the species may transmit some pathogens such as the virus of the swine fever diseases, causing huge economic losses (Guberti et al., 2019). Moreover, the wild boar may be a vehicle of zoonoses, representing a serious threat to human health too (Bueno et al., 2009; Meng et al., 2009; Schley et al., 2008; Pisanu et al., 2012). Furthermore, road accidents are also a growing concern for human safety (Thurfjell et al., 2015). Nevertheless, the currently most common, widespread and increasing problems arise from the damage to agricultural productions. In France, for examples, compensation for crop damage caused by wild boars increased from 2.5 million Euros in 1973 to 21 million Euros in 2005 and 32.5 million Euros in 2008 (Guibert, 2008; Maillard et al., 2010). A similar trend, with a doubling of the amount of damage every 10 years, has been observed in several other European countries (Schley et al., 2008; Slovenia Forest Service, 2014). At present an annual cost of 80,000,000 Euros is estimated for the whole Europe (Apollonio, 2010; Linnel et al., 2020)

In general, the extent of crop damages depends on the population density, the population structure, the food availability in forest areas, the development of margins between forest and cultivated areas, the distance from human settlements, and on the stage of crop maturation (Schley et al., 2008; Novosel et al., 2012; Frackowiak et al., 2013; Laznik and Trdan, 2014).

Despite the strong impact of wild boar on farming, attempts to model and predict the occurrence of damage and its intensity have so far been limited. The feeding activity of wild boar in cultivated fields can be analyzed from the perspective of the general predictions of the optimal foraging theory, trying to identify which factors related to energy intake, energy expenditure and animal safety contribute to the choice of fields in to go to for food (Stephen and Krebs, 1986; Krebs and Kalcenik, 1991; Begon et al., 2006; Rubenstein and Alcock, 2018). Through the analysis of the factors that influence the occurrence of damage it is possible to formulate predictive risk models that allow to identify the most threatened areas and to act before the damage occurs with prevention tools (Ficetola et al., 2014; Lombardini et al., 2017; Cappa et al., 2019).

Moreover, numerical control is often assumed be effective for damage reduction, but there is little evidence of this, and lethal control is ethically questionable and controversial (Meriggi et al., 2016; Linnell et al., 2020; Vajas et al., 2020). In particular, the effectiveness of numerical control should be measured in terms of substantial damage and population reduction but often it is measured in the number of animals removed. In doing so, the true objective of numerical control is lost sight of (Sinclair et al., 2006).

The main aims of our study were to identify the factors affecting the crop damage and to assess the effectiveness of lethal control to reduce it. The study was carried out in the Regional Park of the Ticino Valley (Piedmont region, North-western Italy), which together with the adjoining Lombard Park of the Ticino Valley, represents the largest protected area in Europe located in lowland environment. The research started from the observation that, despite the efforts made by the administration of the protected area to contain wild boar population and reduce damage to agriculture, the trend of damages is still increasing. Damages in the Park area from 2010 to 2017 were analysed to highlight their trend, distribution and the most affected crops. Furthermore, the trend of wild boar killing was analysed to verify any relationship with the extent of damages. A predictive model of the risk of damage was then formulated by comparing the characteristics of the damaged fields with those of the undamaged ones. Finally, simulations of the population viability (PVA) were carried out under different culling rate scenarios.

To achieve our aims, we tried to answer the following questions: a) are there crop types selected by the wild boar?, b) does the current wild boar culling rate affect the overall amount of damages?, c) is it possible to foresee the risk of damage based on the characteristics of the fields?, d) does the current rate of culling affect the dynamics of the wild boar population?, and e) does an increasing of culling on a particular age class and sex produce a significant reduction in the population?

Considering the dramatic increase in wild boar populations and their range in Europe, this study could find wide application in similar environmental contexts because the problems facing large parks to reduce the damage caused by wildlife to crops are similar throughout Europe (Apollonio, 2010; Morelle and Lejeune, 2015; Gren et al., 2020; Johann et al., 2020; Linnell et al., 2020).

Study Area

Our study area corresponds to the Ticino Valley Natural Park (66.5 km^2; 45° 34′ 1.2″ N, 8° 40′ 58.8″ E; located in the Novara Province (Piedmont Region, North-western Italy), South of Lake Maggiore and ranging from 96 and 290 m a.s.l. (Fig. 1). The Park is characterized by a mixed natural and agricultural landscape. The climate is temperate, with cold winters and hot and sultry summers. The average yearly temperature was 11.8 °C (the monthly average of minimum temperature of the coldest month, January, was -2.9°C and the monthly average of maximum temperature of the hottest month, July, was 28.3°C). The average rainfall was 1000 mm, with two peaks in spring (April-May) and autumn (November) (National Institute for Meteorology and

Aeronautical Climatology, 2008). Woods, with prevailing broad-leaved trees such as common oak *Quercus robur*, hornbeam *Carpinus betulus*, elm *Ulmus minor* and locust-tree *Robinia pseudoacacia* cover 60% of the protected area surface. Agricultural areas cover 23 km^2, of which 65% are meadows, 26% maize, 4% rice fields, and 5% winter cereals and soybean. Agriculture characterises the floodplain which develops longitudinally and it is bordered on one side by the wooded areas along the river bank and on the opposite side by the woods that extends on the escarpment of the river terrace going to define a cultivation corridor interrupted transversally by human infrastructures (railway, highway, main roads) (Fig. 1). These characteristics allow the wild boars to invade the crops being always close to refuge areas. A network of secondary roads for agricultural use, cycle paths and trekking paths spread through cultivated areas and wooded areas. Moreover, the presence of settlements is scarce and represented mainly by farmsteads scattered in the Park.

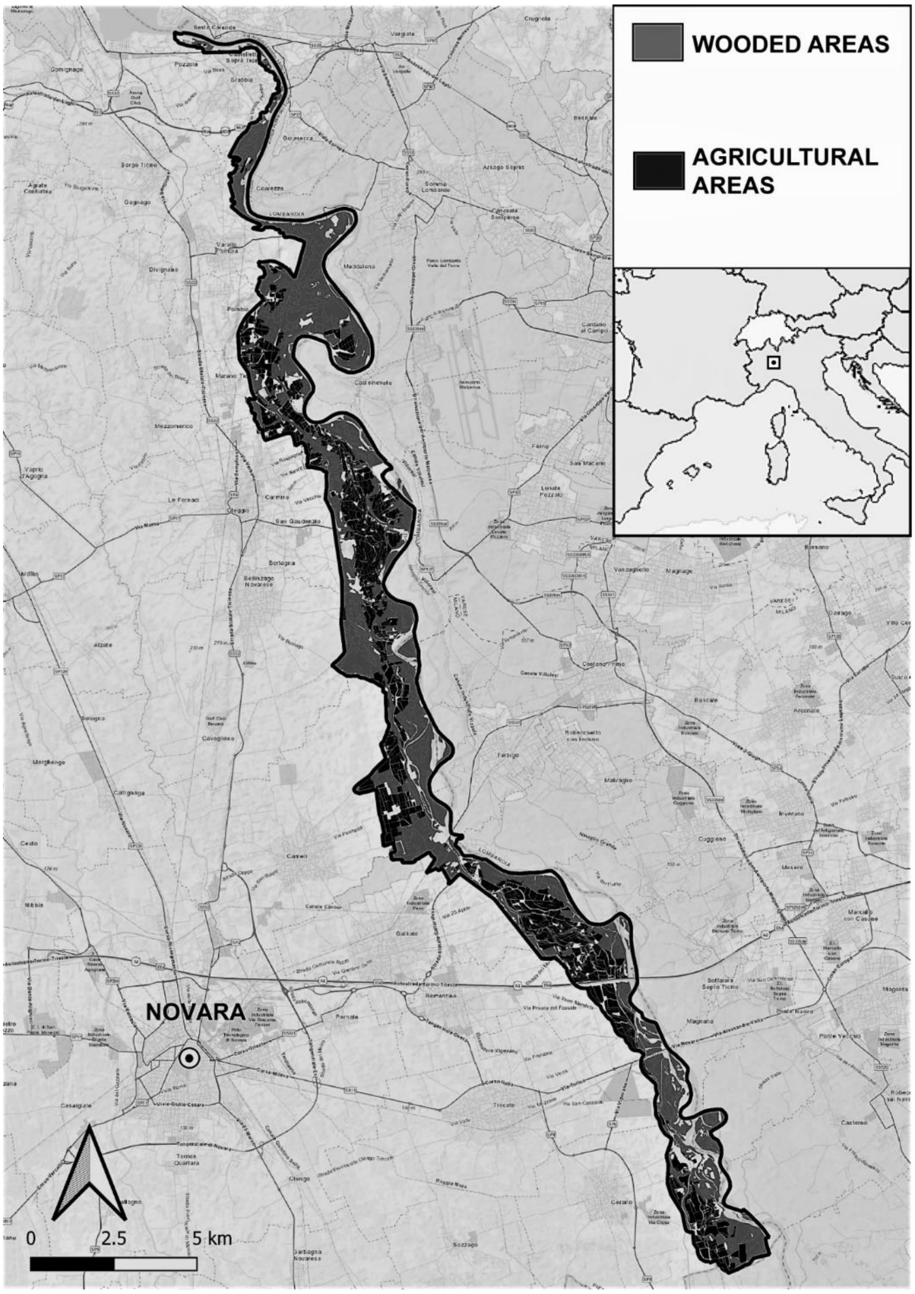

Figure 1 Study area with detail of forest (*grey*) and agricultural areas (*black*).

Materials and methods

Data collection

We used the official data of damage claims from 2010 to 2017 from the Wildlife Service of the Novara Province. The data included the following information: a) date; b) private data of the owner; c) type of crop affected by the damage; d) type of damage (trampling, rooting and feeding, wallowing); e) amount of damage in Euros; f) damaged surface (ha). We also collected the data on the numerical control on the population, for the period 2006-2017. All data were geo-referenced with QGIS software 3.4.5.

Damage analyses

We calculated the occurrence of damage claims considered as damage events and the compensation paid for each event, year, month and crop type. Firstly we compared the observed damage occurrence per crop type with the expected ones on the basis of the proportion of crop types, by the X^2 Goodness-of-Fit test and Bonferroni's Confidence Interval Analysis (Manly et al. 2002); for this we considered the occurrence of damages in the whole study period (2010-2017) and the average availability proportions of the different crop types in the same period (Agricultural Service, Province of Novara) assuming quite constant percentages of crop types in the years. Then we analysed the damage trend (event number and compensation paid) by linear regression and curve fit analyses with the year as time variable, testing the fit of linear, quadratic, and cubic models by the determination coefficient (R^2) and the Analysis of Variance (ANOVA). Moreover, we tested for the difference between the observed monthly distribution of damages and the expected one based on a hypothesis of evenness by the X^2 Goodness-of-Fit test.

The predictive model of damage risk

To formulate the predictive model of damage risk we compared the characteristics of the damaged fields with those of undamaged ones following an use vs. unused design (Cumming, 2000; Boyce et al., 2002). We calculated for each field 12 variables of which two (area and perimeter) related to the size of feeding patches and, consequently, to the amount of food, two other concerning the energy expenditure required to go to feeding patches from shelter areas (distance from the woods and from water bodies), five variables related to the anthropogenic disturbance (distances from buildings, railroads, main and secondary roads and cycle paths), one variable related to the position of the fields in respect to the flood plain (inside or outside the flood plain), and, finally, two variable descriptive of the field complexity (shape index and fractal dimension) (see Table 1). The distances from the woods were coded in three levels: adjacent to the woods (1), within 100 m from the woods (2) and over 100 m from woods (3). We calculated the distances using the "*NNjoin*" plugin, implemented in the QGIS 3.4.5 software. We calculated the area (A) and the perimeter (P) of the fields with QGIS, respectively with the functions "*area*" and "*length*", while the fractal dimension $(2 \times (ln(P) \ / \ (lnA)))$ and the shape index $(P/\,(2\sqrt{\pi}\,A))$ of the fields have been calculated with Microsoft Office Excel. Moreover, we calculated the average number of culled wild boar from 2013 to 2017 in each municipality of the Park and used it as predictor in the risk model.

We tested each variable by the Mann-Whitney U test to identify the field variables with significant differences between damaged and undamaged fields. Then we used those significantly different as predictors to perform a Binary Logistic Regression Analysis (BLRA) with the response variable 0 (undamaged fields) and 1 (damaged fields) and to assess the damage probability in relation to the values of field variables (Saino and Meriggi, 1990; Treves et al., 2004; Dondina et al., 2015). Variables that showed significant deviation from normality were transformed; in particular we used the *log (x+1)* transformation for the variables heavily skewed (Legendre and Legendre, 1998). We used the stepwise forward procedure and the Akaike Information Criterion to select the best model (Akaike, 1973; Anderson et al., 2001; Burnham and Anderson, 2002; Symonds and Moussalli, 2011). The importance of predictor variables was measured by the significance of the regression coefficients and by the Exp (B). We verified the collinearity among variables by the Variance Inflation Factor (VIF), retaining VIF = 3 as a threshold value (Zuur et al., 2010). We evaluated the model performance subdividing the total cases in two randomly selected subsets of equal size. Each subset was then used to formulate a logistic model and to predict the probability of damage occurrence for the other subset. We then used the X^2 test to verify for significant differences from random classifications and Spearman rank correlations between predicted probability classes (n = 10) and the frequency of true positive cases to evaluate the model performance (Boyce et al. 2002).

We performed all statistical analyses with the software R (R Core Team, 2017); a value of P = 0.05 was used as significance threshold.

Effects of population control on damages

We calculated the total number of wild boars removed by the operators in the study area, their distribution for each control technique (shooting from hides, drive hunting, captures with live traps), and their yearly distribution from 2006 to 2017 from records by Park administration. Moreover, shot wild boars were classified by sex and age using the fur colour, body weight, and tooth eruption and erosion. We analysed the trend of wild boar culled for numerical control by linear regression with curve estimation, setting the number of individuals as the dependent variable and the time (year) as independent one. Moreover, we carried out correlation analyses (Pearson's correlation coefficient) between the number of removed wild boars and the number of damages (event number and refunds) of the same and of the following year to highlight a possible delayed effect of culling on the damage.

Population Viability Analysis

We carried out Population Viability Analyses (PVA) to evidence the effect of present culling rate on the size and survival probability of the wild boar population and to test the effectiveness of additional culling to reduce the population size in the Park (Galimberti et al., 2001; Chilvers, 2012; Carroll et al., 2014; Meriggi et al., 2016). For PVA we used the control data provided by the Park administration from 2006 to 2016, assuming that control was not selective on sexes and age classes (Meriggi et al., 2016) (Table 1). In particular, we estimated the average values (±SD) of the following demographic parameters of the wild boar population: a) age of first reproduction of females (the youngest female with foetuses in the study period), b) maximum reproduction age of female (the oldest female with foetuses in the study period), c) maximum litter size (maximum number of foetuses over the study period), d) litter size distribution (considering all females with foetuses over the study period), e) breeding success (% of females with foetuses in each year), f) first-year mortality (%), g) second year mortality (%), h) mortality after second year (%). Mortality was calculated for males and for females in each year by Life Table method. The absence of a monitoring plan of the wild boar in the study area determined the lack of data on the size and density of the population. Thus, we defined the starting population considering the number of animal shot in 2018 (410 animals, latest data available) and accounting for two different scenarios: S1) the shot wild boars were 30% of the total population present in the Park and S2) the wild boar population size was at the carrying capacity level. The carrying capacity was estimated from bibliographic data on post-birth densities in three different wooded areas in Italy: 12 individuals per km^2 (Massolo and Mazzoni Della Stella, 2006), 11.6 individuals per km^2 (Cutini et al., 2013), and 23.9 individuals per km^2 (Maselli et al., 2014). The average density obtained was therefore 15.8 individuals per km^2 (SD = 6.93). Considering the number of animals shot during the study period the carrying capacity obtained was too low to be realistic, therefore we decided to double it. The carrying capacity was therefore 2101 wild boars (SD = 426.26). Additional scenarios were then simulated for each population level, doubling (*S1a*, *S2a*) and tripling (*S1b*, *S2b*) the harvest rate and concentrating it on the sub-adults and adult females. For each scenario, 100 iterations were carried out and the predictions of the population trend and its survival probability were made over 30 years. PVA was carried out with the software VORTEX 10.3.6.0 (Lacy et al., 2020).

Variables	Scenario 1	Scenario 2
Extinction	Only one sex remaining	
Lethal equivalent	6.29	
Proportion of lethal genetic load	50%	
Mating system	Polygynous	
Age of the first reproduction (females)	1 year	
Age of the first reproduction (males)	2 years	

Maximum reproduction age (years)	F 6 years - M 8 years	
Sex ratio at birth	1:1	
Maximum litter size	8	
Mean litter size (±SD)	4.7 (±1.3)	
Reproductive success % (±SD)	29 (±13)	
Mortality before year 1 (±SD) (age 0)	F 0.34 (± 0.32) - M 0.3 (± 0.42)	
Mortality year 1 to year 2(±SD) (age 1)	F 0.56 (± 0.25) - M 0.39 (± 0.25)	
Mortality year 2 to year 3(±SD) (age 2)	M 0.58 (± 0.39)	
Males in a breeding pool	100%	
Starting population	1367	2101
Males and females of age 1	318 - 308	489 - 474
Carrying capacity (±SD)	2101 (± 426.26)	

Table 1 Demographic input values used for the population viability analyses.

Results

General description of crop damage

From 2010 to 2017, 560 damage events occurred in the study area. The most affected crops were meadows and maize (50% and 43% of events respectively). The differences between observed and expected occurrence of events was globally significant (X^2 = 87.23, *gl* = 3, $P < 0.0001$); in particular the observed proportions (*OP*) were significantly ($P < 0.05$) lower than the availability ones (*AP*) for meadows (*OP* = 0.50; *SE* = 0.021; *AP* = 0.65) and for rice fields (*OP* = 0.02; *SE* = 0.006; *AP* = 0.04), and greater for maize (*OP* = 0.43; *SE* = 0.021; *AP* = 0.26), winter cereals and soybean were used in proportion to the availability (OP = 0.05; SE = 0.009; AP = 0.05). The total refunds in the study period amounted to € 928.858 (35% for meadows and 47.3% for maize). The damages occurred mainly between February and March, in May, and between August and September (X^2 = 122.88, *gl*= 11, *P* < 0.001). The damage to maize was concentrated in May and between August and September (X^2 = 203.05, *gl* = 11, *P* < 0.001) while the damage to the meadows occurred mainly between February and March (X^2= 127.85, *gl* = 11, *P* < 0.001).

During the study period there was no significant trend either for damage events (R^2 = 0.141; *SEE* = 15.64; *Beta* = -0.375; *P* = 0.360) or refunds (R^2 = 0.003; *SEE* = 39677.48; *Beta* = -0.05; *P* = 0.902).

The predictive model of damage risk

Out of 1586 fields present in the study area, 1026 were damaged by wild boars during the study period (2010-2017). All the measured field variables with exception of the distance from cycle paths and of the average number of shot wild boars showed significant differences between damaged and undamaged fields (Mann-Whitney U test, P ≤ 0.001 in all cases). Consequently, we used 11 predictors for risk modelling. Out of the 11 predictors, 7 were included in the predictive model of damage risk (Table 2). The shape index and the distances from railways, main roads and buildings had positive effects on the risk probability while the distance from secondary roads had a negative one. Moreover, the risk probability decreased for fields out of the flooded plain and increased for those at distances greater than 100 m from woods. The model correctly classified 71.6 % of the original cases, 32.5 % of the undamaged fields and 92.9 % of damaged ones.
Classifications obtained with the models formulated with the two random subsets resulted significantly other than randomness (Subset 1: X2= 69.62, df = 1, P < 0.0001; Subset 2: X2= 55.80, df = 1, P < 0.0001). The frequency of damaged fields resulted highly correlated with the predicted probability classes (Rho = 0.960, P < 0.0001) showing a good performance of the risk model.

Field variables	B	SE	Z	P	Exp (B)	VIF
Position out of flood plain	-0.6	0.13	-4.86	< 0.0001	0.528	1.12
Shape index	0.5	0.06	8.31	< 0.0001	1.661	1.08
Distance from railways	0.3	0.08	4.07	< 0.0001	1.373	1.08

Distance from main roads	0.2	0.04	4.39	<0.0001	1.184	1.14
Distance from woods (2)	0.4	0.14	2.98	0.003	1.516	1.09
Distance from woods (3)	0.6	0.17	3.59	0.0003	1.845	
Distance from buildings	0.1	0.04	3.54	0.0004	1.147	1.03
Distance from secondary roads	-0.1	0.03	-2.15	0.032	0.938	1.06
Intercept	-8.7	0.99	-8.79	< 0.0001	0.0002	

Table 2 Results of Logistic Regression Analysis of damaged (n = 1026) vs. undamaged (n = 560) fields.

Numerical control and relationships with the damages

The wild boars culled between 2006 and 2017 amounted to 2423. The years with the highest number of removed animals were 2013 and 2017 (450 and 472 respectively). The most used control method was shooting from hides, with 1990 individuals culled over the study period, while 122 wild boars were shot by drive hunting, and 220 were trapped. The number of removed wild boars showed a positive and significant trend ($\beta \pm SE$ = 26.199±7.69; P = 0.007) according to a linear model which explained 53.7% of the variance (R^2 = 0.537; *SEE* = 92.04). No significant correlations resulted between the number of removed wild boars and the number of damage events or refunds in the study period (Table 3).

Damage variables	r	P
Damage events in the same year	0.446	0.192
Damage events in the following year	0.099	0.785
Refunds in the same year	0.481	0.227
Refunds in the following year	-0.590	0.123

Table 3 Results of the correlation analysis between the number of wild boars removed each year and damage events and reimbursement amount.

Population Viability Analysis

The simulation S1 showed that a population decrease, and a survival probability reduction are not achievable with the current removal rate. A slight difference resulted doubling the removal rate and concentrating it on the sub-adults and females (S1a simulation). The same result occurred for the simulation S2 and S2a. By tripling the removal rate on the same sex and age classes, a drastic reduction in the population (50% in 7 years) and a halving of survival probability in 3 (S1b) and 4 years (S2b) was obtained (Figg. 2 and 3).

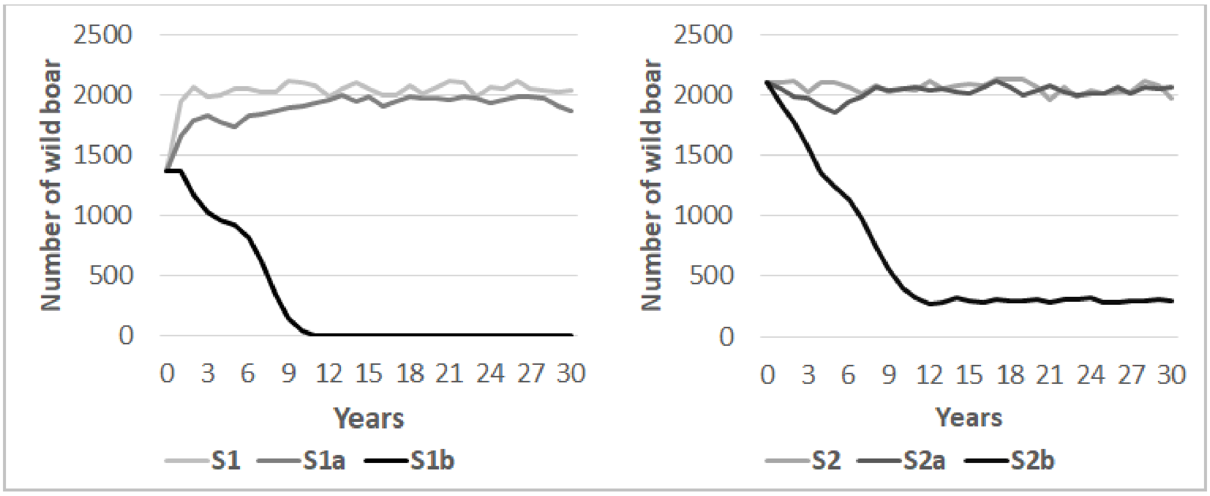

Figure 2 Population size of Ticino Valley Natural Park wild boar population based on Population Viability Analysis (PVA) simulations. On the left, the first simulation of the current harvesting rate on the population assuming that shot wild boars were 30% of the total population present in the Park (S1) (r =0.473, SD =0.187, PEE =0) in *light grey*, simulation of the doubled harvesting rate (S1a) (r = 0.414, SD =0.212, PEE =0.04) on sub-adults and females in *grey* and simulation of the

triplicate harvesting rate (S1b) (r = -0.039, SD =0.244, PEE =1) on sub-adults and females in *black*. On the right, the second simulation of the current harvesting rate assuming that the population size is at the carrying capacity (S2) (r =0.471, SD =0.188, PEE =0) in *light grey*, simulation of the doubled harvesting rate (S2a) (r = 0.433, SD =0.198, PEE =0.01) on sub-adults and females in *grey* and simulation of the triplicate harvesting rate (S2b) (r = 0.236, SD =0.310, PEE =0.84) on sub-adults and females in *black*.

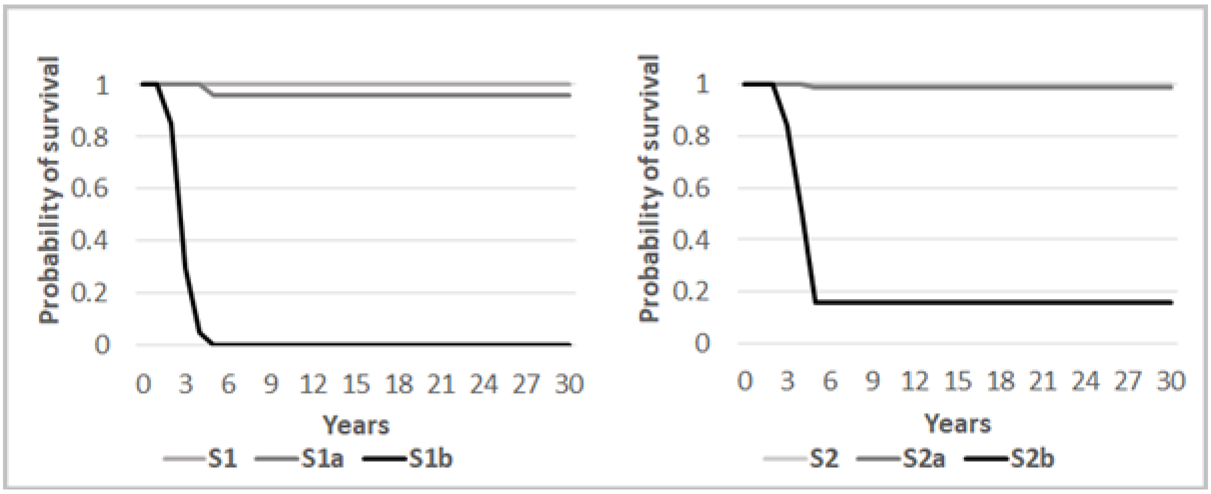

Figure 3 Survival probability of the Ticino Valley Natural Park wild boar theoretical population based on Population Viability Analysis (PVA) simulations. On the left, simulation (S1) that represents the 30% of the population in *light grey*, simulation of the doubled harvesting rate (S1a) on sub-adults and females in *grey* and simulation of the triplicate harvesting rate (S1b) on sub-adults and females in *black*. On the right, simulation of the current harvesting rate (S2) assuming that the population size is at the carrying capacity in *light grey*, simulation of the doubled harvesting rate (S2a) on sub-adults and females in *grey* and simulation of the triplicate harvesting rate (S2b) on sub-adults and females in *black*.

Discussion

Our results confirm that the wild boar selects specific types of crops. The maize is one of the most damaged crop by wild boar in many areas (e.g. Spain, Nores et al., 1999; Herrero et al., 2006; China, Cai et al., 2008; Luxembourg, Schley et al., 2008; Italy, Serrani, 2012). Several studies indicate a wild boar preference for maize respect to winter cereals (Briedermann 1976, Herrero et al., 2006). The damage to maize fields, as confirmed by our results, is typically concentrated in the periods of sowing and milky ripening of the cob (Vasudeva et al., 2017; Boyce et al., 2020) that occurs between July and September. In this period, usually characterized by the absence of natural caloric food such as acorns, the cobs are odorous and juicy and therefore very attractive for wild boar and easier to digest (Schley and Roper, 2003; Calenge et al., 2004; Cai et al., 2008). In addition, maize crops provide good coverage from early summer to autumn compared to other crops (Geisser, 2000). The meadows are the second most important type of cultivation damaged in our study area, even if we have found a significant underutilization probably due in part to their great availability. The use of grassland by wild boar as a foraging habitat is common in several countries (Schley and Roper, 2003; Schley et al., 2008; Thurfjell et al., 2009; Frackowiak et al., 2013; Lombardini et al., 2017;). The damages can be linked both to rooting and trampling activities (Barrios-Garcia and Ballari, 2012; Bueno et al., 2013), and our results confirm that the meadows are particularly affected by wild boar in late winter and early spring (Brangi and Meriggi, 2003; Schley et al., 2008; Amici et al., 2012) because in this period the earthworms and many insect larvae inhabit the upper layers of the soil, making them more accessible (Baubet et al., 2004; Frackowiak et al., 2013). The diet of the wild boar, with a high presence of corn and acorns, is rich in carbohydrates. Therefore, the proteins offered by invertebrates, mainly earthworm (Baubet et al., 2003, 2004; Bueno and Jiménez, 2014), inhabiting the meadows are important supplementary food sources (Massei et al., 1996; Schley and Roper, 2003; Ballari and Barrios-García, 2014).

The predictive model of damage risk showed how anthropic disturbance, the location of the field and its characteristics affect the probability of damage. In particular, the risk of damage decreases in the fields near the main roads, the rail network and buildings. This condition is mainly due to the disturbance caused both by the vehicular traffic and by the tourist use of the park because, despite the wild boar can colonize peri-urban environments (Cahill et al. 2012), wooded habitats are preferred by the species (Merli and Meriggi 2006, Hebeisen et al. 2008, Amendolia et al. 2019). Fields with complex shape, located within the floodplain are at greater risk of damage. In the floodplain, there are more natural habitats such as woods, reeds, and marshes, which represent the shelter places of the wild boar in our study area. Consequently, the fields placed in this environment represent easier to reach and safer feeding places (Lima and Dill 1990; Tolon et al. 2009; Thurfjell et al. 2013; Morelle and Lejeune 2015). Surprisingly, the fields adjacent to the woods have a lower probability of risk than those further away. This could be caused by the control activity from hides which are mainly placed at the edge of the woods. In accord with the Optimal Foraging theory in our study area wild boar seems to select the most profitable crops in the periods when they can offer high-quality food and in conditions that can guarantee greater safety (Begon et al. 2006).

To reduce the long-term impacts of wild boar one of the most used method is the lethal control of populations, which has proven to be an effective method in different countries (Geisser and Reyer, 2004; ELO, 2012; Mazzoni della Stella et al., 2014; Giménez-Anaya et al., 2016). In the Ticino and Lake Maggiore Park, from 2006 to 2017, the control was not selective, the ratio between males and females removed was one. Moreover, the most used control method was shooting from hides. The correlation between the number of removed boar and the number of damages that occurred the following year was close to the significance threshold. This result suggests a possible delayed effect of lethal population control, which should be considered in planning long-term population control but, in general, the ineffectiveness of culling carried out in the study area is demonstrated by the absence of a damage reduction during the study period.

The present control seems not to be effective for wild boar, because unable to mitigate the population increase, even in situations of strong hunting pressure (Servanty et al., 2011; Massei et al., 2015). The hunting acts differently from the natural mortality that tends to concentrate on individuals under one-year-old (Servanty et al., 2011; Keuling et al., 2013; Bassi et al. in press). Furthermore, it alters the spatial behavior of individuals, causing an increase in the size of the home range (Scillitani et al., 2010), and a greater use of "secondary" habitats, including cultivated ones (Stankowich, 2008; Thurfjell et al., 2013). Furthermore, the effectiveness of the culling plan may have been affected by the availability of natural food, in particular acorns for which no data are available. This parameter can have an important influence on the selection of secondary habitats, such as crops, by wild boar for feeding.

The absence of a population-monitoring plan in the study area led to the absence of information such as population density, which is essential for planning a numerical control strategy for wild boar. Furthermore, data regarding mast production are lacking. Considering this background, the numerical control methods could be useless, if not self-defeating, when not scientifically supported. For this purpose, Population Viability Analyses could be effectively used (Meriggi et al. 2016; Gürtler et al., 2017; Gonzalez-Crespo et al., 2018). Our PVA simulations showed that to obtain a drastic reduction in the size of the population it would be necessary to carry on a massive culling plan focused on reproductive females and sub-adults. In this way, the reproductive potential of the population can be reduced year by year without triggering a density-dependent compensation.

Several studies have shown that, in open populations, annual harvest levels above 60% are required to obtain a fast decrease in population size (Keuling et al., 2013; Bengsen et al., 2014; González-Crespo et al., 2018), but applying massive culling could be costly and unrealistic in the long run. A recent study, which concerned the wild boar populations of the Castelporziano State Reserve (Croft et al., 2020) in Italy also demonstrated that in a closed population it is necessary to have a high harvest rate, similarly to what emerged from our simulations, to obtain a marked reduction of the population in a reasonable time. The authors also evaluated the effects of the simultaneous application of culling and fertility control methods which showed how integrating a realistic culling rate with fertility reduction allows to obtain significant results in a short time. Although fertility control alone was not sufficient to achieve the desired results, the application of a control strategy based on a balanced mix of culling and sterilization seems to be an important opportunity to reduce wild boar populations. In this way, it is possible to shorten the time needed to reduce the population to a sustainable level, limiting at the same time the stress caused to other species. This should be a priority when control activities are carried out in protected areas or where high levels of culling may not be socially acceptable.

Conclusions

Although it is an autochthonous species of a large part of the European continent, wild boar can have characteristics of invasive species because of several factors attributable to man. The abandonment of marginal agricultural areas, changes in agricultural practices, releases for hunting or reduction in harvesting pressure, lack of predators, and climatic changes (Genov, 1981; Sáaez-Royuela and Telleriia, 1986) have led to a significant increase in its populations which, in turn, have produced and they still produce ecological as well as economic damages (Massei and Genov, 2004). Consequently, a management plan for wild boar is now necessary in all those situations where the species reaches population densities that are not compatible with the ecological but also the economic context. To properly plan the management, the biological traits that make wild boar a potentially invasive species must be considered, with particular reference to population growth rates and opportunistic characteristics of foraging behaviour (Pastick, 2012; Sales et al., 2017).
In landscapes where farming is particularly developed, also thanks to high quality crops, an effective management plan for the wild boar aimed to reduce the conflicts between the species and

humans becomes an increasingly priority need. The basic knowledge for the plan comes from a monitoring program of wild boar populations and from an updated inventory of economic damages caused by the species.

Prevention methods (electric fences, sound and olfactory bollards and dissuasive foraging) are commonly used to mitigate the impact of the wild boar on agriculture but they can be very expensive if adopted indiscriminately over large areas (Schlageter and Haag-Wackernagel, 2012). To allow the implementation of targeted and effective prevention measures, it is desirable to formulate predictive models of risk that allow the identification of the fields most exposed to damages (Saito et al., 2012; Ficetola et al., 2014; Meriggi et al., 2016). In most cases, the prevention methods, where and when adopted, are applied after the damages have already occurred, and without a cost-benefit analysis (Massei et al., 2011; Meriggi et al., 2016). The formulation of risk prediction models allows acting in advance by assigning a risk class to each field and therefore to identify the fields most at risk (Cappa et al., 2019), where it is possible to provide deterrent systems such as electrified fences or acoustic deterrents. This would improve the effectiveness of these tools and could partially reduce their economic impact on single farms.

The control activities aiming to produce a significant reduction in population size by means of culling should be concentrated on females older than or equal to one year, piglet and sub-adults (Bieber and Ruf, 2005; Servanty et al., 2011; Gamelon et al., 2012; Meriggi et al., 2016;). The culling of sub-adults is necessary because they more easily use secondary habitats such as cultivated areas, and because they will enter in the reproductive pool in the following year (Keuling et al., 2008). Concerning the wild boar culling methods, those that ensure greater precision in the selection of individuals to be removed would be preferred. Although in some cases collective culling methods have proven effective in reducing damage (Giménez-Anaya et al. 2016), we believe that collective hunting methods, although they may have good results, are not the correct way to manage the problem of damage within protected areas, because of the possible disturbance caused to other species, such as *Capreolus capreolus*.

The adoption of preventive methods aimed at the crops mostly at risk together with the targeted numerical control can be the solution that allows to reduce damage while maintaining the presence of the wild boar.

Acknowledgements

We are grateful to the Wildlife Service of the Novara Province for its help in data collection. We also wish to thank the Ticino and Lake Maggiore Park, in particular, Paola Trovò and Angelo Ongaro, for their precious collaboration in the acquisition of data on the numerical control of the wild boar.

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Chapter 4

Feeding habitat selection by wild boar in woodlands: can the rooting affect nemoral species?

Cappa, F., Foti, F., Bocca, F., Bani, L., Meriggi, A. (2020). Feeding habitat selection by wild boar in woodlands: can the rooting affect nemoral species?

Abstract

Wild boar is a potentially problematic species due to the different negative impacts that its presence and activities can cause to natural plant and animal communities (Massei and Genov 2004). In this study, carried out between March and August 2019 in the lowland forests of the Ticino Valley Natural Park (North-western Italy), we investigated the factors influencing feeding habitat selection of the wild boar, and whether nemoral flora is negatively affected by rooting. Feeding activities during the spring and summer periods seem concentrated in wooded areas characterized by fresh soils, where the thickness of the litter is greater and the mast content, especially acorns, is greater. Although there is a significant correlation between the intensity of rooting and the presence of nemoral species, it does not seem to have a significant and negative effect in short-term on the number of species present or their abundance in the sampled areas, and the floristic diversity and the dominance ratios between the nemoral species seems to be not influenced by the rooting intensity.

Introduction

The wild boar (*Sus scrofa*) is one of the ungulate species that has most expanded its range worldwide together with an increase of population size (Veličković et al., 2016). Measuring and assessing the potential negative impacts of the wild boar presence has become the subject of public attention (Vallée et al., 2016). The study of negative impacts on human activities has been deepened by several researches and the critical issues are mainly related to the damage of agricultural production, the transmission of infectious diseases, and collision with vehicles (Barrios-Garcia and Ballari 2012; Bengsen et al. 2014; Bosch et al., 2017; Meier and Ryser-Degiorgis 2018). Concerning potential impacts on biodiversity, wild boar can act both as an invasive species and an ecosystem engineer; some studies have highlighted positive effects of the presence of wild boar which can create, for example, new aquatic habitats for amphibians and maintain them by wallowing or trampling (Baruzzi and Krofel, 2017), increase heterogeneity and species diversity of semidry grassland vegetation (Horčičková et al., 2019) and rooting could provide a positive effect on microhabitat quality for the endangered butterfly *Pyrgus malvaeas* (De Schaetzen et al., 2018). On the other hand, in some cases, wild boar can harm both animal and plant communities (Tierney and Cushman, 2006; Cuevas et al., 2012; Barrios-Garcia and Ballari 2012; Zeman et al., 2016; Genov et al., 2017; Bongi et al., 2017; Mori et al., 2020). Negative impacts are generally related to trampling and feeding activities together with predation upon invertebrates, small vertebrates, and eggs of ground-nesting birds (Baubet et al., 2003; Amori et al., 2016; Senserini and Santilli 2016; Oja et al., 2017; Mori et al., 2020). Moreover, depending on the intensity of rooting, wild boar can alter soil properties (Bueno et al., 2013; Palacio et al., 2013) and damage plant communities (Brunet et al. 2016; Sondej and Kwiatkowska-Falińska 2017). Several studies have shown a negative impact on the species richness of vascular plants (Hone, 2002; Welander, 2014), damage to herbaceous cover (Howe and Bratton, 1976; Howe et al., 1981), and a negative impact in terms of composition, dominance and abundance ratios of the undergrowth flora (Burrascano et al., 2015). For the evaluation of the potential negative impact on the undergrowth, two aspects should be considered: the first concerns the indirect effect on the height and density of the shrub layer and the second the selection of plants with bulbs and fruits with high-energy content. In particular, the feeding activity of the wild boar can favour the penetration of light with a consequent impact at the level of the microhabitat, thus favouring the development of the herbaceous layer and reducing plant diversity. (Boulanger et al., 2018). The selection of bulbs and fruits of some species, on the other hand, can alter the reproductive and dissemination capabilities of the selected species to the point of causing local extinction (Cuevas et al., 2016). These impacts, if combined, could have negative short-term and long-term effects on the conservation of both protected plant species and the natural landscape. This study aims to identify the factors that influence the selection of wooded areas used by wild boar for feeding and to assess the potential effects of rooting on the most important nemoral species that characterize the undergrowth of the lowland woods present in the study area. Our main hypothesis is that rooting is not randomly distributed within the wood, but occurs in areas characterized by *a)* the presence of masts, *b)* the presence of abundant litter, *c)* moist and soft soils, and *d)* good coverage of the undergrowth shrub flora. Moreover, we hypothesize that the rooting is not linked to the direct consumption of nemoral species. The damages to this vegetation could be indirectly caused by the excavation activities of wild boar in search of mast and invertebrates present in the litter and the superficial layers of the soil, therefore the damages to the nemoral flora are not a threat to the conservation of this species.

Study area

Our study area corresponds to the Ticino Valley Natural Park (66.5 km^2; 45° 34′ 1.2″ N, 8° 40′ 58.8″ E; located in the Novara Province (Piedmont Region, North-western Italy), South of Lake Maggiore (Fig. 1). The protected area, with an altitude between 96 and 290 m a.s.l. is characterized by a temperate climate, with cold winters and hot and sultry summers. The average rainfall is 1000 mm, with two peaks in spring (April-May) and autumn (November). The average yearly temperature is

11.8°C (the average of the minimum temperature of the coldest month, January, is -2.9°C and the average of the maximum temperature of the hottest month, July, is 28.3°C) (National Institute for Meteorology and Aeronautical Climatology, 2008). The 40% of the park is used for agriculture (23 km^2), with a relative prevalence of maize (26%) and meadows (65%), while the remaining 60% is covered by woodland. The 42% of the wooded area of the park was covered by natural mixed forests of oaks (*Quercus robur* and *Quercus petraea*), hornbeam (*Carpinus betulus*), and linden (*Tilia cordata*), the 22% was covered by locust tree woods (*Robinia pseudoacacia*) and 13% by mixed woods of oak elm (*Ulmus minor*) and ash (*Fraxinus excelsior*). In addition to the shrubby forms of the aforementioned tree species, in the area, the most common shrub species are: Wild plums, Hazel, Hawthorn, Elder, Common spindle and European cornel, which are usually associated with Bramble and Privet tree. Moreover, according to the Council Directive 92/43/EEC of 21 May 1992, the following habitats have been identified in the park: *a*) 9160; *b*) 91F0; *c*) 91E0*; *d*) 9260; *e*) 91L0.

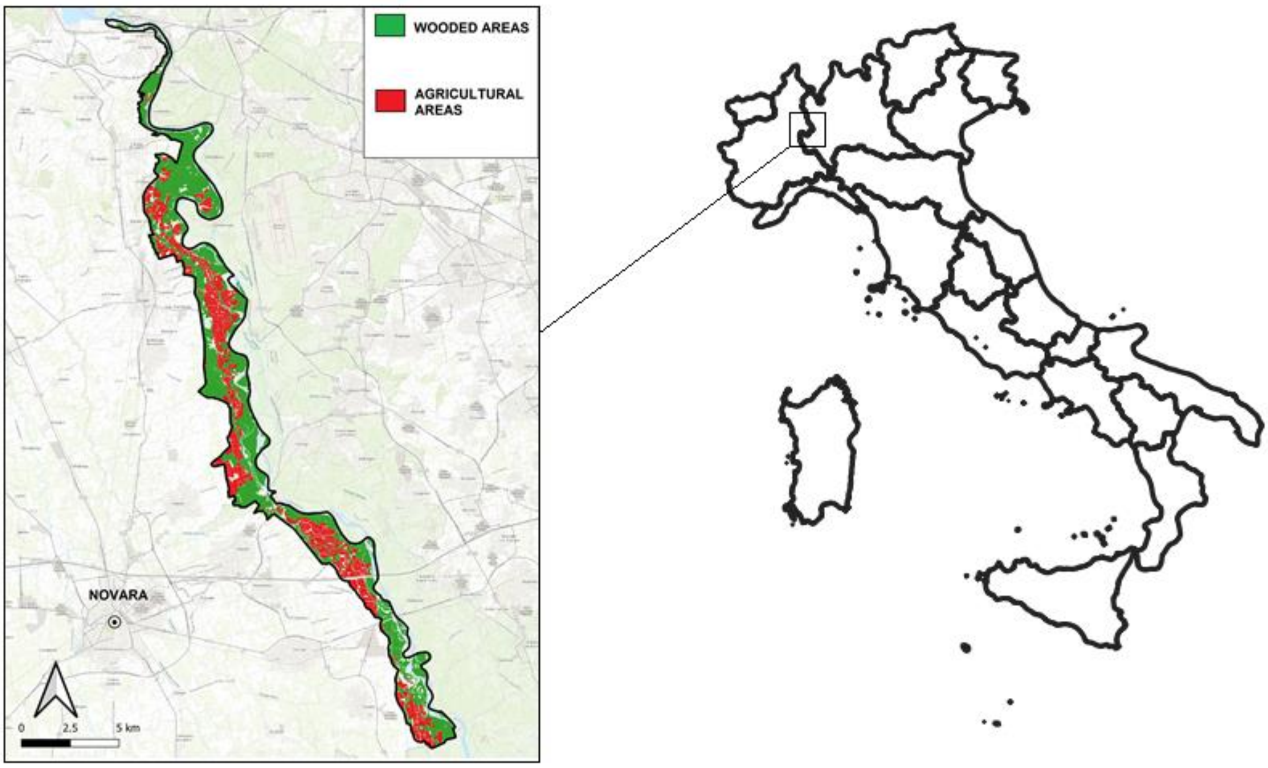

Figure 1 Location of the study area

Materials and methods

Data collection

Data collection started in March and ended in August 2019, during the flowering period of the nemoral species. We placed, 132 5 meter-radius circular plots with a density of 1 plot every 25 ha of each wood type adopting a random tessellation stratified sampling (TSS, Sutherland 2006; Barabesi and Fattorini, 2013) using QGIS 2.18 LTR Las Palmas software (Table 1). We checked for the presence of rooting and counted the number of diggings as an index of rooting intensity in each plot. We collected information in each plot concerning *a*) the main environmental variables; *b*) the wood structure; *c*) the main parameters of the litter and *d*) presence of rooting; moreover we calculated the Shannon diversity index (H') and the Simpson dominance index (D') (Appendix 1). We performed the sampling of herbaceous floristic composition in each plot using the Quadrat sampling methods (Anderson 1942; Smith et al., 1987; Sorrells and Glenn 1990) in 5 subplots ($1m^2$ each one) randomly placed.

Wood types	Hectares	N° of plots
Sub-Atlantic stitchwort oak-hornbeam woods	1465	58
Locust tree woods	765	30
Mixed oak-elm-ash woods	438	17
Woods of *Pinus sylvestris*	393	16
Woods of ash and alder	159	6
Chestnut woods	105	4
Illyrian oak-hornbeam woods	48	2
Small woods	45	2

Quercus cerris woods	39	2
Other deciduous woods	21	1

Table 1 Extension of wood types in the study area and number of sampling plots in each type (N= 138).

Feeding habitat selection

We tested for significant differences of the 19 wood variables between plots of presence and absence of rooting by the Mann-Whitney U test. Moreover, we analyzed the occurrence of rooting considering *a*) the type of forest; *b*) the status of the soil; *c*) the type of water source available, and *d*) the type of mast present in the litter by the X^2 test for contingency tables. To identify which variables influenced the feeding activity, we formulated a model to describe the probability of occurrence of rooting, using binary logistic regression analysis (BLRA) with as dependent variable the rooting presence (1) and absence (0) in the sample plots (Meriggi and Sacchi 2000). Variable selection was made by the stepwise forward procedure and the Akaike Information Criterion corrected for small samples (AICc, Akaike 1973; Anderson et al. 2000, 2001; Burnham & Anderson 2002). We evaluated the goodness of fit of the model by the Nagelkerke R^2 and the model performance by the area under the Receiver Operating Characteristics (ROC) curve (AUC), which can assume values ranging from 0.50 (random prediction of the model) to 1.00 (perfect prediction of the model). Model discrimination ability was categorized 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). Finally, we computed the Variance Inflation Factor (VIF) to test variable collinearity and used the Shaphiro-Wilks test to check for residual normality (Quinn & Keough 2002; Zuur et al. 2010).

Moreover, we analyzed the relationship between the characteristics of the woods and the rooting intensity by Pearson correlation coefficient and Multiple Linear Regression Analysis (MLRA). To select the predictor variables in the MLRA model we used the stepwise forward procedure and the Akaike Information Criterion corrected for small samples (AICc, Akaike 1973; Anderson et al. 2000, 2001; Burnham & Anderson 2002). We evaluated the model performance by the adjusted R^2 (explained variance) and by the correlation between observed and predicted values of the response variable (number of diggings). We checked for collinearity of predictors by VIF, for residual normality by Shapiro-Wilk test, and residual autocorrelation by Durbin-Watson test (Zuur et al. 2010).

Impacts on nemoral flora

To evaluate the possible impacts of the rooting on the nemoral flora we compared the frequency of occurrence of pooled species of nemoral flora recorded in the plots with and without rooting by the X^2 test for contingency tables. Moreover, we used the same analysis to compare the frequency of occurrence of the nemoral species present in more than 10 plots among *i*) the types of forest, *ii*) the soil status, and *iii*) the types of available water source; we carried out the same analyses pooling all the nemoral species. Furthermore, we used correlation (Pearson's correlation coefficient) and curve-fit analyses to relate the number of rooting signs in each sample plot with the number of nemoral species and their percent coverage and to evaluate the relationships between rooting intensity and the Shannon diversity index (H') and the Simpson dominance index (D'). Finally, we verified the existence of significant differences in rooting intensity between plots of presence and absence of the main nemoral species by the Mann-Whitney U test.

We carried out all statistical analyses using the SPSS 20.0 (Sweet and Grace-Martin, 1999) and R statistical software. For all statistical analyses, we used a value of P = 0.05 as a significance threshold.

Results

Feeding habitat selection

Between plots with and without rooting, significant differences resulted for soil temperature, lower in the plots with rooting (U = 1644.50, df = 1, P = 0.042), and for the litter thickness, greater in the presence plots (U = 2587, df = 1, P = 0.015) (Fig. 2).

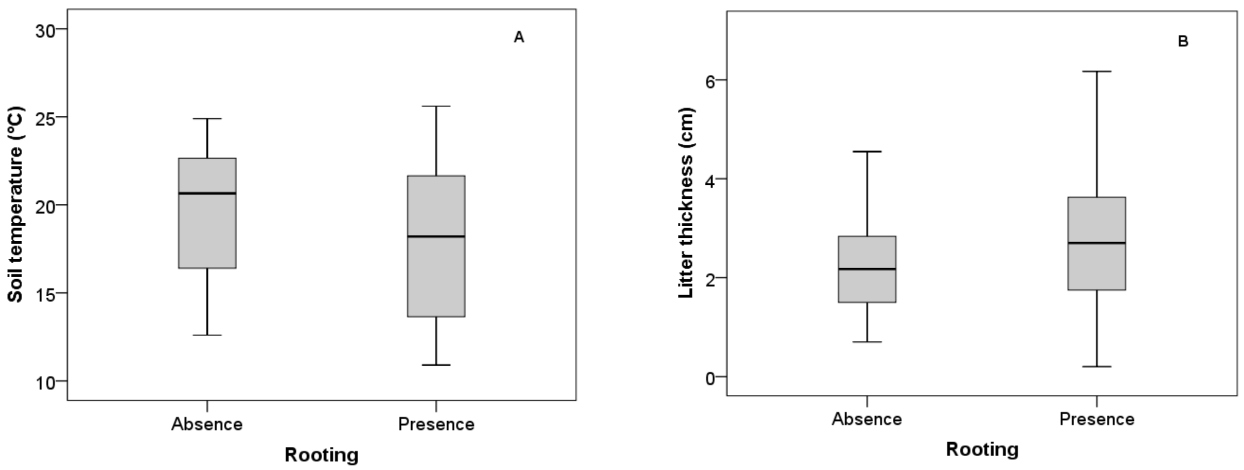

Figure 2 Box plots of Soil temperature (A) and Litter thickness (B) in plots with and without rooting

The occurrence of rooting was not significantly different between the types of woodland (X^2 = 2.43, *gl* = 4, *P* = 0.657). The same was for the soil state (X^2 = 3.82, *gl* = 1, *P* = 0.076) and for the types of water sources (X^2 = 5.74, *gl* = 3, *P* = 0.125) while the occurrence of rooting was greater in the plots with only one type of mast, in particular acorns or hazelnuts (X^2 = 8.75, *gl* = 2, *P* = 0.013).

Seven wood variables entered the logistic model for rooting occurrence (AICc = 144.91) of which six had significant effects (Table 2). In particular, brightness at soil level, fruit availability, and the height of the shrub layer increased the probability of rooting occurrence, whereas brightness at 150 cm, dry soils, and the presence of the river, ditches, and ponds decreased it.

Wood variables	B	SE	Wald statistic	df	P	Exp (B)	VIF
Brightness at 0 cm (lux)	8.6	3.36	6.50	1	0.011	5193.36	1.89
Brightness at 150 cm (lux)	-7.5	2.75	7.38	1	0.007	0.00	1.94
Dry soil	-1.7	0.58	8.95	1	0.003	0.18	1.17
Water source			5.90	3	0.117		1.03
River	-2.3	1.22	3.68	1	0.055	0.10	
Ditches	-2.7	1.31	4.11	1	0.043	0.07	
Ponds	-3.2	1.37	5.61	1	0.018	0.04	
Fruit cover (%)	7.3	2.48	8.76	1	0.003	1551.65	1.14
Herbaceous layer cover (%)	-1.3	0.84	2.42	1	0.119	0.27	1.20
Shrub layer height (cm)	0.6	0.25	5.91	1	0.015	1.84	1.04
Constant	2.5	1.48	2.85	1	0.091	12.13	

Table 2 Results of the logistic regression analysis of the rooting presence vs. wood variables

The model explained 43.2% of the variance (Nagelkerke R^2 = 0.432) and correctly classified 74.2% of the original cases (61.5% of absence and 82.5% of presence).

The AUC was equal to 0.85 (*ES* = 0.03; *P* <0.0001), demonstrating a good predictive power of the model (Fig. 3).

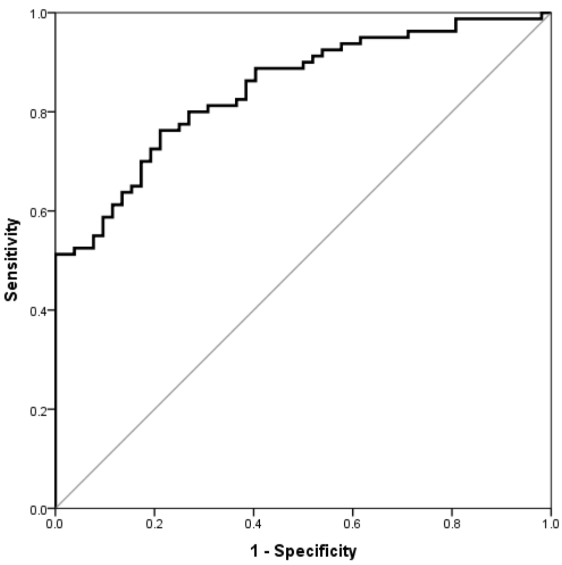

Figure 3 ROC curve of the logistic model of the rooting presence vs. wood variables (*black*) compared with the curve of a model that classify randomly the cases (*grey*)

The intensity of rooting resulted negatively correlated with the temperature inside the wood (r = -0.195, P = 0.025) and with the soil temperature (r = -0.214, P = 0.014), and positively with the availability of mast in the litter (r = 0.234, P = 0.007). Furthermore, the percent cover of the herbaceous layer and the height of the shrub layer showed significant correlations with the rooting intensity (r = -0.159, P = 0.069 and r = 0.150, P = 0.087, respectively).

The MLRA produced a significant regression model of rooting intensity (F = 6.67, gl = 6, 125, P < 0.0001, AICc = 354.69) which entered six wood variables of these five had significant effects (Table 3). In particular, the tree layer cover and the fruit availability on the soil increased the rooting intensity while herbaceous layer cover, litter cover, and soil temperature decreased it. The model explained 20.6% of the dependent variable variance ($R^2 = 0.206$) and predicted and observed values resulted significantly correlated (r = 0.502, P < 0.0001).

Wood variables	B	SE	β	t	P	VIF
Tree layer cover (%)	0.1	0.02	0.19	2.19	0.030	1.21
Herbaceous layer cover (%)	-2.3	1.18	-0.17	-1.96	0.052	1.21
Fruits cover (%)	6.8	2.09	0.29	3.27	0.001	1.29
Litter cover (%)	-4.7	1.46	-0.29	-3.20	0.002	1.32
Shrub layer height (cm)	0.6	0.36	0.14	1.76	0.081	1.03
Soil temperature (°C)	-0.2	0.08	-0.22	-2.67	0.009	1.14
Constant	6.2	2.53		2.45	0.016	

Table 3 Results of the multiple regression analysis of rooting intensity vs wood variables.

Impact on nemoral flora

We identified 23 nemoral species in the sample plots but for the genera *Carex* and *Ranunculus* we did not reach the species determination (Appendix 2). The most common species were *Polygonatum multiflorum* (43.9% of the plots), *Vinca minor* (20.5%), *Pteridium aquilinum* (15.9%), *Anemonoides nemorosa* (8.3 %), and *Asparagus tenuifolius* (6.8%) (Table 4). *Vinca minor*, *Carex* sp., *Convallaria majalis*, *Neottia ovata*, *Anemonoides nemorosa*, and *Allium triquetrum* reached the highest average percent cover in the plots of presence (Table 4).

Species	*Average percent cover in the plots*	*Plots of presence*
Alliaria petiolata	0,6	1
Allium triquetrum	13,0	1
Anemonoides nemorosa	17,1	11
Asarum europeaum	1,2	2
Asparagus tenuifolius	3,4	9
Athyrium filix-femina	7,0	2
Calluna vulgaris	4,4	1
Cardamine flexuosa	0,4	1
Carex sp.	26,3	4
Convallaria majalis	18,5	3
Dryopteris filix-mas	5,2	1
Erythronium dens-canis	0,2	3
Ficaria verna	1,9	2
Fragaria vesca	6,5	4
Geranium robertianum	0,2	1
Glechoma Hederacea	2,2	1
Iris pseudacorus	1,4	1
Neottia ovata	18,2	1
Polygonatum multiflorum	4,5	58

Pteridium aquilinum	4,3	21
Ranunculus sp.	0,2	1
Symphytum tuberosum	2,5	2
Teucrium scorodonia	0,6	1
Vinca minor	31,3	27
Viola reichenbachiana	0,8	1

Table 4 Average percent coverage and number of presence plots of nemoral species.

The presence of nemoral flora was greater in the plots with rooting but the difference with the plots without was not significant (X^2 = 3.22; *gl* = 1; *P* = 0.073). Also, for each species, we did not find significant differences in the occurrence between plots with and without rooting. The number of species present and their coverage were not significantly related with the intensity of rooting (*r* = 0.104; *P* = 0.235 and *r* = 0.023; *P* = 0.789 respectively). Wild boar feeding activity was significantly higher in the plots of nemoral flora presence (*U* = 2219; df = 1, *P* = 0.015) (Fig. 4), but not considering each species alone.

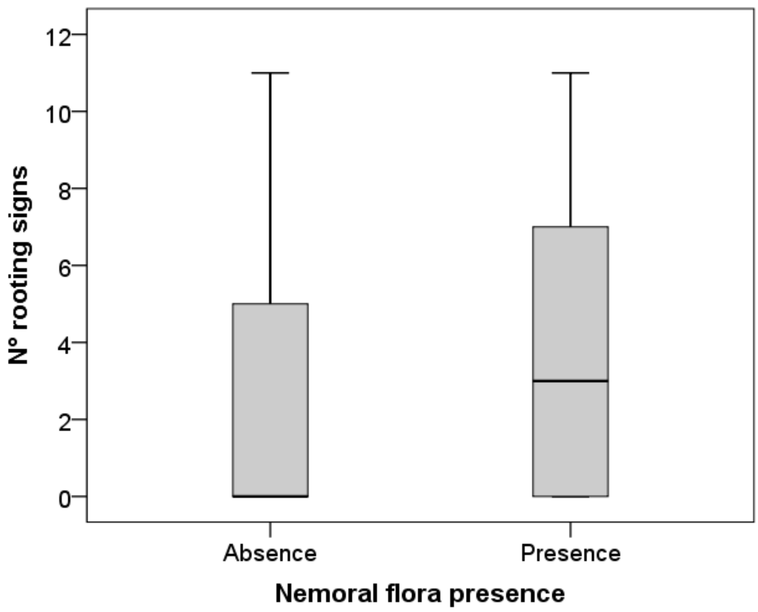

Figure 4 Box plot of rooting intensity in plots of absence (N= 37) and presence (N= 95) of nemoral flora.

The distribution of nemoral species was concentrated in the plots characterized by the absence of water sources (X^2 = 8.11; *gl* = 3; *P* = 0.044), but between dry and wet soils the difference was not significant (X^2 = 0.33; *gl* = 1; *P* = 0.669). The same was for the different types of wood (X^2 = 0.696; *gl* = 4; *P* = 0.952). The nemoral flora coverage showed a negative and significant relationship according to a linear model (*Beta* = -0.17; *P* = 0.048; R^2 = 0.030; *SE* of estimate = 20.00) with the average vegetation shielding and a positive one with the height of the shrub layer (*Beta* = 0.22; *P* = 0.011; R^2 = 0.048; *SE* of estimate = 19.81). The number of nemoral species did not show any correlation with the environmental and structural variables of the woods. Finally, rooting intensity was not correlated with both the H' index (*r* = -0.040; *P* = 0.674) and D' index (*r* = -0.120; *P* = 0.250).

Discussion

Feeding habitat selection

The results obtained seem to confirm the hypothesis that rooting in woodland areas is not randomly distributed, but some factors determine it. The rooting occurrence model highlights how the availability of wood fruits, the brightness at soil level, and the height of the shrub layer increase the probability of rooting occurrence while dry soils, brightness at 150 cm, and areas presence of water sources decrease it. This evidence suggests that rooting occurrence is higher in the more open and illuminated undergrowth areas, characterized by mature undergrowth and therefore higher and more productive shrubs. The more open and luminous wooded areas, with a low density of shrubs and drier soils, seem to be less attractive from a food point of view, as for the areas close to rivers and other water sources. The results obtained by the rooting intensity model confirm that rooting is more intense in dense forest areas, where the soil temperature is lower, and the presence of masts is higher. At least, rooting activities during the spring and summer periods seem concentrated in areas characterized by fresh soils, where the thickness of the litter is greater and the mast content, especially acorns, is greater. Probably, fresh and soft soils are positively selected by wild boar because the excavation activities are less energy-consuming compared to bare and dry soils (Vittoz and Hainard 2002). The presence of abundant litter appears to be an attractive food source for wild boar (Zeman et al., 2016) for some reasons. In the forest litter, usually, there are large quantities of masts, especially during the autumn season, which represent a fundamental food in the wild boar diet and a key to understanding the feeding and spatial behavior of wild boar (Schley and Roper 2003; Cutini et al., 2013; Zeman et al., 2016; Mikulka et al., 2018). Moreover, as the thickness of the litter increases, the abundance and diversity of invertebrates species inhabiting it can significantly increase (Xu et al., 2017) and, in the diet of the wild boar, the proteins offered by invertebrates are important supplementary components (Massei et al., 1996; Schley e Roper, 2003; Ballari and Barrios-Garcìa, 2014).

Impact on nemoral flora

Studies of wild boar’s impact on vegetation have shown different and contrasting results (Cuevas et al., 2020), in particular, in some cases, it appears that rooting has a positive effect, increasing species richness (Vild et al., 2016) and favoring the recovery of vegetation in semi-natural landscapes (Rusina et al., 2018) but, in other cases, the effect is opposite and there is a decrease in the species richness and diversity of herbaceous plant communities (Cuevas et al., 2012), ruderal plants are favored (Vild et al., 2016) and tree species richness is reduced (Bongi et al., 2017).

Considering the above, the results obtained from this study appeared slightly contradictory, showing the complexity of accurately quantifying the possible effects of rooting on spontaneous undergrowth species. The absence of significant correlation between the distribution of rooting and the distribution of nemoral species in the forest, the number of species, and their coverage, suggested that the possible impact on nemoral flora in the short term is not significant, nevertheless, they are not sufficient to exclude the possibility of long term impacts.

The significant correlation between the intensity of rooting and the presence of nemoral species could suggest a specific interest in this vegetation by the wild boar but in the short term did not result in a significant and negative effect on the number of species present or their abundance in the sampled areas, moreover, the floristic diversity and the dominance ratios between the nemoral species did not seem influenced by the rooting intensity.

This evidence did not allow to exclude the possibility that the wild boar, actively selecting the wood patches characterized by the presence of nemoral flora, could impact these species in the long term. It is not clear whether nemoral flora, in general or individual species, could represent a priority or occasional food resource, furthermore, it has not been possible to exclude that some variables that could influence the presence and abundance of nemoral species, such as the height of the shrub layer and brightness at soil level, also influenced the selection of feeding areas by the wild boar and the possible long term negative impacts on nemoral flora could be not related to direct consumption.

Management implications for conservation

Recent research on the impacts of rooting has highlighted how much wild boar feeding activities affect the environment; therefore, for natural habitat conservation, it is important to understand which factors influence rooting activities. The results obtained with our research show that some factors are fundamental for the rooting occurrence and to determine its intensity. Although the results demonstrate that in the study area there are no short-term negative effects on the composition and abundance of nemoral flora, the possible long-term effects must be deepened, therefore it would be necessary to monitor the effects of rooting on the nemoral flora and collect data for subsequent long-term analysis. In cases where short-term effects occur or the monitoring plan provides evidence of possible long-term effects, direct interventions should be arranged, for example by placing exclusion fences in the most affected sites or the ones that have high conservation importance.

Another important aspect suggested by the results obtained is related to the impacts of rooting activities on the fauna that inhabits the forest litter. Wild boar populations have shown considerable growth and spatial expansion in the last decades due to the great adaptability of this species and its reproductive rate, which is higher among ungulates (Bevins et al., 2014; Massei et al., 2015; Frauendorf et al., 2016). Wild boar populations, living in wooded areas characterized by high environmental quality, can grow fast and cause significant direct and indirect negative effects on invertebrates, resulting in a cascade effect. Wild boar, decreasing litter depth (Singer et al., 1984), indirectly reduced invertebrate diversity and increased soil compaction, which also decreased invertebrate diversity (Ramirez et al., 2020).

The wild boar, although it can have negative effects on some environmental components, plays a fundamental and positive role in the dispersion of the fleshy fruit's seeds that often pass intact through their digestive tract (Massei and Genov, 2004). Furthermore, wild boar plays an important role in the dissemination of fungal spores inside and outside the forest (Piattoni et al., 2013; Livne-Luzon et al., 2017). Finally, this evidence suggests that wild boar and ungulate populations in general, if limited and maintained at not excessive densities, could have a positive effect on the forest, increasing the resilience of temperate forests (Ramirez et al., 2020).

Conclusions

The importance of the conservation of natural woods and spontaneous undergrowth vegetation is now a shared awareness. Although several issues related to the presence of wild boar and its impact on the environment have been described (Massei and Genov 2004), our initial hypotheses have been almost totally confirmed. If on the one hand, the results obtained on rooting occurrence agree with the findings of many studies, on the other hand, the conflicting results highlighted by the various studies cited above seem to confirm a certain heterogeneity in the impacts of this species on natural plant communities, therefore it is necessary to further investigate the possible consumption of nemoral species by wild boar through an analysis of the diet targeted on the spontaneous undergrowth flora to verify if nemoral species are usually consumed and which of them are selected.

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Appendix 1: *List of variables measured in sample plots.*

Environment

Weather conditions

Cloudiness coverage – (0%, 25%, 50%, 75%, 100%)

Brightness at 0 cm – (brightness at 0 cm from the ground as a ratio of the Lux measured on the point over the Lux measured in open space; a measure of the cover of canopy, understory; and herbaceous cumulated layers)

Brightness at 60 cm – (brightness at 60 cm from the ground; a measure of canopy and understory cover)

Brightness at 150 cm – (brightness at 150 cm from the ground; a measure of canopy cover)

The temperature outside the forest – (°C)

The temperature inside the forest – (°C)

Distance of the plot centre from the forest margins – (m)

Distance of the plot centre from the nearest water source – (m)

Type of the nearest water source – (0-absent, 1-River, 2-ditches, 3-pools, 4-puddle)

Soil status – (1-dry, 2-moist, 3-muddy)

Soil temperature – (°C)

Forest structure

Type of forest

Forest management – (1-natural, 2-high forest, 3-coppice)

Herbaceous coverage of the ground – (%)

Average height of the herbaceous layer – (cm)

Shrubs coverage of the ground – (%)

The average height of the shrub layer – (m)

Arboreal coverage of the ground – (%)

The average height of the tree layer – (m)

The average arboreal girth – (cm)

The average vegetation shielding – (density of the vegetation, measured as the average percentage of a 2-m graduated pole visible at 5 m from the four cardinal points; a measure of the horizontal transparency of the vegetation)

Flora

Trees floristic composition

Shrubs floristic composition

Herbs floristic composition

Litter

Litter coverage of the ground – (%)

The average height of the litter – (cm)

Mast richness in the litter – (0-absent, 1-one type, 2- mixed)

Type of mast – (0-absent, 1-acorn, 2-hazelnut, 3-chestnut, 4-pine cone)

Average mast coverage of the ground – (%)

Wild boar

Wild boar presence signs – (0-absent, 1-rubbing point, 2-footprint, 3-nest, 4-bath point, 5-rooting)

Wild boar rooting signs – (number)

Rooting signs average length – (cm)

Rooting signs average width – (cm)

Rooting signs average depth – (cm)

Appendix 2: *List of nemoral species found in the sample plots.*

Family	***Species***		
Apocynaceae	*Vinca minor*		
Aristolochiaceae	*Asarum europeaum*		
Asparagaceae	*Asparagus tenuifolius*	*Convallaria majalis*	*Polygonatum multiflorum*
Boraginaceae	*Symphytum tuberosum*		
Brassicaceae	*Alliaria petiolata*	*Cardamine flexuosa*	
Cyperaceae	*Carex sp.*		
Hypolepidaceae	*Pteridium aquilinum*		
Dryopteridaceae	*Athyrium filix-femina*	*Dryopteris filix-mas*	
Ericaceae	*Calluna vulgaris*		
Geraniaceae	*Geranium robertianum*		
Iridaceae	*Iris pseudacorus*		
Lamiaceae	*Glechoma Hederacea*	*Teucrium scorodonia*	
Liliaceae	*Allium triquetrum*	*Erythronium dens-canis*	
Orchidaceae	*Neottia ovata*		
Ranunculaceae	*Anemonoides nemorosa*	*Ficaria verna*	*Ranunculus sp.*
Rosaceae	*Fragaria vesca*		
Violaceae	*Viola reichenbachiana*		

Conclusions

Although the plain areas of northern Italy are part of the wild boar native range, the agricultural and productive vocation of these territories requires management strategies focused on minimizing conflicts between human activities and the wild boar populations.

According to what emerged from the results obtained (**Chapter 1**), wild boar shows a strong preference for natural forest environments. Deciduous woods, composed mainly of oaks and characterized by an undergrowth rich in hazelnut, elderberry, wild cherry and blackthorn, are typical of these areas and offers shelter and abundant food reserves that support the growth of wild boars even in the most unfavorable periods. The use of secondary habitats such as crops is limited and concentrated in the spring and summer periods where very attractive crops provide an easily accessible supplementary food resource.

The results of the damage analysis (**Chapter 2**) highlight how the selection process of the damaged fields is influenced by various factors. In the special protection area "Risaie Della Lomellina", a territory with a strong agricultural vocation where the presence of the forest is limited, 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). Damage is mainly concentrated in two periods. Spring is the sowing season for maize, during which time wild boars unearth and consume seeds, and 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 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. The presence of fields at the edge of the wood, without barriers designed to limit the incursions of wild boars as fixed or electrified fences, favors the damage to agricultural production.

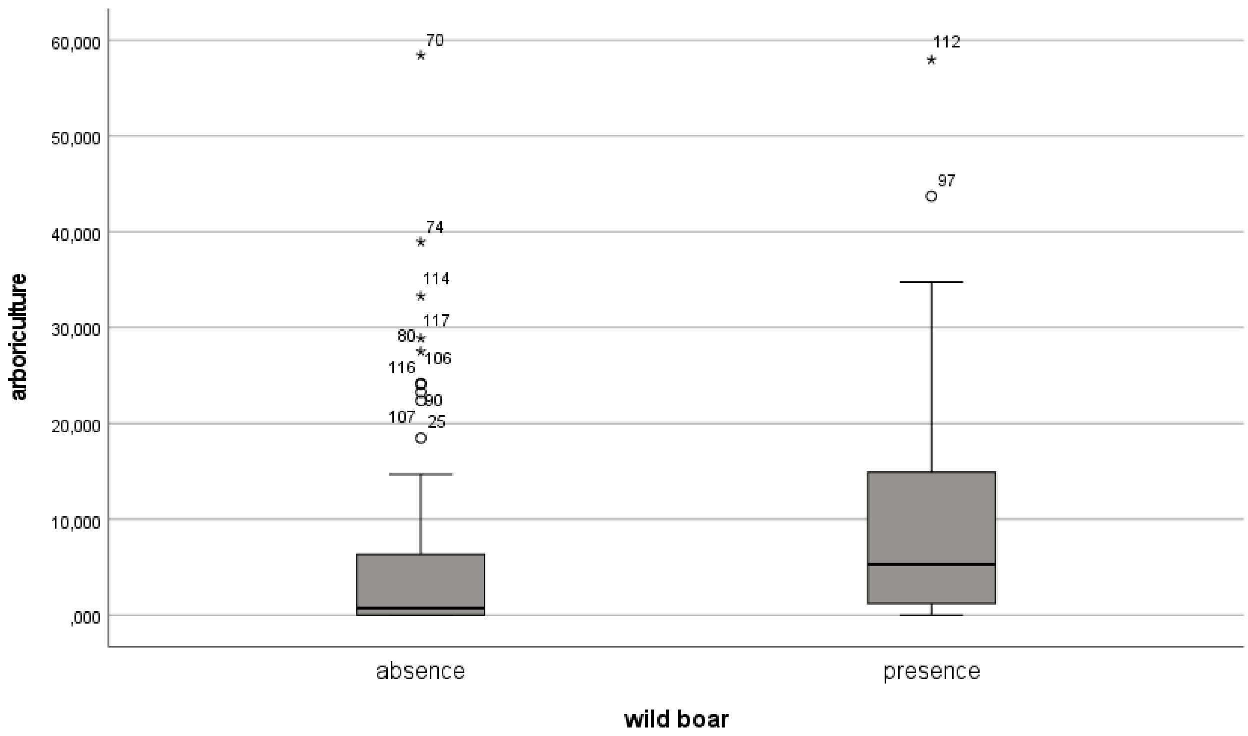
The results obtained from the damage analysis in Ticino and Lake Maggiore Park (**Chapter 3**) partially confirm what emerged in the second chapter. Maize is one of the most damaged crops by wild boars. The meadows are the second most important type of cultivation damaged in our study area, even if we have found a significant underutilization probably due in part to their great availability. Moreover, meadows are particularly affected by wild boar in late winter and early spring because in this period the earthworms and other soil invertebrates are more accessible. The risk of damage decreases in the fields near the main roads, the rail network, and cycle paths, confirming the strong negative influence of human disturbance. Fields with a large and irregular surface, located within the floodplain and close to the forest edges, show greater risk of damage because probably offer to wild boar a greater coverage and better chance of escape (Lima and Dill 1990; Tolon et al. 2009; Thurfjell et al. 2013; Morelle and Lejeune 2015). According to the Optimal Foraging theory in our study area wild boar select the most profitable crops in the periods when they can offer high-quality food and in conditions that can guarantee greater safety (Begon et al. 2006). In contexts where the agricultural surface extends into protected natural areas, the identification of the factors involved in damaging crop processes should represent the first step in the establishment of management models that promote the coexistence of natural wild boar populations and agricultural production. The present wild boar numerical control results not effective, because unable to mitigate the population increase, even in situations of strong hunting pressure (Servanty et al., 2011; Massei et al., 2015). The absence of a population monitoring plan in the study area led to the absence of information such as population density, which is essential for planning a numerical control strategy for wild boar. The PVA simulations performed on a theoretical population estimated from the hunting bags collected in the park showed that to obtain a drastic reduction in the size of the population it would be necessary to carry on a massive culling plan focused on reproductive females and sub-adults. In this way, the reproductive potential of the population can be reduced year by year without triggering a density-dependent compensation.

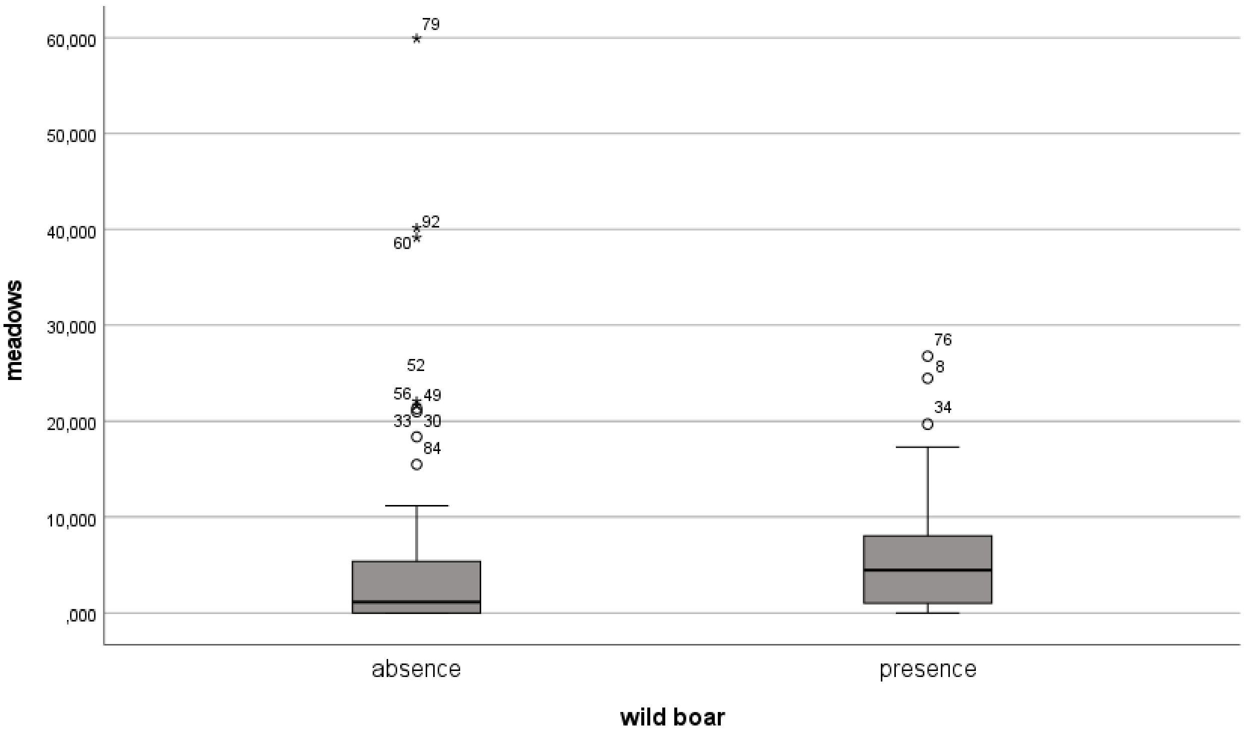
The results obtained by the rooting occurrence model, (**Chapter 4**), highlights that rooting is higher in the more open and illuminated undergrowth areas, characterized by mature undergrowth and therefore higher and more productive shrubs. Rooting intensity is higher in dense forest areas, where the soil temperature is lower, and the presence of masts is higher. Fresh and soft soils are positively selected by wild boar and the presence of abundant litter seems an attractive food source for wild boar. Concerning the wild boar potential negative impact on the undergrowth flora, no significant correlation between the distribution of rooting and the distribution of nemoral species in the forest, the number of species, and their coverage emerged from the results. Moreover, the intensity of rooting and the presence of nemoral species, didn't show a significant and negative effect on the number of species present or their abundance in the sampled areas and the floristic diversity and the dominance ratios between the nemoral species seems not influenced by the rooting intensity. However, the results obtained did not allow to exclude an impact of the long-term rooting activities on the nemoral flora present in the study area, although the investigation of the short-term effects seems to suggest the absence of a significant impact.

Supplementary materials

Chapter 1

Figure 4 *Box plots of habitat variables in presence (n = 55) and absence (n = 63) cells (autumn-winter).*

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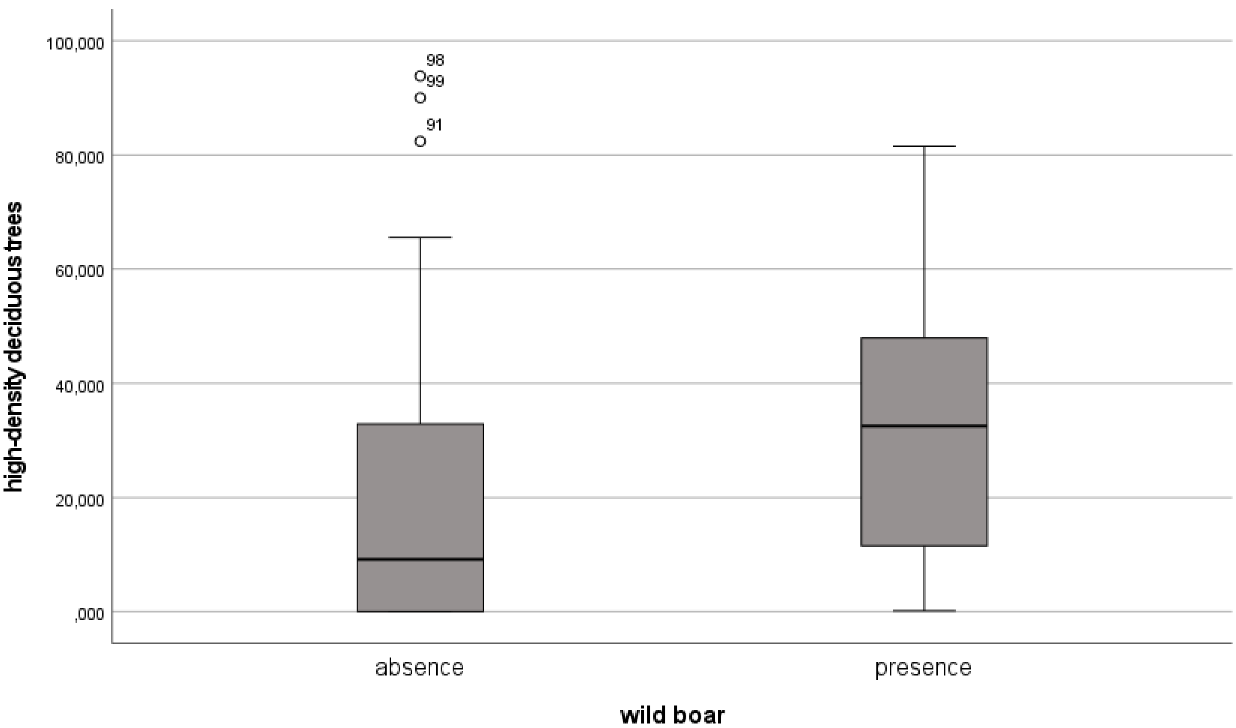
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high-density deciduous trees
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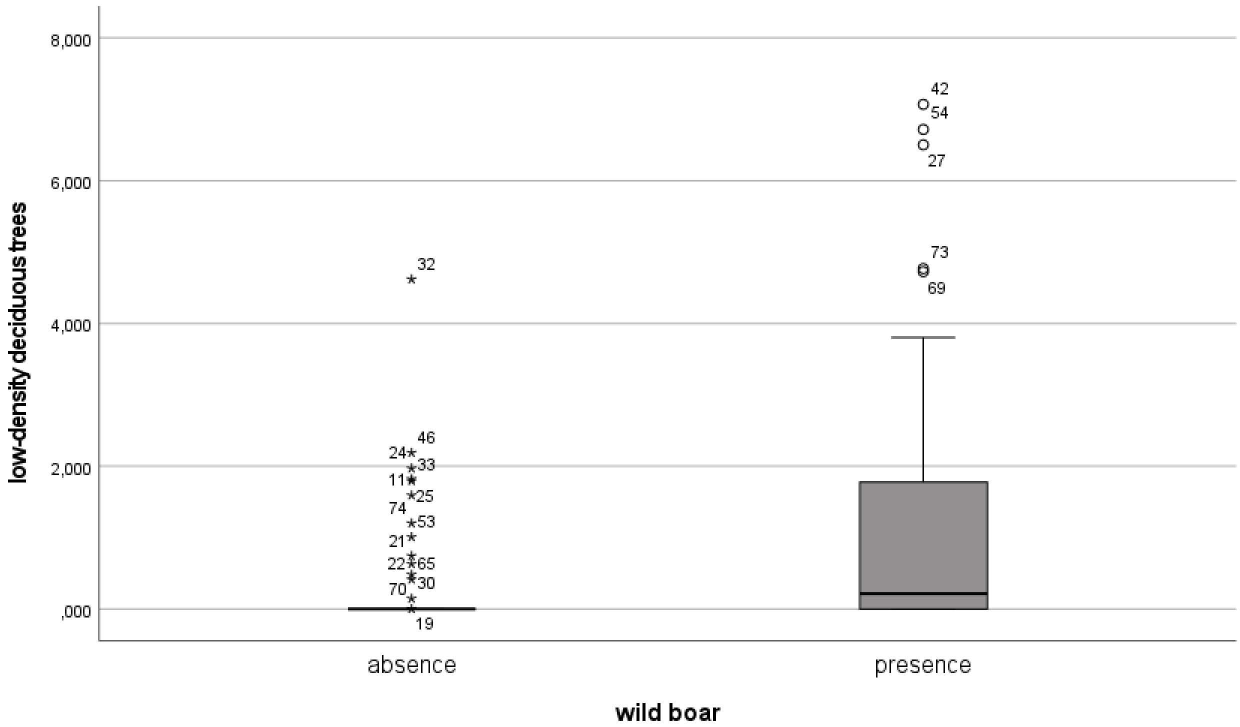
99
91
absence
presence
wild boar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low-density deciduous trees
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25
74
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21
22
65
70
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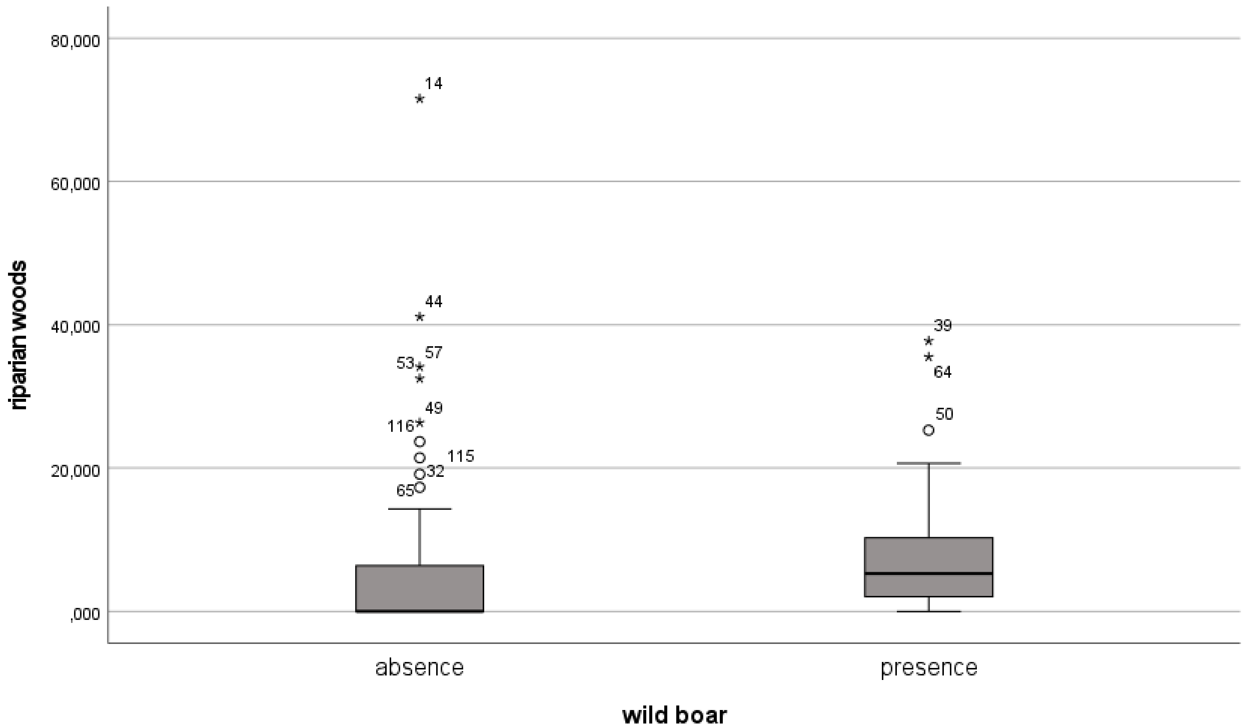
19
absence
presence
wild boar


80,000
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riparian woods
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absence
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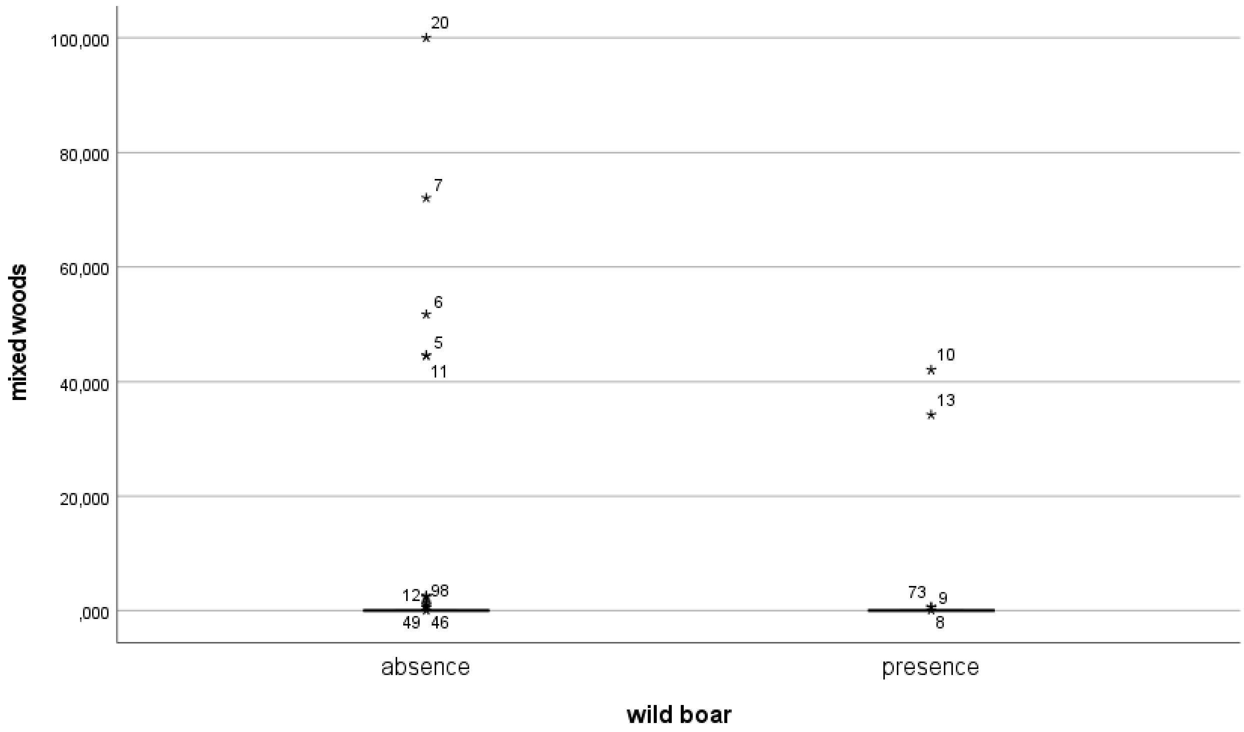
wild boar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absence
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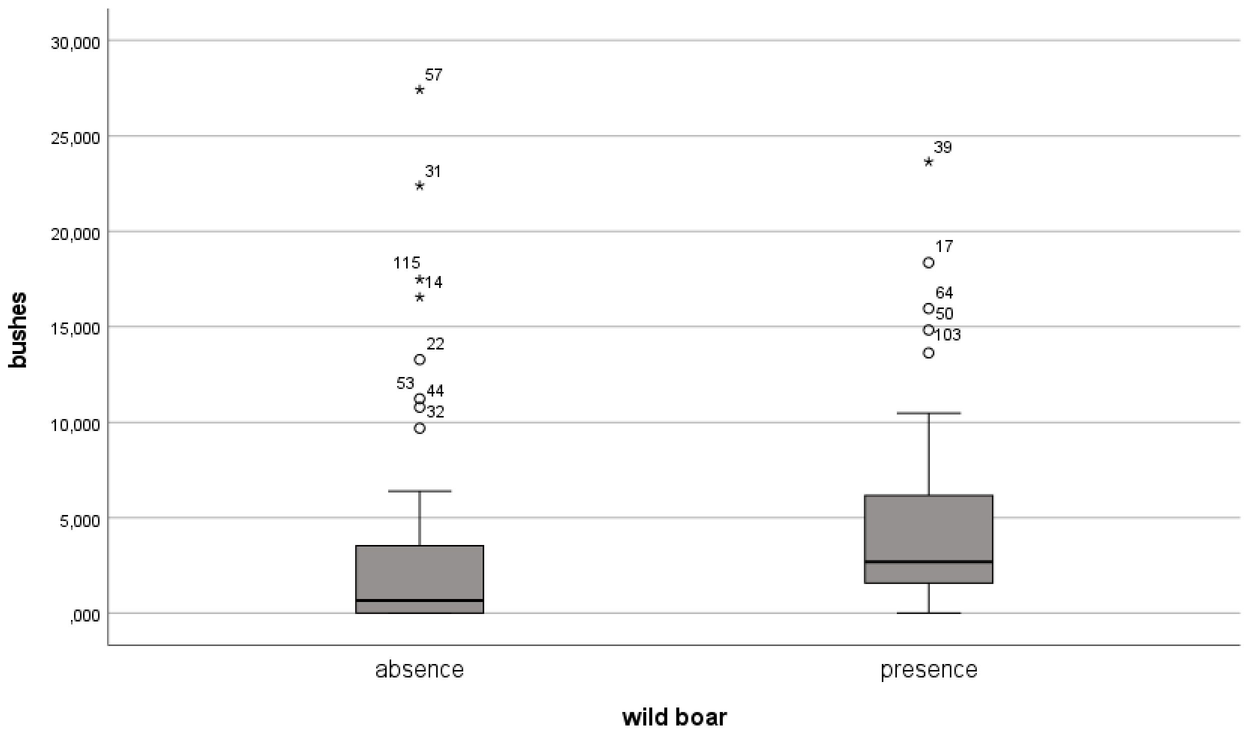
wild boar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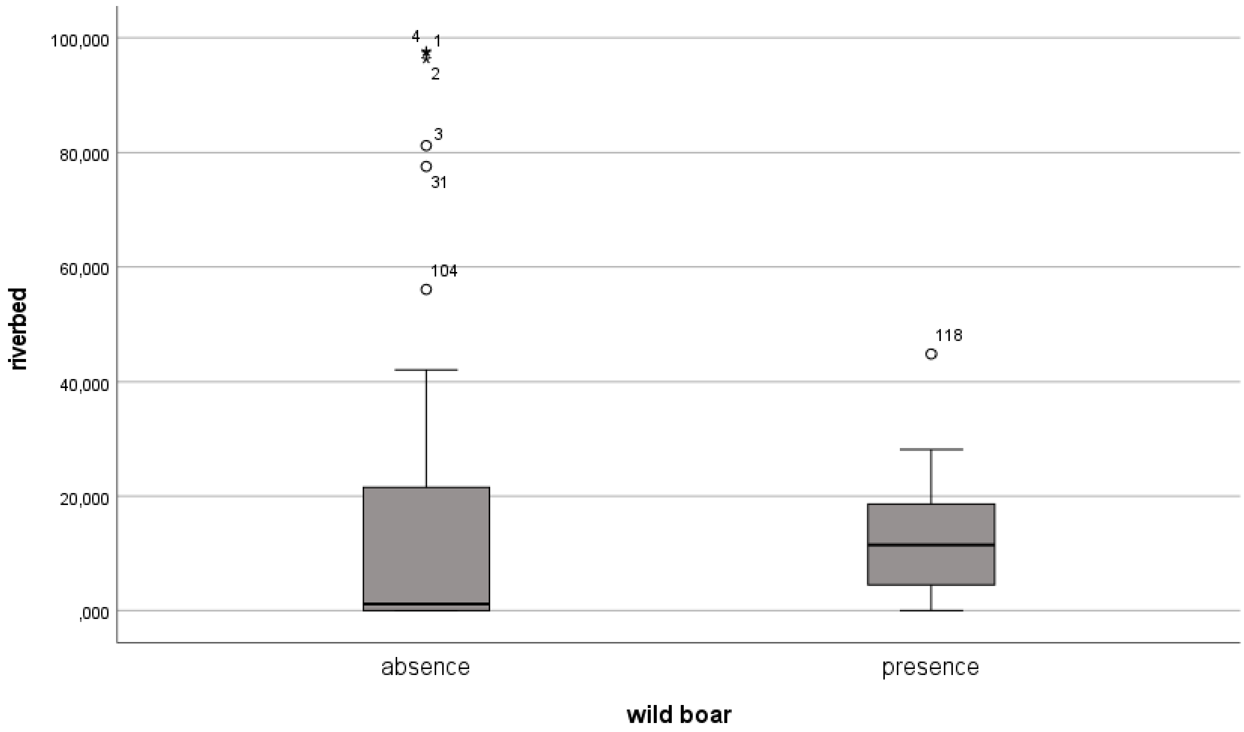
103
absence
presence
wild boar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riverbed
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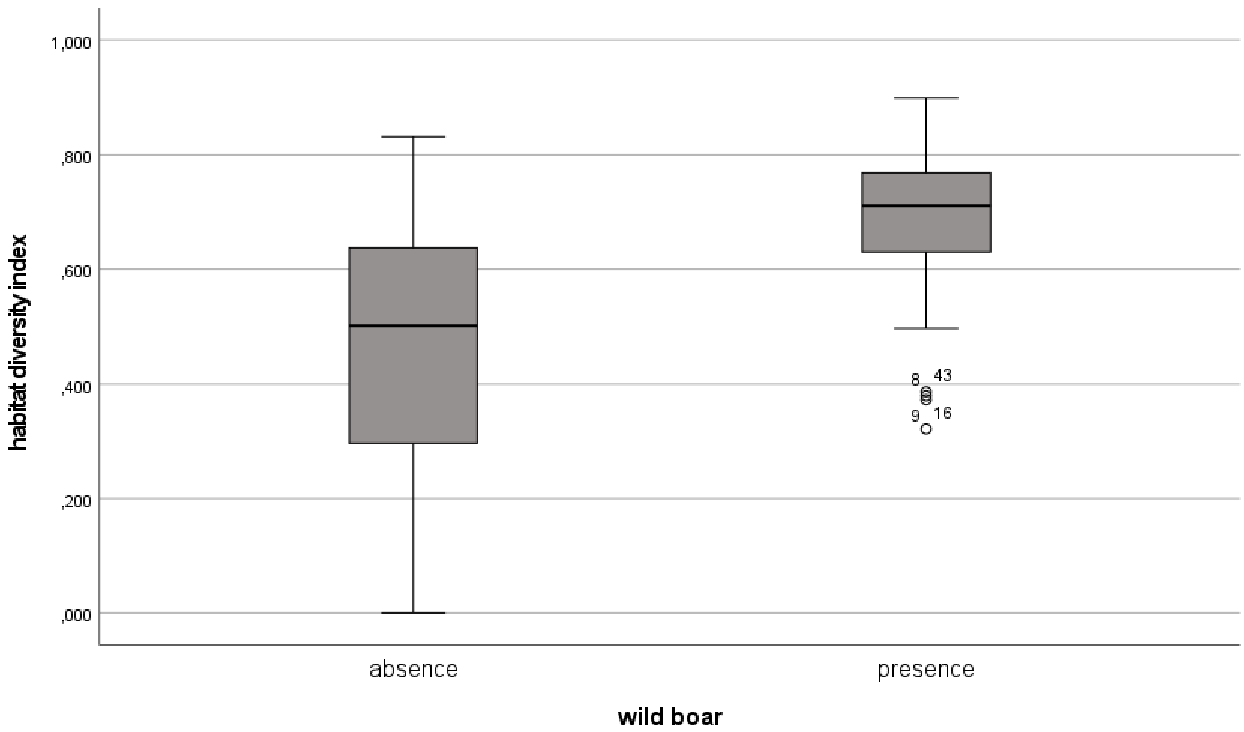
absence
presence
wild boar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habitat diversity index
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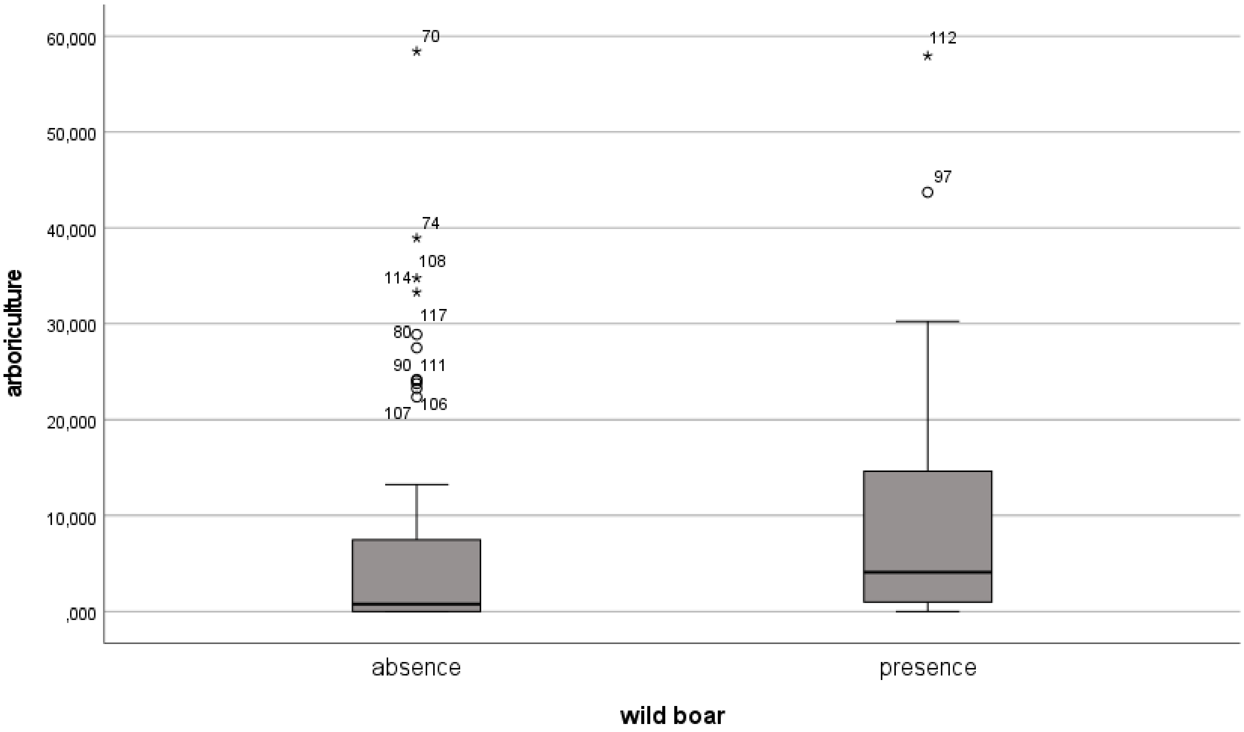
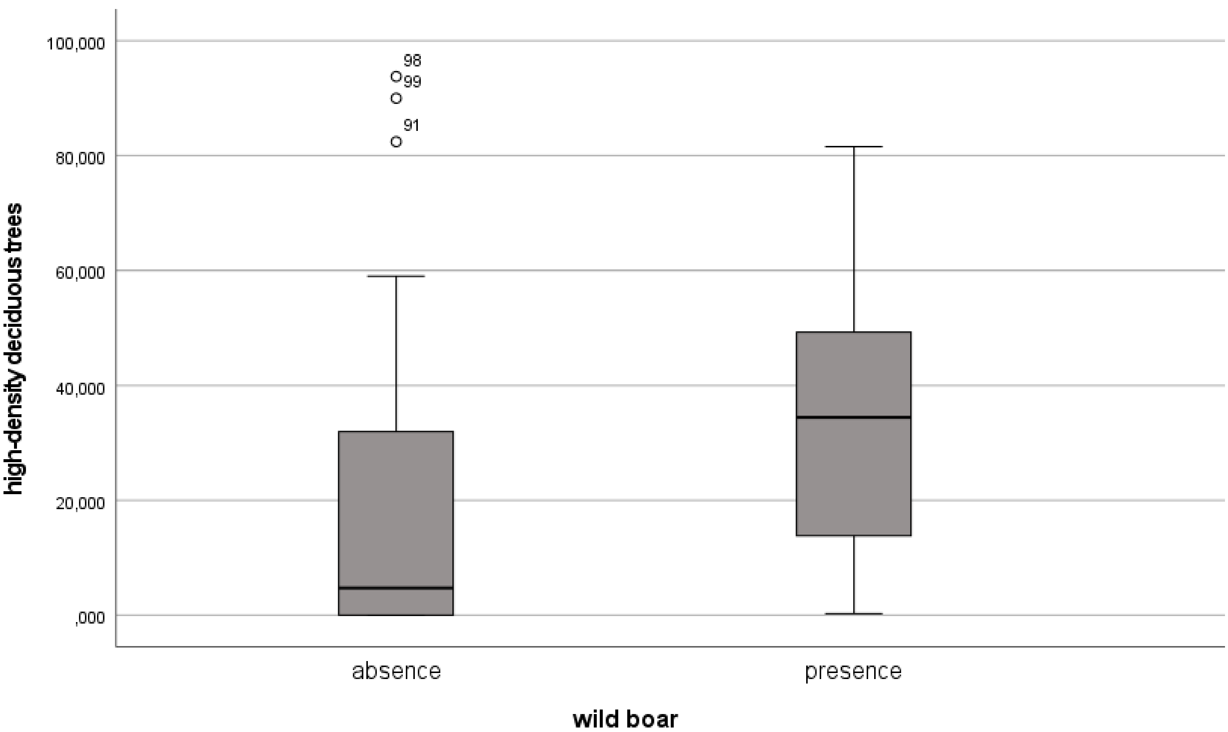
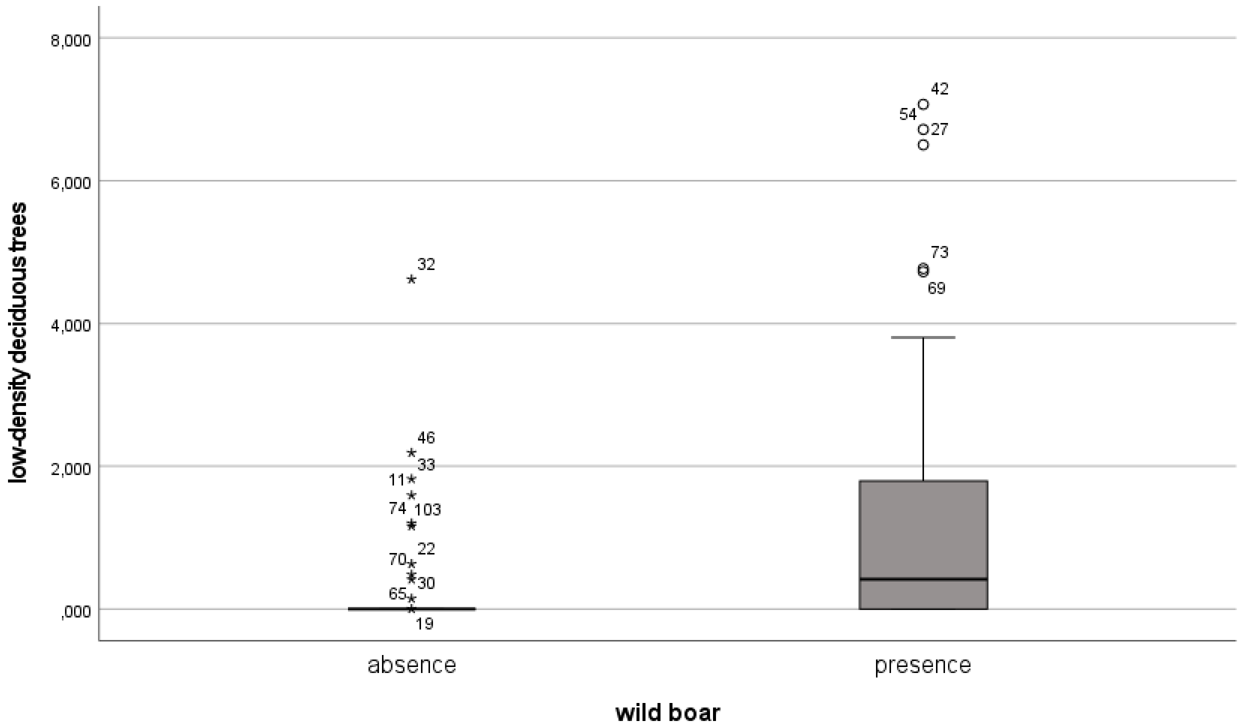
absence
presence
wild boar

Figure 5 *Box plots of habitat variables in presence (n = 58) and absence (n = 60) cells (spring).*



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absence
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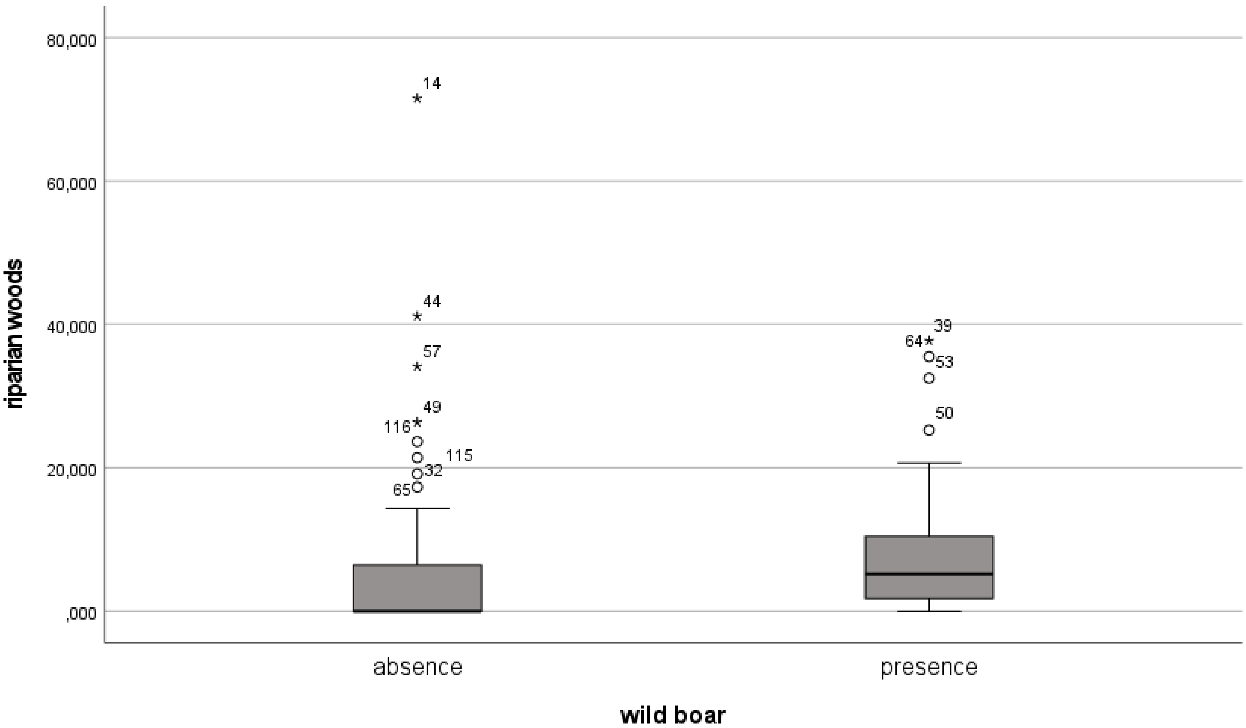
wild boar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riparian woods
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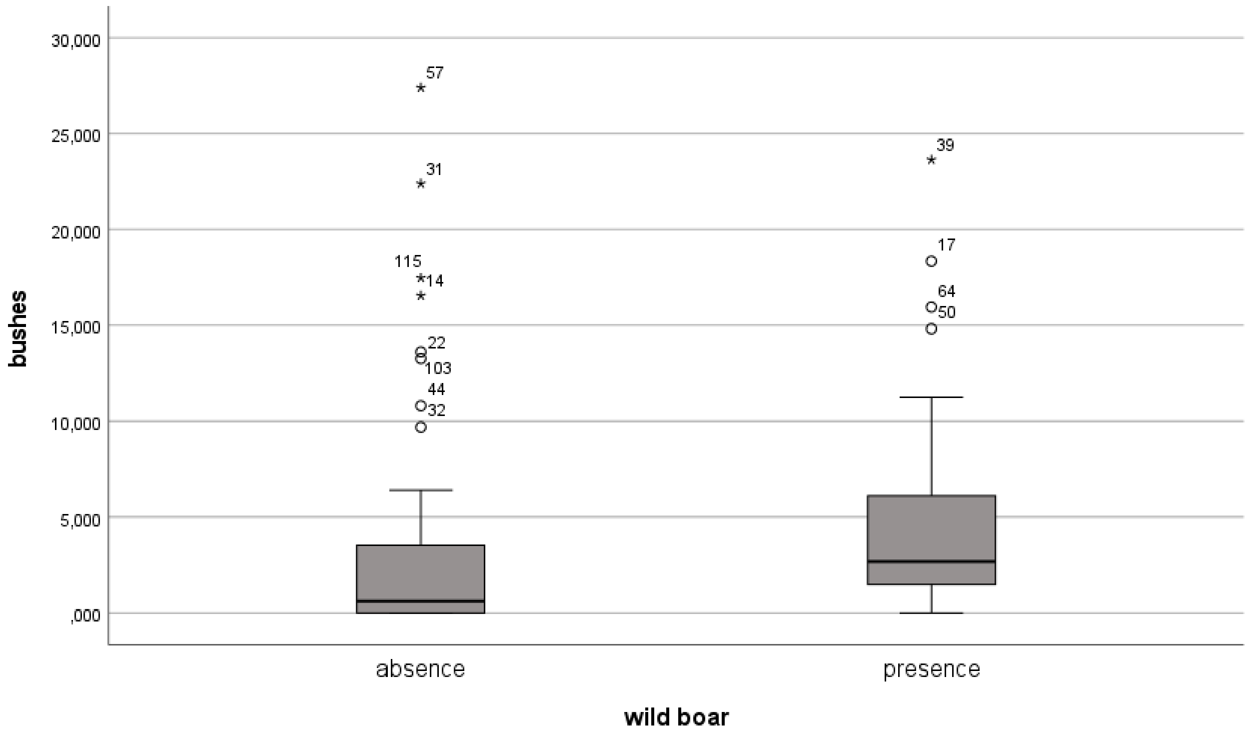
absence
presence
wild boar



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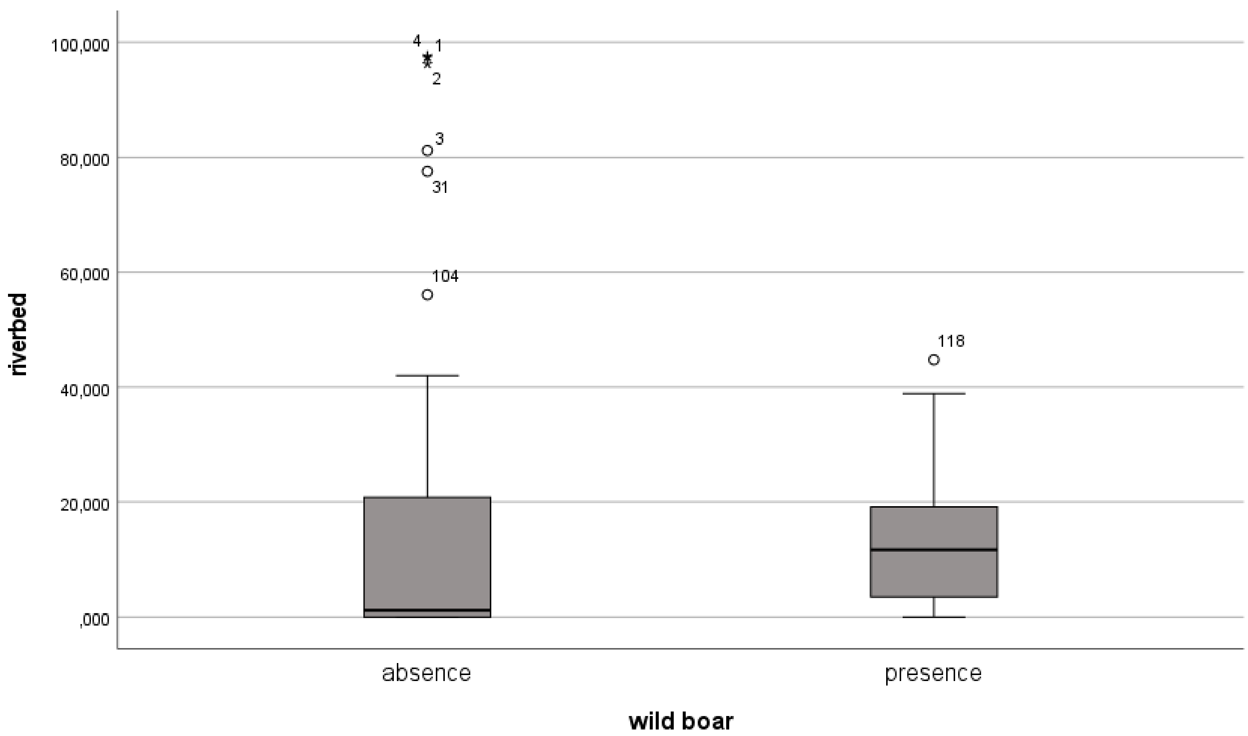

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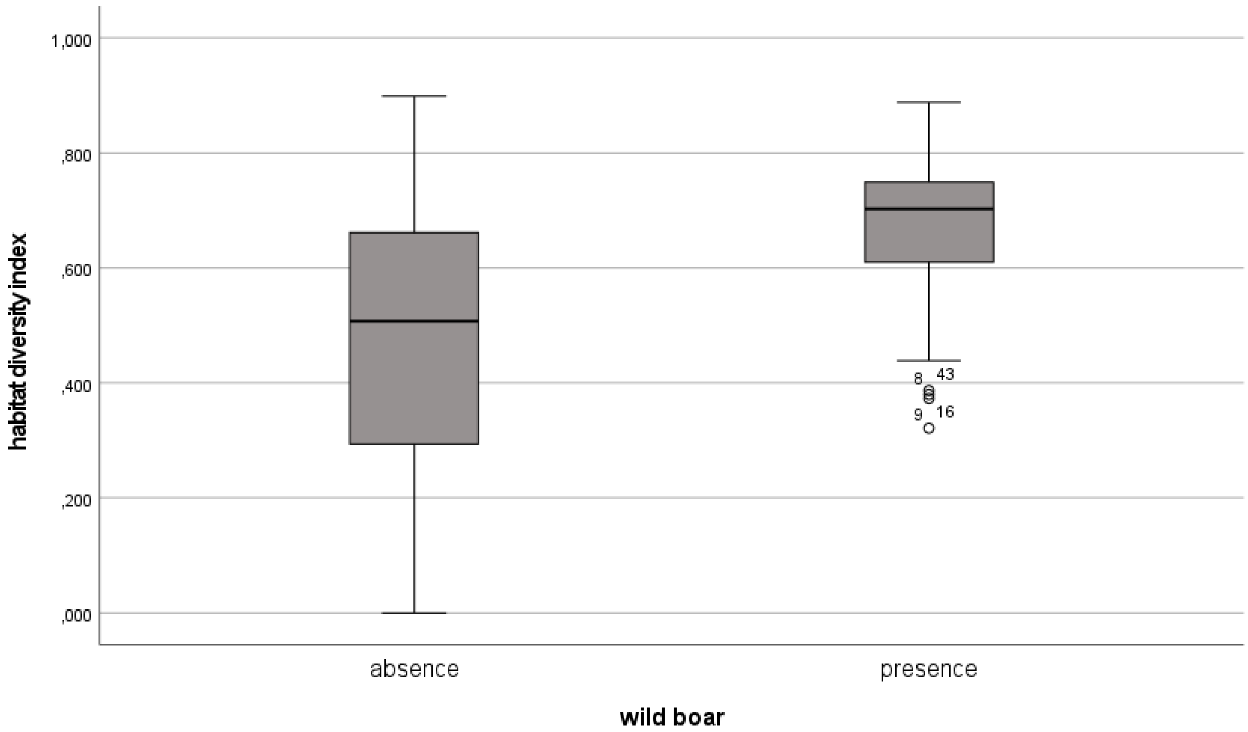
wild boar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habitat diversity index
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absence
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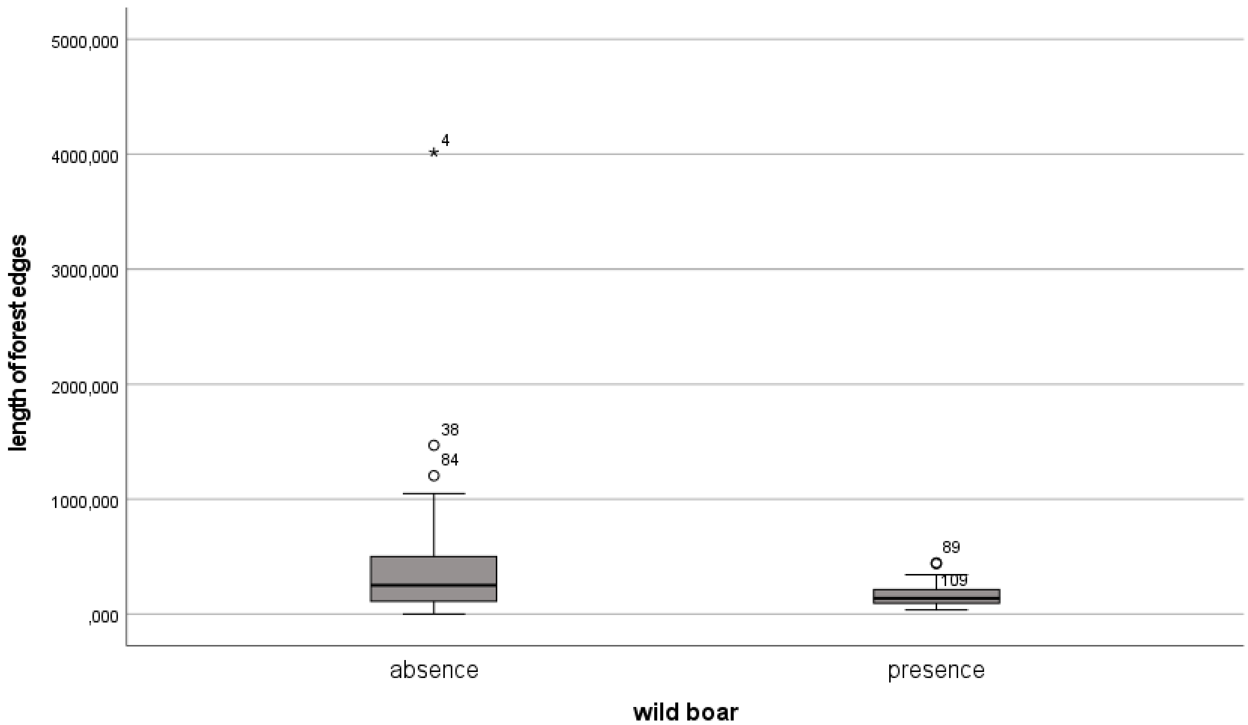
wild boar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length of forest edges
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84
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109
absence
presence
wild boar