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Research Article

Factors affecting wild boar (*Sus scrofa*) abundance in southern Tuscany

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Abstract

The wild boar harvest of fifteen hunting areas located in southern Tuscany (from 2001 to 2005) was used as a measure of wild boar density and used to assess habitat-abundance relationship. For each hunting area, the percentage of 13 land use classes was measured by intersecting hunting areas with a digitalized land-use map. Moreover, the percentage of perimeter of hunting areas bordering with protected woody areas and the percentage of main water bodies were measured. Correlation and regression analyses were carried out considering the harvest density as a dependent variable. Twelve multiple linear regression models each including three environmental variables were ranked by means of the information-theoretic approach (modified Akaike's information criterion). Protected woody areas (Parks and Wildlife Refuges), where hunting is not allowed, resulted the most important variable, positively affecting wild boar hunting yelds. Also young woodlands (naturally regenerated or by coppice), chestnut woods and conifer woods showed a positive effect. Models obtained from hunting data and digitalized land use maps can be very useful to plan wild boar population management at local scale. These data are generally available or quickly collectable. However caution must be used in the use of source data, since land use might be changed with respect to available maps and hunting efficiency may differ between different contexts.

Introduction

Since about 1980, in many parts of Europe, populations of wild boar (*Sus scrofa*) have remarkably increased, and the species have recolonised areas where it had been disappeared since centuries. The wild boar is now widely distributed in Italy from the Alps to the southern part of the country (Carnevali et al., 2009; Toso and Pedrotti, 2001). In the southern part of Tuscany this species was never gone extinct and as such it is considered the area from which wild boar populations have spread in the whole region, in combination with releases of animal imported from central Europe and/or farm-reared (Masseti, 2004).

This demographic eruption can be primarily related to habitat changes. The decrease of human population in rural areas prompted extensive recovery of natural woodlands which are suitable habitat for wild boar. However, also non biological factors as extensive reintroduction of animals and placement of artificial feeding sites, have probably played an important role (Massei and Genov, 2000; Massei and Toso, 1993).

The spread and increase in population size have intensified the conflicts with human activities. The wild boar causes considerable damages to agricultural crops in many European countries (particularly cereals and vineyard) (Brangi and Meriggi, 2003; Meriggi and Sacchi, 1992; Schley, 2008; Vassant and Breton, 1986). In Tuscany, more than two thousands Euro per year are paid as compensation for crops damage (Santilli and Mazzoni della Stella, 2006). Wild boars are also considered important disease reservoirs causing concerns about epidemiological risk (Acevedo et al., 2007; Hone et al., 1992; Naranjo et al., 2008; Ruiz-Fons et al., 2008). On the other hand, wild boars have a great socio-economic importance in rural areas. Hunting business, in Italy, is estimated in more than 125 millions Euro (Toso and Pedrotti, 2001) and involves about 100,000 hunters (Pedrotti et al., 2001).

A good understanding of key environmental factors which are related to wild boar density is an important step towards a development of a correct management. Hunting bag records are considered a good measure to estimate the population density of wild boars (Geisser and Reyer, 2005) and can be used to analyse habitat-population relationships instead of estimates of abundance or density based on data collections made on purpose (Acevedo et al., 2006; Merli and Meriggi, 2006). Indeed, even estimating population size by standard census techniques proves difficult (brandt.ea.1988, focardi.ea.1996). However, the use of hunting bag data for density and abundance estimates assume a close correlation between harvest data and species abundance and/or density (Roseberry and Woolf, 1991). Wild boar harvest may be influenced by hunting effort and in particular by the number of dogs and hunters involved during the drive hunts (Scillitani et al., 2010). This fact may reduce the correlation between harvest and density. However this source of variability is limited in the present case because harvest is not planned and no seasonal bag limit was imposed to the hunting teams whose composition in each hunting area were very similar. Moreover the duration of hunting sessions and hunting methods (drive hunt with hounds) are the same for all areas. In addition, the difference in hunting efficiency might be limited by the length of the hunting season (three months) and by the large average number of hunting days used in each hunting area (Hansen et al., 1986). Recently, Imperio et al. (2010) found that wild boar bag record was significantly correlated with animal counts in a Mediterranean area.

The present study was carried out to investigate how the density of wild boars harvested is related to the main environmental variables, in order to obtain useful information about wild boar management.

Materials and methods

Study area

The study was carried out in 15 hunting areas covering a total of 71.1 km2 and located in one of the three Hunting Districts of the

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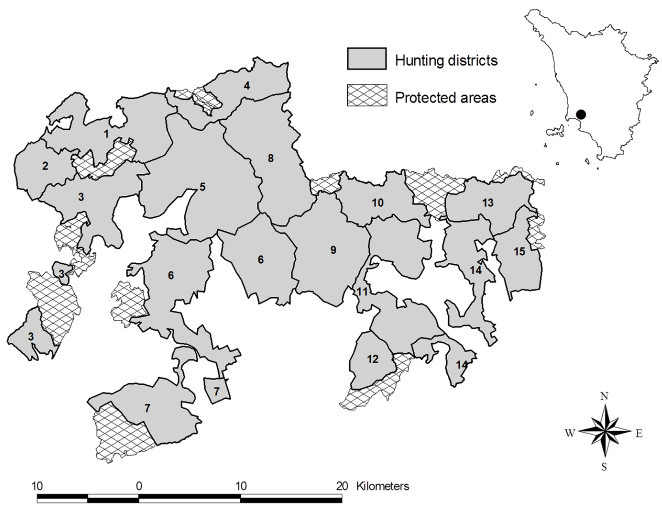

Figure 1 – Map of the 15 hunting areas.

Table 1 – Habitat characteristics of the 15 hunting areas, Grosseto, Central Italy.

Habitat variables	average	S.D.	min	max
Surface (km2)	4.74	2.59	1.48	11.90
Croplands (%)	9.8	7.80	0.6	24.7
Specialized cultivations (%)	4.2	4.68	0.0	14.8
Meadows and pastures (%)	11.3	6.26	0.0	21.6
Woodlands (%)	71.6	11.47	48.4	87.5
Scrublands (%)	3.1	3.94	0.0	14.1
Average altitude (m.a.s.l.)	343.0	129.33	220.0	680.0

Grosseto province named A.T.C. Gr 6 between 65 and 1,050 m a.s.l. (43°11'00"–42°54'25"N and 11°01'14"–11°14'58"E) (Fig.1). Climate is Mediterranean, with mean temperature varying from 6°C in February to 23°C in July. Precipitation (500-750 mm/yr) is seasonal and mainly concentrated in spring and autumn. Morphology is hilly, with open valleys which narrowed with the increase of elevation of hill tops. Woods covered 72% of the total area (Tab.1). Mediterranean forests, woodlands and shrub, were present mainly in the areas close to the cost. The more internal hills were covered by mixed and deciduous forests, dominated by oaks *Quercus pubescens*, *Quercus cerris*, *Quercus ilex* and chestnut *Castanea sativa*. Hornbeams *Ostrya carpinifolia* and cork oak *Quercus suber* were also presents. Conifer woods were mainly due to the Italian stone pine *Pinus pinea*. Rotational crops (winter wheat, spring crops and lucerne) were cultivated in small patches. Olive tree groves were the most representative specialized cultivation. Pastures were also present but only partially used. Both abandoned arable lands and pastures were colonised by shrubs (*Juniperus communis*, *Spartium junceum*, *Rosa* spp., *Rubus* spp.).

The wild boar was recorded at variable densities, but officials estimates were not available. Other species of wild ungulate in the area included the roe deer *Capreolus capreolus* and the fallow deer *Dama dama*.

The wolf *Canis lupus* was likely present in the area (Corsi et al., 1999; Fabbri et al., 2007).

The hunting season was regulated to start from the beginning of November to the end of January. The hunters were organised in 55 teams, whose minimum number of participants were fixed by law: the drive hunts cannot be carried out with less than 15 hunters. The average number of hunters per drive was 36 (range 20–50). Each team used 20–30 dogs per drive. The dog breed employed was Italian hound with few exceptions. Each team operated in given area of its hunting district and had to provide record for each animal killed. Hunting was performed twice a week and there was no limit in the number of wild boar that could be harvested.

Data collection

The number of wild boar harvested in each hunting area from 2001 to 2005 was recorded. We used them as density index (per km^2 of hunting area). For each hunting area the percentage of 13 land use classes (Tab. 2) was measured intersecting hunting areas with a digitised land-use map (Inventario Forestale Toscano, 1993, Regione Toscana) using ArcView GIS v. 3.2. Moreover the percentage of perimeter of hunting areas bordering with protected woody areas and the percentage of main water bodies was measured. Rivers and streams, in fact, can provide important resting sites for the wild boar (Tab. 2). Protected areas established to conserve and produce small game species were not considered since their habitat is mainly represented by agricultural crops. In addition in this areas wild boars were controlled by culling to prevent crop damages.

Statistical analysis

The density of wild boars harvested in the different years and in the 15 hunting areas were compared by two-way ANOVA considering years and hunting areas as categorical variables.

The associations between variables and the relative density index of wild boars were investigated by correlation analyses (Pearson's r product moment coefficient).

In order to address the potential effects of habitat characteristics on wild boar harvest yield, multiple linear regression models applied to identify the most important habitat variable, likely affecting wild boar abundance, were developed. Models were bound to include only three independent variables chosen among the less correlates ones so to avoid over-parametrization and Freedman's paradox (Anderson and Burnham, 2002). The factor year was used as dummy variable. For these analyses, a correlation matrix among independent variables was calculated beforehand, with the aim to identify the subset of independent non-correlated variables.

Inference from models was made according to the Information-theoretic approach (Anderson et al., 2000, 2001; Anderson and Burnham, 2002). Modified Akaike's Information Criterion (AICc), differences with the minimum AICc (Δi) and Akaike weight (w_i) for each i-model were computed to rank and scale the models. AICc is:

$$AICc = 2k - 2ln(L) + \frac{2k(k+1)}{n-k-1} \quad (1)$$

where k is the number of parameters in the statistical model, L is the maximized value of the likelihood function for the estimated model and n denotes the sample size.

The relative importance of predictor variables were measured, as resulted from the best models, by the sum of the models Akaike's weight were each variable appeared (Burnham and Anderson, 2002).

The kind of relationship between the variables selected by multi model inference was investigated by regression analyses.

All analyses were carried out by using JMP 5.0.1 for Windows.

Results

Differences in density of harvested wild boars among the five years of the study were not significant (Tab. 3) whereas strong significant differences were observed among the 15 hunting areas (Tab. 4).

Correlation analyses showed 10 significant relationship between the relative abundance index and the 15 habitat variables (Tab. 5).

The density of harvested wild boars resulted positively associated with protected areas, water bodies, chestnut woods, mixed deciduous woods, conifer woods and regeneration areas whereas crops, pubescens oak woods, holly oak woods, meadows and pastures resulted negatively correlated. Correlation analyses among habitat variables led to build 12 different models taking into account all the original 15 variables (Tab. 6).

Comparison among the multiple regression models showed that the density of harvested wild boars was best predicted (the minimum loss of Kullback-Leibler information, Anderson et al. 2000) by the model including regeneration areas, protected areas and pubescens oak woods.

Table 2 – Variable list and description.

Variables	Description
Protected areas	Perimeter of hunting area bordering with no-hunting areas (%)
Water body	Hunting area taken by water bodies, rivers and streams (%)
Specialized cultivations	Hunting area covered by specialised cultivations as olive tree grooves or vineyards etc. (%)
Crops	Hunting area covered by agricultural crops (%)
Meadows and pastures	Hunting area covered by Meadows and pastures (%)
Chestnut woods	Hunting area covered by Chestnut woods (Castanea sativa) (%)
Pubescens Oak woods	Hunting area covered by Pubescens Oak woods(Quercus pubescens) (%)
Turkey Oak woods	Hunting area covered by Turkey Oak woods (Quercus cerris) (%)
Holly Oak woods	Hunting area covered by Holly Oak woods (Quercus ilex) (%)
Conifer woods	Hunting area covered by conifer woods (%)
Mixed woods	Hunting area covered by mixed deciduous-conifer woods (%)
Mixed deciduous woods	Hunting area covered by mixed deciduous woods (%)
Regeneration areas	Hunting area covered by woodland regeneration areas (reafforestation, coppice, natural regeneration) (%)
Scrublands	Hunting area covered by shrubs (%)
Mediterranean woods	Hunting area covered by mediterranean woods (%)

Table 3 – Density of wild boars harvested in the different years, averaged across 15 hunting areas.

Years	average (per km^2)	S.D.	
2001-02	6.1	2.42	A[1]
2002-03	6.9	2.38	A
2003-04	6.1	1.92	A
2004-05	6.1	2.54	A
2005-06	6.6	1.92	A

[1] Years not connected by same letter are significantly different

Table 4 – Density of wild boars harvested in the 15 hunting areas.

Hunting area	average (per km^2)	S.D.	
1	10.9	1.84	A[1]
2	9.8	2.06	A
3	7.5	1.98	B
4	7.1	0.93	BC
5	7.0	1.42	BC
6	6.9	1.76	BC
7	6.4	1.60	BCD
8	6.1	0.45	BCDE
9	5.7	0.73	CDEF
10	5.2	0.67	DEF
11	4.8	0.79	DEF
12	4.7	0.68	EF
13	4.7	0.63	EF
14	4.5	0.76	EF
15	4.1	1.29	F

[1] Hunting areas not connected by same letter are significantly different

Only another model including protected areas, conifer woods and chestnuts woods, compared in likelihood. The other models all had ΔAICc greater than 5 and/or Akaike weight w smaller than 0.1 suggesting a small contribution to the prediction of the response variable (Tab. 6).

The sum of Akaike weight showed the relative importance of protected areas, regeneration areas, chestnut woods and conifer woods as predictive positive variables of the wild boar harvest (Tab. 7).

The relationship between the density of harvested wild boars with protected areas and regeneration areas was better explained by a linear regression function whereas the relationship with chestnut woods and conifer woods by a quadratic polynomial function (Fig. 2).

Discussion

The large differences in the density of harvested wild boars among the 15 hunting areas are probably related to environmental factors which can provide a better habitat and/or facilitate hunting efficiency. According to our results, protected areas, where hunting is not allowed, seem to play a prominent role in determining the hunting yield of wild boars. In the study areas they are represented by forest areas (Parks and Wildlife Refuges) whose size varied by 5 to 20 km^2. They offer refuge to wild boars during the hunting seasons, but in many cases they are wide enough to hold stable populations. Given the high recruitment rate of this species, during summer and early autumn many boars spread outside toward hunting areas as a consequence of the raised density. This finding suggests that protected areas are involved in over-abundance of this species and may play a role in the conflict with agricultural activities (Bueno et al., 2009). The spatial behaviour of wild boar populations in presence of wide protected areas needs more investigation in order to detect how to manage wild boars in these areas.

Table 5 – Correlation coefficients between density of wild-boars harvested and habitat variables.

Variables	n	r_p	*p*-value
Protected areas	15	0.55	<0.0001
Water bodies	15	0.38	<0.001
Regeneration areas	15	0.36	<0.01
Meadows and pastures	15	-0.35	<0.01
Mixed deciduous woods	15	0.30	<0.01
Crops	15	-0.15	<0.01
Chestnut woods	15	0.28	<0.05
Pubescens Oak woods	15	-0.28	<0.05
Holly Oak woods	15	-0.24	<0.05
Conifer woods	15	0.23	0.051
Turkey Oak woods	15	0.37	n.s.
Mediterranean woods	15	-0.18	n.s.
Scrublands	15	0.12	n.s.
Mixed woods	15	0.06	n.s.

Regeneration areas are woodlands with tree canopy inferior to 5 m. They include young coppices and high forests at young stage. More mature formations are present nowadays, as compared to the time of map development as foundby comparing the digitalized map with more recent areal images. The increased forest cover of these areas probably has also increased suitability for wild boar (Acevedo et al., 2006; Massei and Genov, 2000; Meriggi and Sacchi, 2001; Merli and Meriggi, 2006). Furthermore, in the coppices of Tuscany and many other regions of central Italy, a large number of standards are commonly released, often leaving all the oldest ones. These standards give a high fruit productions (Casanova et al., 1993) which are the favourite food resources of wild boars (Geisser and Reyer, 2005; Giménez-Anaya et al., 2008; Groot Bruinderink et al., 1994; Massei et al., 1996; Valet et al., 1994; Vassant, 1997).

Also in a study carried out in the northern Appenines (N Italy), chestnut woods and conifer woods resulted important in predicting wild boars harvest rate (Merli and Meriggi, 2006). Mast production of oaks and chestnut are similar (Casanova et al., 1993), but the last one has higher nutritional value. Chestnut fructification is very important for wild boar reproduction and the number of foetuses varies sensibly with mast production (Bucci and Casanova, 2006). Furthermore, chestnut woods are localized in wetter areas and produce a soft litter of leaves which favours "rooting" activity. Rooting allows to integrate the diet with protein foods (insects, larvae and roots) which are very important especially for young boars (Dardaillon, 1984; Geisser, 2000; Groot Bruinderink et al., 1994; Schley and Roper, 2003). Also conifer woods are characterised by a thick layer of needles allowing rooting also dur-

Table 6 – Candidate multiple regression models and model inference criteria for density of wild boars harvested and habitat variables.

Habitat variables	R^2	Neg. Log-Likelihood	AICc	ΔAICc	*w*
Regeneration areas, Protected areas, Pubescens Oak woods	0.433	37.813	86.496	0.00	0.585
Conifer woods, Protected areas, Chestnut woods	0.426	38.295	87.460	0.96	0.361
Chestnut woods, Water bodies, Protected areas	0.386	40.809	92.488	5.99	0.029
Mixed deciduous woods, Protected areas, Mixed woods	0.383	40.987	92.844	6.35	0.024
Turkey Oak woods, Water bodies, Meadows and pastures	0.236	49.500	109.870	23.37	0.000
Mediterranean woods, Water bodies, Specialized cultivations	0.183	51.533	113.936	27.44	0.000
Water bodies, Specialized cultivations, Crops	0.143	53.405	117.680	31.18	0.000
Scrublands, Water bodies, Specialized cultivations	0.141	53.405	117.680	31.18	0.000
Holly Oak woods, Specialized cultivations, Pubescens Oak woods	0.140	53.480	117.829	31.33	0.000
Pubescens Oak woods, Specialized cultivations, Chestnut woods	0.136	53.626	118.121	31.63	0.000
Meadows and pastures, Crops, Specialized cultivations	0.124	54.163	119.195	32.70	0.000
Mixed woods, crops, Turkey Oak woods	0.000	59.118	129.105	42.61	0.000

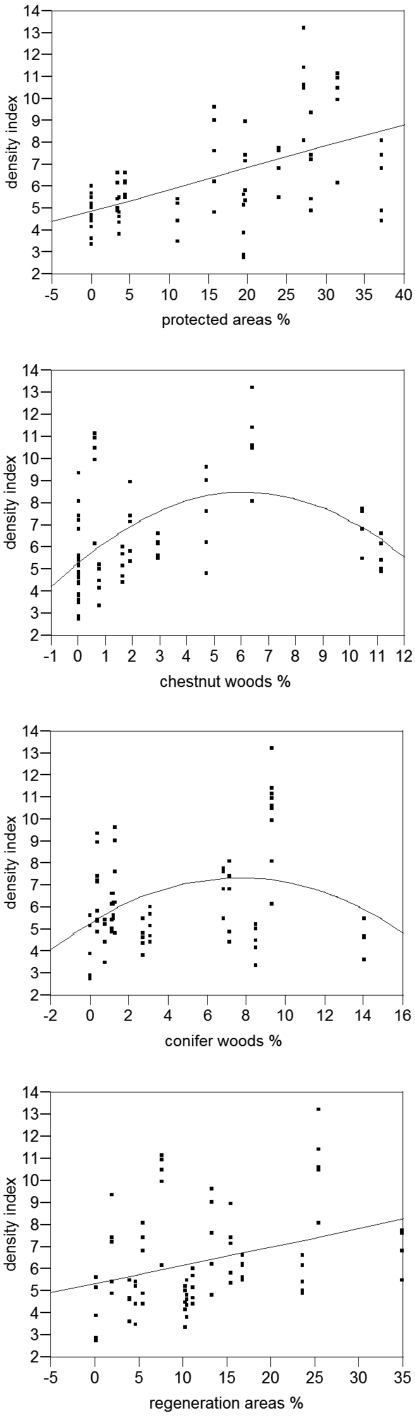

Figure 2 – Regression functions of density of wild boars harvested on the variables selected by multi model inference.

Table 7 – Multi model inference on model parameters and relative importance of environmental variables for density of wild boars harvested.

Predictors	Σ*w*	effects	numbers of models
Protected areas	0.976	+	3
Regeneration areas	0.585	+	1
Chestnut woods	0.390	+	3
Conifer woods	0.361	+	1
Mixed deciduous woods	0.024	+	1

ing periods of precipitation shortage when the ground is dry and hard (Massei and Genov, 2000; Meriggi and Sacchi, 2001). In addition, pine seeds often occur in the wild boar diet (Massei et al., 1996; Schley and Roper, 2003).

It is surprising that in 2003-04 any decline in wild boar density was recorded, since the summer 2003 has been particularly dry and hot, factors which would affect the reproduction and the survival. However the main factor that affect the population dynamics of wild boar is the acorn production. It is possible that a high acorn availability have helped to limit the losses.

Models obtained from hunting data and digitalized land use maps can be very useful to plan wild boar population management at local scale: for example the comparison of the maps of suitable areas with the maps of crop-damages distribution may help to program the damages prevention (Merli and Meriggi, 2006). Hunting data are generally available or quickly collectable. However, these data sources should be used with caution, for example considering the modifications occurring in land use as compared to what described in maps. Moreover, the correct use of this kind of data is limited to areas with a standardized hunting effort and lack of heterogeneity for other possible sources of spatio-temporal population variations (Merli and Meriggi, 2006).

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