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Conifer plantations negatively affect density of wild boars in a Mediterranean ecosystem

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Abstract. Several decades ago, large areas of the Iberian Peninsula were planted with allochthonous tree species for timber production among other reasons. This severe habitat transformation is likely to affect a large spectrum of the biodiversity in the area. The wild boar *Sus scrofa* is a widely distributed large mammal, for which population density can be estimated on the basis of hunting results relative to effort in each area. Our goal was to analyze the influence of pine plantations on the relative density of this species in Southern Spain. Based on data obtained from hunts, we found that the relative density of wild boar was negatively related to the relative area covered by pine trees. Our results support a negative effect of pine plantations on wild boar density and indicate that restoration and conservation of native oak forests can favour not only biodiversity but also the maintenance of wild boar populations.

Key words: pine plantations, hunting, *Sus scrofa*, population distribution

Introduction

Tree plantations have been established in more than 124 countries covering 130 mha (Winjum & Schroeder 1997, Powers 1999). Different reasons motivated the progressive substitution of native shrub-land and remnant oak forest by pine (*Pinus* sp.) plantations in the south of the Iberian Peninsula from 1950 onwards (Sánchez-Martínez et al. 2008). This practice eliminated extensive forest areas traditionally dominated by oaks (*Quercus* sp.) and a great diversity of shrub species. In their place, several species of pines were planted (Groome 1989), resulting in a mosaic distribution of native vegetation and reforested areas. The effects of pine plantations on native species have also been widely studied (see Stephens & Wagner 2007), showing a negative impact on plant diversity in the Mediterranean (Andrés & Ojeda 2002, Proença et al. 2010, González-Moreno et al. 2011), and on animal diversity, specifically invertebrates (Gee & Stoner 1989, Giller et al. 1993), amphibians (Harvey Pough et al. 1987, Mitchell et al. 1997), various species of birds (Tomialojc & Wesolowki 1996, Díaz et al. 1998, Díaz 2006) and mammals, although the latter group has been less studied (Lindenmayer et al. 1999, Virgós et al. 2003, see Stephens & Wagner 2007).

However, there are studies that question the negative role of plantations on animals (Donald et al. 1998, Sánchez-Zapata & Calvo 1999) and vegetation (Hofstede et al. 2002) and support their potential role to favour ecological succession in degraded places (Parrotta 1995, Fimbel & Fimbel 1996, Loumeto & Huttel 1997), increasing the diversity of landscape and density of ecotones (Estades & Temple 1999, Bonet et al. 2001). Regarding the impact of these formations on ungulates, negative influences were found in the use of these forests by the roe deer *Capreolus capreolus* (Gill et al. 1996) and the red deer *Cervus elaphus* (Lazo et al. 1994, Debeljak et al. 2001). In the case of the wild boar *Sus scrofa*, little is known about the effect of plantations and there are few studies comparing their populations in areas with both natural and modified habitats in close proximity (Meriggi & Sacchi 2001). Thus, most of the work has focused on assessing stock levels in certain places and assessing dynamics with regard to climate, food, the

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presence of predators or hunting (Kanzaki et al. 1998, Volokh 2002, Melis et al. 2006). Pine woods may be less suitable habitats for wild boars compared to oak forests (Massei et al. 1996, Fernández-Llario 1996, 2004). However, the presence of areas with pines may increase the heterogeneity of habitat producing a mosaic structure of pine and oak forests that might positively influence the abundance of wild boar (Acevedo et al. 2006, Merli & Meriggi 2006).

The area studied here is a good example of terrain where both plantations and native forest areas coexist, thus providing a good opportunity for comparing their effects on wild boars within a short geographical distance. The study area was located in "Sierra Morena" in southern Spain and is characterized by a high ecological value due to its biodiversity, greater than in central and northern Europe (Grubb 1987) where conifers dominate forest landscape (Dafis 1997). In the area under study, hunting wild ungulates is widespread, wild boar being the second most abundant species (after red deer) harvested every year. The objective of this study was to analyze the possible influence of an anthropogenic change in the ecosystem, the plantations with exotic pine species, on the relative density of wild boar in a Mediterranean area.

Material and Methods

Study area

This study took place in an area of 58120 hectares (free from the presence of wolves), which includes 57 estates located in "Sierra Morena" (37°53′-38°11′ N, 4°57′-5°34′ W) in the province of Córdoba (Spain) with altitude ranging between 120 and 896 meters. The average size of the estates is 1026.56 ± 540.37 ha (± SD) with a minimum of 427 ha and a maximum of 3728 ha. The climate is characterized as typically Mediterranean with irregular rainfall and hot, dry summers. The average annual precipitation was 536 mm while the mean temperature was 17.6 °C, ranging from a minimum of 9.2 °C in winter (January) to a maximum of 27.2 °C in summer (July-August). Natural vegetation consists predominantly of Mediterranean forest with oak (*Quercus ilex*) and cork oak trees (*Quercus suber*) along with various species of shrubs (including genus *Cistus*, *Erica*, *Genista*, *Pistacia*, *Arbutus*, *Phyllirea*), and 35.83 % of the area is covered by pure plantations of coniferous species (Fig. 1), such as stone pine (*Pinus pinea*) and cluster pine (*P. pinaster*), both type of forests with small areas of pasturelands. The main use of these estates is big game hunting of red deer and wild boar, sometimes

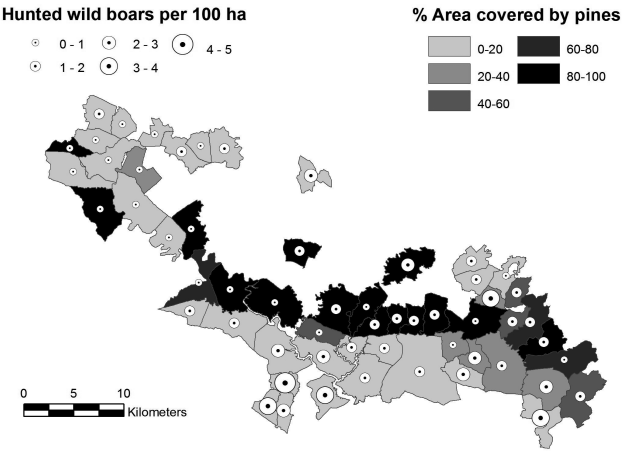

Fig. 1. Percentage of area covered by pines forest and average number of wild boars hunted per 100 hectares in each estate.

with other species like the fallow deer (*Dama dama*) and the mouflon (*Ovis aries musimon*). Some estates have perimeter fences designed to prevent deer from leaving the area but allow the movement of the wild boar across them. Human presence is restricted to houses of foresters.

Data collection

Data were obtained from two sources: first, record of number of animal culled and hunting effort obtained by the regional government (Consejería de Agricultura, Pesca y Medio Ambiente de la Junta de Andalucía) of the hunts held in the 1996-1997 to the 2004-2005 seasons in the hunting estates within the study area. This type of hunt (called Montería) is typical of southern regions of the Iberian Peninsula, and involves packs of dogs being released within a shrub area to drive the ungulates towards the sites, where hunters are waiting for them. Hunting takes place in the early afternoon, approximately from 12:00 to 15:00, in the months of October to February. There is only one Montería per year in each area. Both male and female wild boar can be legally hunted in the Montería. There are no fixed quotas per area for wild boars to be culled, and hunters are allowed to shot every wild boar they see. Thus, hunting bag becomes a viable index of density when corrected by hunting effort (Fernández-Llario et al. 2003).

Second, by using aerial photographs (1:10000), we determined the major vegetation units in the area. Areas covered by ligneous vegetation in comparison to pastureland were delineated, obtaining the area of ligneous cover in each estate. Thus, ligneous cover was the percentage of the area covered by trees or shrubs, either native oak forests and shrub-lands or pines (i.e. the opposite to open lands). We

also used cartographic information from the regional government to differentiate between areas with pines and native forest/shrub-land and measured the area of pines within each estate. The ArcGIS v.9.3 (ESRI®) software was used for handling cartographic information and creating the maps.

Statistical analysis

Data included 57 hunting estates followed during nine years. To investigate whether the number of wild boar hunted related to the vegetal composition of the area, we used Generalized Estimating Equations procedure (GEE) in SPSS v.20 (SPSS, Chicago, IL, U.S.A.). The GEE analysis is a generalized version of a General Mixed Model that accounts for correlated data (Hardin & Hilbe 2003). The chosen type of model was Negative Binomial with log link. The model included "year" as a random effect to account both for the correlation between repeated observations on estates and for random between year-variation.

In order to assess the spatial structure of wild boar population in our area while controlling for correlations between estates and, also, to distinguish between spatial and environmental effects, we have used the third-order polynomial function based on the x- and y-geographic coordinates of the sampling points (estates in this case) as Borcard et al. (1992) have suggested. The x- and y- coordinates of each estate were first z-scored transformed and the rest of the nine polynomial variables of the spatial matrix (Legendre 1990) were then calculated: x, y, xy, x^2, y^2, x^3, y^3, x^2y, xy^2.

We used the proportions of ligneous cover and pine forest in each estate as explanatory variables of interest. Also, for an alternative model, area of pine forest was categorized. We established two levels: pine forest cover less than 50 % of the estate and more than 50 % of the estate.

The number of wild boars hunted in each estate, as well as by the extent of the estate, can vary depending on the number of hunters and the number of packs of dogs (hunting pressure effect), so these variables should be introduced as control variables. However, both covariates are also highly correlated (r = 0.82) and to avoid co-linearity problems, we used only the "number of packs of dogs" as the best proxy of hunting pressure.

Since the dependent variable (number of wild boars hunted) has different probability of occurrence depending on the extension of each estate, we have introduced the land-area (ln transformed) as an offset variable, which allows to transform the dependent variable in relative values (density values) without affecting the rest of explanatory variables, as the offset variable is not itself introduced in the model.

For selecting the best correlation structure, we used de QIC information criterion. A first-order autoregressive relationship (AR 1) produced the lower value for the QIC, meaning that the correlations between adjacent years are bigger than that between more distant years. The results proved to be very consistent between the first full model and the last one, showing the significant effect of five spatial terms (x, xy, y^2, x^3, x^2y) on the wild boar density.

Afterwards, with all the selected variables (spatial, environmental and control variables) we constructed three alternative models and compared them by using the QIC information criterion as goodness of fit statistic. The three alternative models we have compared were: (1) a model in which both main predictive environmental variables (area of ligneous vegetation and pine forest) are introduced as proportions, (2) a model with "area of pine forest" introduced as a categorical variable whereas ligneous cover remains as proportions (see above), (3) a model introducing the interaction between the categorized "area of pine forest" and the proportion of the area covered by ligneous vegetation. We used the Type III analysis in all cases.

Results

The average number of wild boars hunted per 100 hectares per year in all the estates was 1.52 ± 1.28

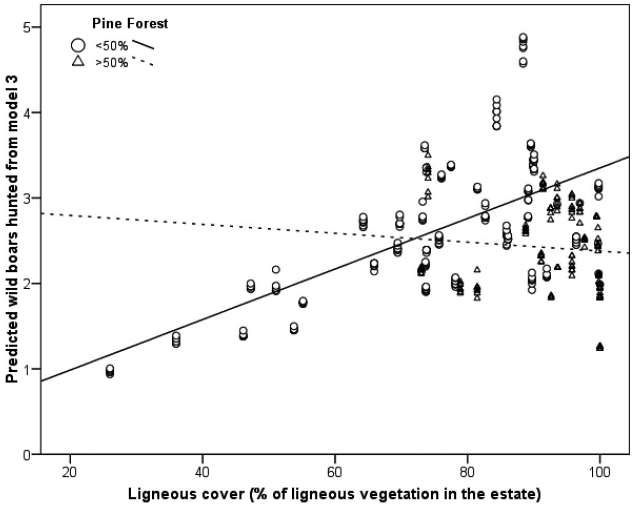

Fig. 2. Effect of pines and ligneous cover: number of wild boars hunted per 100 hectares predicted from Model 3 of Table 1, plotted against the percentage of the area of the estate covered by ligneous vegetation, for estates with less (circles and continuous line, R^2 = 0.434) and more (triangles and discontinuous line, R^2 = 0.006) than 50 % of the area covered by pine forests.

Table 1. Results from a Generalized Estimating Equations procedure (GEEs) to study the effect of independent variables for 57 estates throughout nine years on the number of wild boars hunted. Estates and years were introduced in the model to define the independent subjects (estates) for the repeated measures effect (years). The three alternative models we have compared were: (1) a model in which both main predictive environmental variables (area of ligneous vegetation and pine forests) are introduced as proportions, (2) a model with area of pine forest introduced as a categorical variable whereas ligneous cover remains as proportions, (3) a model introducing the interaction between the categorized "area of pine forest" and the proportion of ligneous cover.

Model 1 (QIC 308.36)					
Parameter	B	SE	Wald Chi2	df	Sig.
Intercept	–5.652	0.355	252.754	1	0.001
x	0.632	0.135	21.664	1	0.001
xy	0.456	0.082	30.625	1	0.001
y^2	0.546	0.090	36.352	1	0.001
x^3	–0.306	0.105	8.477	1	0.004
x^2y	–0.211	0.096	4.742	1	0.029
Dog packs	0.005	0.003	2.525	1	0.112
Ligneous cover (%)	0.015	0.004	9.347	1	0.002
Pine forest (%)	–0.004	0.002	3.921	1	0.048
Model 2 (QIC 306.94)					
Parameter	B	SE	Wald Chi2	df	Sig.
Intercept	–5.976	0.486	151.240	1	0.001
x	0.580	0.127	20.538	1	0.001
xy	0.449	0.083	28.815	1	0.001
y^2	0.537	0.093	33.021	1	0.001
x^3	–0.271	0.109	6.160	1	0.013
x^2y	–0.199	0.099	4.035	1	0.045
Dog packs	0.006	0.003	3.356	1	0.067
Ligneous cover (%)	0.014	0.004	9.520	1	0.002
Pine forest < 50 %	0.334	0.169	3.893	1	0.048
Pine forest > 50 %	0				
Model 3 (QIC 303.26)					
Parameter	B	SE	Wald Chi2	df	Sig.
Intercept	–3.960	1.035	14.629	1	0.001
x	0.647	0.122	28.025	1	0.001
xy	0.468	0.085	30.182	1	0.001
y^2	0.574	0.093	37.406	1	0.001
x^3	–0.309	0.0106	8.443	1	0.004
x^2y	–0.191	0.922	4.291	1	0.038
Dog packs	0.007	0.002	5.729	1	0.017
Ligneous cover (%)	–0.008	0.010	0.610	1	0.435
Pine forest < 50 %	–2.090	1.005	4.320	1	0.038
Pine forest > 50 %	0				
Pine forest < 50 % * Ligneous cover	0.027	0.010	6.489	1	0.011
Pine forest > 50 % * Ligneous cover	0				

(SD), the average number of hunters/100 ha and dog packs/100 ha per year were 10.39 ± 4.29 and 2.67 ± 1.11 respectively. Although data seemed to vary little among years (wild boars/100 ha range: 1.27-1.88; hunters/100 ha range: 9.84-10.93; dog packs/100 ha range: 2.55-2.81), there was wide variation in the number of wild boars hunted among different estates (wild boars/100 ha range: 0.12-4.60; Fig. 1) as well as in the number of hunters (hunters/100 ha range: 2.98-19.58) and dog packs (dog packs/100 ha range: 0.33-4.83).

Models 1 and 2 produced very similar results. In both, ligneous cover and area of pine forest showed a significant effect after controlling for the spatial variables and hunting pressure (dog packs), but in the opposite direction: ligneous cover favoured wild boar density, while pine forest area decreased it, either when introduced as a percentage or as a categorized variable (Models 1 and 2, respectively; Table 1).

We found a significant interaction between the categorized area of pine forest and the ligneous cover (Model 3) on the density of wild boars (Table 1, Fig. 2). A positive effect of the ligneous cover only occurred in estates where the area of pine forest was low. However, when the forest pine area was high, the relationship between hunted wild boars and ligneous cover disappeared (Fig. 2).

Discussion

The results show that the presence of pine trees was negatively associated with the number of wild boars harvested. The differences between estates were consistent throughout the nine years of study, which supports that hunting results may relate to the actual density of wild boars using the area when other influencing variables are taken into account. It is important to emphasize a positive influence of the ligneous cover on the relative abundance of this species when pines are not the predominant type of forest in the area. On average, the area occupied by pine forests represents 35.83 % of the total area. The presence of large areas with pines might influence the abundance of wild boars not only within the pine woods but also in the whole area under study. The average number of wild boars hunted per 100 ha in the whole study area was 1.52 ± 1.28, which is notably smaller than estimates obtained for other Mediterranean areas in the Iberian Peninsula, such as Alentejo (Portugal) or Extremadura (Spain) where figures were 9.49 and 2.70 respectively (Fernández-Llario et al. 2003). In more Atlantic environments, such as northern Spain, reported values were 3.0 (Leranoz & Castién 1996), 1.9-4.2 (Tellería & Sáez-Royuela 1985) and 3.1 (Herrero et al. 1995). Therefore, our study area shows one of the lowest densities in the Iberian Peninsula, even if it has a high potential resource values for the species (Bosch et al. 2012); something remarkable in an area with great hunting tradition, in which wild boar is the second most important big game species after the red deer.

The relatively small hunting bag for wild boar in our study area was not caused by a low hunting effort, which was even higher than in other areas of Iberia. For example the hunting effort reported for a similar Mediterranean area in Extremadura was even lower (5.53 hunters/100 ha and 2.0 dog packs/100 ha, Fernández-Llario et al. 2003) than in the study area (10.39 ± 4.29 and 2.67 ± 1.11 respectively) despite yielding a twofold sized hunting bag.

But what are the possible mechanisms that cause a lower density in the pine forests? The presence of pine forests reduces the area of native forest and thus the presence of species of the genus *Quercus* that produce acorns, which constitute a key element of the wild boar diet (Massei et al. 1996) and, along with beech tree fruit in other areas, may strongly influence population growth (Okarma et al. 1995, Jędrzejewska et al. 1997, Bieber & Ruf 2005). In addition, pine forests usually include poor understory layers compared to native Mediterranean shrubland, which are also valuable for shelter (Welander 2000, Fernández-Llario 2004). Pines produce some food for wild boars in the form of pine nuts, although these are only available in summer and are of much lower relative importance compared with acorns (Fernández-Llario 1996). Also, in our study area, as in most reforested areas in Spain, the pine-nut-producer stone pine is used only in some patches with the non-pine-nut-producer cluster pine being the dominant species.

Another interesting result is the lack of inter-annual variation in the number of wild boars hunted in the area. Population dynamics in this species usually includes strong fluctuations in size, probably related to density dependent factors (Jędrzejewska et al. 1997). In our study area, wild boars appeared to be in low density and seem not to show too strong population fluctuations. One possible explanation is that habitat quality limits both density and population fluctuations. In our study area, habitat may be poor on average, not because plant productivity is limited by poor environmental or weather conditions, but because it is composed of a mosaic of productive oak patches together with largely unproductive areas of pines that do not contribute to provide extra-food for wild boars even under good weather conditions. Thus, good years may not produce big population increases, so that there may be little opportunity for density dependent effects to lead to population fluctuations.

In conclusion, our results indicate that the presence of pine woods may negatively affect wild boar density. This association is clear among estates within the study area. Our data suggest that restoring the native forest may be valuable, not only for increasing biodiversity, but also to improve economy, since big

game hunting is one of the main sources of income in these areas. On the other hand, most European populations of wild boar are increasing and can produce several types of negative impacts (Acevedo et al. 2006, Bosch et al. 2012), which is also worth considering as a factor in the management of these populations oriented to make compatible economical use and conservation.

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