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WILD BOAR ABUNDANCE AND HUNTING EFFECTIVENESS IN ATLANTIC SPAIN: ENVIRONMENTAL CONSTRAINTS

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Abstract

Wild boar populations have increased over the species' entire Spanish range even in areas with no direct influence of humans (like artificial feeding, watering, etc.). Some detrimental effects were raised in relation with the wild boar increase, which justifies the development and improvement of methods to estimate wild boar abundance and population trends. Harvesting information is important for planning the extraction policy and managements goals, mainly for elusive species as wild boar. Nevertheless this information could be biased by several factors, being hunting effectiveness one of them. Thus, our objective was to investigate how landscape structure affects wild boar abundance and hunting effectiveness. Based on data of 44 game territories for 4 seasons (from 1998-1999 to 2001-2002), we quantified hunting effectiveness as the proportion of animals caught in relation to the total seen by hunters. Then, we estimated a corrected wild boar abundance index following the De Lury' method. Twenty two factors related with landscape structure, topography, human infrastructures, and hunting pressure, were considered to study their effects on wild boar abundance and hunting effectiveness by means of General Linear Models (GLM). Landscape structure factors that possibly resembled increased visibility (abundance of fern and landscape diversity index) and availability of wild boar resting places (percentage with south-west orientation) statistically associated with effectiveness. Factors related food availability (abundance of pre-forest but also landscape diversity index) statistically and positively associated with wild boar abundance. We suggest that corrected wild boar abundances should be considered in monitoring schemes to obtain more suitable wild boar abundance estimates. The applicability of hunting effectiveness data in catch-effort methodologies is discussed.

Key words: Cantabric chains, Fragstats, hunting effectiveness, *Sus scrofa*, wildlife abundance.

Resumen

Abundancia y eficacia de caza de jabalí en España Atlántica: condicionantes ambientales

Las poblaciones de jabalí están en aumento en toda la España peninsular incluso en áreas no sujetas a manejos cinegéticos intensivos. El aumento excesivo de sus poblaciones tiene efectos negativos sobre el ecosistema, razón por la que es necesario contar con métodos fiables para estimar la abundancia de las poblaciones y sus tendencias a lo largo del tiempo. Los datos derivados de las actividades cinegéticas han sido utilizados en otras ocasiones para este propósito, sin embargo esta información no debe ser usada en bruto ya que depende del número de animales cazados y éste es un dato a su vez determinado por numerosos factores entre los que cabe destacar la eficacia de los cazadores a la hora de abatir los animales. Con información de 4 temporadas de caza (de 1998-1999 a 2001-2002) registrada para 44 territorios cinegéticos del Principado de Asturias se ha calculado la eficacia de caza (proporción de animales que se cazan del total de animales vistos en una cacería). Dicha eficacia ha sido considerada para estimar un índice de abundancia poblacional de jabalí usando el método desarrollado por De Lury. Ambos índices, eficacia y abundancia, han sido relacionados con variables ambientales (estructura del paisaje, topografía, estructuras humanas y presión cinegética) por medio de modelos lineales generales. Los resultados han mostrado que tanto variables relacionadas con la visibilidad, como por ejemplo la abundancia de helechales y la diversidad paisajística, como otras relacionadas con la disponibilidad de lugares de encame, determinan la eficacia de las cacerías. Por otro lado, la abundancia de las poblaciones de jabalí se encuentra principalmente determinada por variables relacionadas con la disponibilidad de alimento. Por tanto, y al estar la eficacia de caza determinada por parámetros ambientales independientes del tamaño de las poblaciones de jabalí, se considera que ésta debe ser tenida en cuenta a la hora de usar los resultados de las actividades cinegéticas como indicadores de abundancia.

Palabras claves: Abundancia, Cordillera Cantábrica, Fragstats, rendimiento cinegético, *Sus scrofa*.

Introduction

Ungulate populations are expanding across Spain, both in distribution and abundance (e.g. Sáez-Royuela and Tellería 1986, Castién and Leránoz 1991, Gortázar *et al.* 2000, Acevedo *et al.* 2005). Undoubtedly, the wild boar (*Sus scrofa* Linnaeus, 1758) is the most widely distributed wild ungulate in the Iberian Peninsula, where both its range and density are still increasing (Acevedo *et al.* 2006, Rosell and Herrero 2007); the Spanish Hunters Association estimated in 130,000 the Spanish wild boar hunting bag in 2003 (Garrido 2004). This widespread expansion has been facilitated by several factors, including, among others, regulation of exploitation and control of poaching (Gortázar *et al.* 2000) and abandonment of agricultural land (Acevedo *et al.* 2006).

Hunting harvest explains the high population turnover of the wild boar (Gaillard *et al.* 1987) and is able to shape the demographic structure of this species (Fernández-Llario and Mateos-Quesada 2003). Harvesting information is relevant for planning the extraction policy for this species (Caughley 1977, Cruz *et al.* 2005), but is also crucial to estimate population in size mainly of elusive species like wild boar and in forested habitats. In these habitats, the estimation of ungulate abundances becomes more difficult than in open habitats due to visual permeability being frequently of low reliability because of the expensiveness and required effort (Lancia *et al.* 1994). In such habitats, hunting bag analysis (Sáez-Royuela 1987, Sáez-Royuela and Tellería 1988, Fernandez-Llario *et al.* 2003) are frequently used to estimate wild boar population abundance (e.g. Acevedo *et al.* 2006, 2007a), and also to determine other parameters related with populations structure (Vicente *et al.* 2005).

Harvesting indices to estimate species abundance are based on the assumption that the ratio of animals caught per unit of expended effort is proportional to the size of the population at the beginning of the capture period (Sirén *et al.* 2004). Thus, the primary variable influencing the number of wild boar killed is the number of individuals of the population (De Lury 1947). The hunting effort (such as the number of hunters per area) also determines the number of hunted wild boar (Caley and Ottley 1995, Fernandez-Llario *et al.* 2003) and therefore harvesting indices. Another important determinant is the hunting effectiveness (proportion of animals caught in relation to the total seen by hunters in a concreted area), it should be taken into account when abundance estimates are based on catch-effort methodologies (De Lury 1947). This parameter is suspected to be also influenced by hunter' and habitat related factors.

Habitat structure is one of the most important factors determining ungulate species distribution and abundance. Thus, this feature has been documented modulating several ungulate species in the Iberian Peninsula (e.g. roe deer [*Capreoulus capreolus*] San José *et al.* 1997, Acevedo *et al.* 2005, and wild boar Cahill *et al.* 2003, Acevedo *et al.* 2006). Concretely, wild boar activities are influenced by environmental characteristics, for example, nest site selection (Fernández-Llario 2004), rooting (Welander 2000), food selection (Schley and Roper 2003), home range (Massei *et al.* 1997), escape movements (Sodeikat and Pohlmeyer 2003) and therefore they are determining the wild boar population abundance (Acevedo *et al.* 2006) and probably wild boar hunting effectiveness.

Particularly, in our study area, Asturias (northern Spain), the wild boar hunting management could have important consequences for the Cantabric brown bear (*Ursus arctos*) conservation. The population increase of this suid is related with an augment of the number of agricultural damages and therefore the use of illegal unspecific capture systems as snares in which occasionally Cantabric brown bear are captured. On the other hand wild boar hunting also produces disturbances on this endangered species (Fundación Oso de Asturias 2002). These questions raised justify the development and improvement of accurate abundance estimating methods in this area.

Thus, our main aim was to examine the landscape structure and composition effects on wild boar hunting effectiveness in order to correct the estimation of abundance based on catch-effort methodologies and monitoring wild boar populations across both spatial and temporal scales.

Material and methods

Study area

We focused our study on the Regional Game Reserves (RGR), located in the region of Asturias, north Iberian Peninsula (Figure 1, UTM 30S 225000-333000, 4760000-4816000). Asturias is included in the Eurosiberian climatic dominion of Atlantic type climate, characterized by the absence of droughts throughout the year and a moderation in the thermal contrast between day and night, and between summer and winter, due to the modulatory action of the Cantabric sea (see Acevedo *et al.* 2007b for a detailed description of the study area).

Deciduous and mixed forests are predominant in the study area. The characteristic trees and scrubs are: oak trees (*Quercus robur*, *Q. ilex*, *Q. petraea*, *Q. orocantabrica*, etc.), beech (*Fagus sylvatica*), birch (*Betula celtiberica*), yew tree (*Taxus baccata*), holly (*Ilex aquifolium*), hazel (*Corylus avellana*), laurel (*Laurus nobilis*) and several scrubs (*Genista* spp., *Cytisus* spp., *Erica* spp., *Calluna* spp., *Vaccinum* spp., *Juniperus* spp.).

Each RGR (N=10) is divided into hunting areas (smaller units of hunting management). These hunting areas, with a size of 3241.97 ± SE 216.52 ha (range 543.46 –8335.89), were our sampling units (N=44), where intensive management strategies linked to hunting (feeding, etc; see Vicente *et al.* 2007) are not carried out in Asturias. Red deer (*Cervus elaphus*), roe deer and Cantabrian Chamois (*Rupicapra pyrenaica*) are also distributed in the study area, but their population densities are not homogeneous in all reserves.

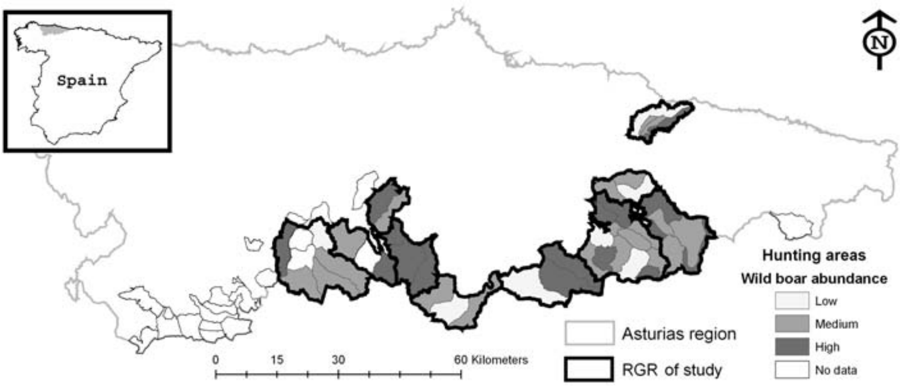

Figure 1. Location of the study areas in Asturias region. Wild boar abundance (0-33% low, 33-66% medium and 66-100% high categories were selected) according to our results are shown for each hunting area.

Localización de Asturias y del área de estudio. Abundancia de jabalí para cada área de caza (0-33% baja, 33-66% media y 66-100% alta).

Catch and effort data

Game wardens of the Environment Agency of Asturias in their activity reports systematically recorded the numbers of wild boar killed, wounded and seen of each game species, and the number of hunters who participated in the hunt. All the activity reports (3597 hunting activities between 1998-1999 and 2002-2003 hunting seasons) were digitalized into a database (GESCAP, Environment Agency of Asturias). Only total values per hunting season for each hunting area can be extracted from GESCAP.

First, we quantified, for each hunting area, the hunting effectiveness as the percentage of animals caught in relation to the total seen in the hunting activities for each hunting season considered. Then, we calculated the corrected wild boar abundance index based on hunting effectiveness and following the De Lury method (De Lury 1947, for a review see Boitani *et al.* 1995a). We use catch rate (C) as index of wild boar abundance:

$$C = qEN$$

Where E is the hunting effort expended, N is the wild boar population size, and q is the fraction of the abundance that is caught by one unit of effort (effectiveness).

Re-arranging the previous equation leads to the fundamental relationship between catch rate and population abundance:

$$\frac{C}{E} = qN$$

However, q may not be constant, but may change spatially and temporally due to changes, for example, in the landscape visibility.

The battues are the most popular hunting discipline in Asturias. The mean surface of the beaten areas was 150.61 ha, SD 104.92, range 590.05. Groups of hunters are limited to 8 to 12 hunters in the RGR, helped by not more than 6 beaters (they cannot carry firearms) and by a maximum of 4 dogs. The number of wild boar killed per hunt is also limited to 5. Therefore, the conditions of hunting effort are here standardized, with only slight variation between battues. These groups of hunters are always accompanied by one or several game wardens.

Development of predictor variables

Landscape structure

We defined 10 different vegetation classes (land uses) using the Vegetation Map of Asturias (GIS of the Environmental Thematic Cartography, Government of Asturias, 1:25000 scaled): mature forest (oak, beech, etc.), pre-forest (holly, birch, etc.), scrub (hazel, laurel, etc.), broom (the genera *Genista* and *Cytisus*), heather (the genera *Erica*, *Calluna*, *Halymium*, etc.), mountain scrub (the genera *Ulex* and *Juniperus*), fern (the genera *Pteridium*, *Osmunda*, *Dryopteris*, etc.), pastures, mountain grass (the genera *Festuca*, *Luzula*, etc.), and others. Those types of vegetation that rarely occurred in the study area were included as 'others'. Original map data in vector format was rasterised to 10 m resolution by mean of the Polyras tool of Idrisi 32 software version I32.21 (Clark Labs 2001, 2004). Therefore the minimum patch size was 0.01 hectares (1 pixel equates to 10 x 10 m).

The effect of landscape structure on wild boar hunting effectiveness and population abundance was analyzed at 2 levels in the study area: 1) the vegetation-class level, and 2) the landscape level considering the hunting areas as sampling unit, similarly to Acevedo *et al.* (2006). We calculated 3 indices for each vegetation class (Level 1), and 3 at landscape level (Level 2) using Fragstats 3.3 software (McGarigal and Marks 1995).

We used the following indices (see Table 1 for descriptions): percentage of landscape (PLAND, quantified the proportional abundance of each vegetation-class patch type in the landscape), average patch size (AS, quantified the average patch area for each vegetation-class), edge density (ED, quantified edge length on a unit area basis), aggregation index (AI, calculated from an adjacency matrix, which showed the frequency with which different pairs of patch types appeared side-by-side on the map) and Shannon's diversity index (SHDI, is a measure of diversity in community ecology).

Topography

We analysed the influence that topographic factors could have on the hunting effectiveness and on wild boar population abundance. The topographic data from a digital elevation model (spatial resolution of 90 m) was extracted by overlaying the DEM with the sampling unit with Idrisi (Clark Labs 2001, 2004; see Acevedo *et al.* 2007b, c). Average altitude (m) and average slope (in percentage) was obtained for each sampling unit. With respect to the aspect, we calculated the percentage of hunting area with each orientation class (we considered north, north-east, east, south-east, south, south-west, west and north-west).

Human infrastructures

Road type influence on hunting effectiveness and relative abundance was analyzed in the present study. We defined 2 types of roads in relation to their hierarchy-class (1-national roads and, 2- regional, local and non asphalt roads), using the Roads coverage of Asturias (GIS of the Environmental Thematic Cartography, Government of Asturias, 1:25000 scaled).

Statistical analysis

Firstly, we calculated descriptive values of the considered hunting factors, and estimated the 'beta' parameter, obtained from a linear regression of the yearly average of relative abundances of the wild boar population for each sampling unit, as a measure of population trend index (Williams *et al.* 2007).

TABLE 1

Indices used to characterize the landscape structure (modified from McGarigal and Marks 1995). The level indicates the scale at which they were applied, vegetation class -Level 1-, and/ or landscape -Level 2-.

Índices usados en la caracterización de la estructura del paisaje (modificado de McGarigal and Marks 1995). El nivel indica la escala a la que estos índices fueron aplicados, tipo de vegetación –nivel 1-, y paisaje –nivel 2-.

Indices	Level	Description	Formula
PLAND	1	A = total landscape area (m^2). a_{ij}= area (m^2) of patch$_{ij}$.	$PLAND_i = (100)\frac{\sum_{j=1}^{n} a_{ij}}{A}$
AS	1	a_{ij}= area (m^2) of patch$_{ij}$. $N_{(i)}$ = number of patches of class i.	$AS_i = (100)\frac{\sum_{j=1}^{n} a_{ij}}{N_i}$
AI	1, 2	g_{ii} = number of adjacencies (joins) between pixels of class i based on the single-count method. P_i = proportion of landscape comprised of class i.	$AI = (100)\left[\sum_{i=1}^{m}\left(\frac{g_{ii}}{\max - g_{ii}}\right)P_i\right]$
ED	2	$E_{(ik)}$ = total length (m) of class i. A = total landscape area (m^2)	$ED = (10,000)\frac{\sum_{k=1}^{m} E_{(ik)}}{A}$
SHDI	2	P_i = proportion of landscape comprised of class i. Shannon index.	$SHDI = -\sum_{i=1}^{m}(P_i \ln P_i)$

Secondly, we designed a two-step procedure to clarify the significance of the predictor factors (N=43, see above) on the response variables: hunting effectiveness and corrected wild boar relative abundance index, respectively. Previously to this procedure, we avoided multicollinearity between predictors using the Spearman rank correlation coefficients. Landscape structure factors were considered to be collinear when Spearman' correlation coefficients were r_s>0.6 (Tischendorf 2001). Twenty two predictors were included in the two-step procedure after this previous analysis.

First step). We discarded a number of variables no significantly related with the response variable (threshold p-value=0.05), building a General Linear Models (GLM), with a normal error distribution and an identity link function, for each predictor, i.e. included a unique explanatory variable. Then, the variables, which captured the effect of any set of highly correlated variables on the outcome, were selected for inclusion in the next step.

Second step). Predictors selected in the first step were integrated in two final multiple models, for hunting effectiveness and relative abundance index as response variables respectively. We similarly employed GLM with a normal error distribution and an identity link function by following a backward stepwise procedure (Crawley 1993). The level of significance was set at 5%.

Results

The average bag of wild boar killed per hunting season in Asturias RGR was 842.67 ± SD 80.84 (range 682.00 –906.00). No clear population trends have been observed for the study period at a regional scale (beta=0.72, p>0.05). Nevertheless, some Reserves appeared to show an increasing population trend (5 out of 10 RGRs), but the limited number of years of study (only 4) does not allow a statistical test of these trends. The average of number of hunters per battue showed a small variability: 10.85 ± SD 1.92 (range 10.06 – 12.23), showing the hunting effort stability supposed to the study area.

Effectiveness model

The average hunting effectiveness (proportion of animals killed per hunting area and per hunting season, %) was 15.61 ± SE 1.33 (range 0.00 – 36.95). The number of catch per effort unit was 1.58 ± SE 0.09 (range 0.71 – 2.85) wild boar per battue, and there were differences between RGRs (Kruskal-Wallis, Chi-square=25.04, df=9, p=0.003).

Twenty-one environmental factors were included in the 'first step' and, after this, 7 were included in the 'second step' (Table 2). The final GLM explained 60.606% of the original variance (p=0.0023; Table 3). The model showed that the hunting effectiveness was higher in those hunting areas with a high proportion of southwest oriented land, high proportion of fern and reduced landscape diversity.

TABLE 2
Variables selected for inclusion in the final GLMs (after the 'first step') and levels of significance (n.s.= not significant, +=p<0.10, ++=p<0.05 and +++=p<0.01).

Variables seleccionadas para ser incluidas en los GLM finales (tras el primer paso), y el nivel de significación (n.s= no significativo, +=p<0.10, ++=p<0.05 y +++=p<0.01).

Variables (codes)	Sig. Effectiveness model	Sig. Abundance model
Average of number of hunters	++	n.s.
Mature Forest PLAND	++	n.s.
Pre-forest PLAND	n.s.	+++
Scrub PLAND	n.s.	+
Broom PLAND	+	++
Fern PLAND	++	n.s.
Shannon index	+++	+++
Edge density	++	n.s.
South-west orientation	+++	n.s.

TABLE 3
General Linear Models for hunting effectiveness and corrected wild boar abundance index, respectively. The distribution error function is the normal with an identity link function. The models explained a 60.606% and a 60.616% of the original variance, respectively.

Modelos lineales generales (distribución normal, vínculo identidad) obtenidos con eficacia de caza e índice de abundancia de jabalí como variables dependientes. Los modelos explicaron el 60,606% (eficacia de caza) y el 60,616% (abundancia de jabalí) de la varianza de la variable dependiente.

Variables	Wald	p-value	Estimate
Hunting effectiveness			
South-west orientation	7.22	0.007	0.31502
Fern PLAND	7.45	0.006	0.12245
Shannon index	6.85	0.009	-1.41389
Corrected abundance index			
Pre-forest PLAND	11.67	0.001	0.81280
Shannon index	8.22	0.004	1.58290

Abundance model

The corrected average wild boar abundance index was 12.22 ± SE 1.16 (range: 2.41 – 39.10) wild boar per battue.

After the 'first step' 4 predictors were included in the 'second step' (Table 2). The final GLM explained the 60.616% of the original variance (p=0.0002; Table 3). The model interpretation indicated that wild boar abundance is higher in those hunting areas with a high proportion pre-forest lands and high landscape diversity. Figure 1 shows the corrected wild boar abundance in the study area.

Discussion

Wild boar catch-effectiveness

Catch-effectiveness has previously been used to correct the estimation of abundance, mainly in fisheries (Maunder and Punt 2004). Nevertheless, it has been less frequently used in mammal' studies. Despite of, according to our results, being a key factor to estimate game species abundance from hunting bag data (Boitani *et al.* 1995b).

There was a high variation in the proportion of wild boar caught in relation to the total seen (range 0.00 – 36.95%), attaining generally low scores of effectiveness (mean 15.61%) in the hunting areas studied. The effectiveness reported here is even smaller than others reported in hunting wild boars in the Spanish Pyrenees, northern Spain (Herrero 2002). This reinforces our approximation to the study of wild boar abundance. When catch effectiveness is low; it is needed to include effectiveness in the catch-effort indices to estimate population abundance due to hunting bags being biased with animal abundance. Furthermore, hunting effectiveness is not constant; depending, among other factors, on the landscape structure and composition.

To date, the effects of environmental factors on big game hunting effectiveness have received only limited attention. Our results suggest that landscape structures, as well as the orientation of hunting areas, are determining the wild boar hunting effectiveness. Firstly, we detected that high effectiveness was positively related with the percentage of territory with southwest orientation (see Figure 2). This result can be explained by behavioural considerations: a) during the hunting season (winter), wild boar may select sunny areas as resting places being the warmest areas those with southwest orientation in Atlantic Spain; b) the last weeks of the hunting season correspond to the beginning of a birth peak, when wild boar construct nests in warm places (Fernández-Llario 2004). Previously it was described the importance of topographic factors determining the vegetation units and indirectly influencing wild boar habitat use (Abaigar *et al.* 1994). Finally; c) south orientation corresponds with more open vegetation comparing with north orientation, which could influence hunting effectiveness. More research is needed in order to properly determine the influence of sunny areas on wild boar patterns of spatial use.

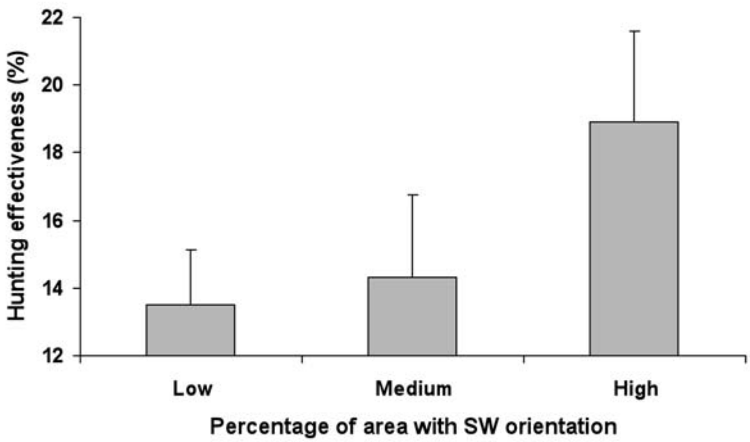

Figure 2. Average hunting effectiveness (%) according to land orientation-class in hunting areas (low, medium and high referring to the percentage of territory with south-west orientation; Low<5.70<Medium<13.63>High).

Eficacia media de caza (%) para cada clase de orientación (bajo, medio y alto están referidos al porcentaje del territorio con orientación suroreste; bajo<5,70<medio<13,63<alto).

Secondly, hunting effectiveness was positively related with the proportion of hunting areas occupied by fern. This may be due to the fact that fern lands provide high visibility in winter. The ferns lie down as a consequence of snowfall; turning into clear, usually large areas, where the probability of successful shots by hunters increases compared with other land uses.

Finally and logically, the landscape diversity index was negatively correlated with the hunting effectiveness. The landscape diversity, quantified as Shannon's diversity index, increased as the number of different patch types increased and/or the proportional distribution of area among patch types became more equitable (McGarigal and Marks 1995). Landscape richness may decrease the visibility and therefore the hunting effectiveness. Landscape diversity may also associate to increased proximity and availability of appropriate hiding patches when wild boar escapes from hunters.

Thus, as our main results we detected that hunting effectiveness is associated by local landscape structure features reason why it is a parameter that should be estimated when hunting bag data are used to estimate game species abundance. Regional Game Reserves of Asturias follow similar game schemes, as regards effort of capture (4 dogs, 6 beaters and 8-12 hunters). This standardized (at least relatively) hunting method provides an excellent opportunity to detect, considering the hunting effectiveness, the environmental determinants of wild boar abundance.

Wild boar abundance

Our results suggest that the percentage of pre-forest lands and the landscape diversity had a positive association with wild boar abundance, similarly to previous studies in the Iberian Peninsula (Acevedo *et al.* 2006). Pre-forests are Atlantic covered patches with high food availability for wild boar: autumnal fruits, with high small animal and invertebrate biodiversity). High values in the landscape diversity index are also indicating high refuge availability. Our results support the idea that the landscape pattern determines species' abundance (Virgós 2002, Acevedo *et al.* 2006). In the case of wild boar, large forests may contribute to its survival through a combination of increased heterogeneity in large surfaces (Freemark and Merriam 1986), which enhance the likelihood of finding a variety of key resources in terms of individual survival: high food diversity, resting and breeding sites with protective cover (Gerard *et al.* 1991, Fernández-Llario 2004), and a low level of interference from people and/or livestock (Spitz and Janeau 1990).

In summary, we evidenced that that hunting effectiveness is a key factor to estimate abundance indices of wild boar in Atlantic areas based on catch-effort methodologies. Since hunting effectiveness was not a constant factor, depending on local landscape structure parameters, we conclude that it should be considered in monitoring schemes, being even more important when comparing different hunting modalities or biogeographical areas. Finally, landscape composition related with availability of food resources and protective cover were the most relevant determining the wild boar abundance. This provides an excellent 'natural' area to compare population trends and habitat effects on wild boars demography with parts of Spain were more intensive hunting management schemes predominate, for which future research is needed.

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