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Main landscape metrics affecting abundance and diversity of game species in a semi-arid agroecosystem in the Mediterranean region

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Abstract

Hunting bags provide important information for conservation measures and wildlife management. This study is to assess relationships between landscape structure and game species. The community parameters (abundance, richness and diversity) and landscape/land use indices have been related, using GIS and statistical analysis, in the South-East of Spain (Marina Baja, Alicante). Game species richness (S) is determined by the presence of fruit groves (p = 0.001, R = 0.714) and landscape shape. The total density of species (TD) is influenced positively by fruit groves (p = 0.001, R = 0.783) and wooded shrublands (p = 0.002, R = 0.911), but is influenced negatively by urban areas (p < 0.001, R = 0.844). Small game communities correlate to irrigated fruit (p = 0.002, R = 0.754) and dry vineyard (p = 0.021, R = 0.839) and also with the diversity landscape index (p = 0.029, R = 0.708). Big game density is positively related to holm oak (p = 0.018, R = 0.812) and dense pine forests (p = 0.001, R = 0.849) and also with the total area landscape index (p = 0.011, R = 0.921). Population control species prefer irrigated fruit (p < 0.001, R = 0.775), fruit groves (p < 0.001, R = 0.857) and irrigated vineyard (p = 0.017, R = 0.833) land uses. Our conclusion is that most game species presents a positive relation with landscape structure, such as fractal dimension and shape index, and traditional agriculture based on irrigated and dry fruit crops.

Additional key words: game community; GIS; hunting bags; Mediterranean agrosystem; semi-arid climate.

Resumen

Principales indicadores del paisaje que afectan a la comunidad de especies cinegéticas en un agroecosistema semiárido en la región mediterránea

Los estadísticos de caza proporcionan información fundamental para implementar medidas de conservación y manejo de fauna. Este estudio pretende evaluar las relaciones entre la estructura del paisaje y las especies de caza. Se han relacionado los parámetros de la comunidad (abundancia, riqueza y diversidad), el paisaje y los índices de uso del suelo, usando SIG y análisis estadísticos, en el sureste de España (Marina Baja, Alicante). La riqueza de especies (S) está correlacionada positivamente con los frutales (p = 0,001, R = 0,714) y la forma del paisaje. La densidad total de especies (TD) está influenciada positivamente por los frutales (p = 0,001, R = 0,783) y el matorral arbolado (p = 0,002, R = 0,911), aunque influida negativamente por las zonas urbanas (p < 0,001, R = 0,844). Las especies de caza menor se correlacionan con el frutal de regadío (p = 0,002, R = 0,754), el viñedo de secano (p = 0,021, R = 0,839) y con el índice de diversidad del paisaje (p = 0,029, R = 0,708). La densidad de especies de caza mayor se relaciona positivamente con el encinar (p = 0,018, R = 0,812), el pinar denso (p = 0,001, R = 0,849) y con el índice de área total del paisaje (p = 0,011, R = 0,921). Las especies que requieren control de la población prefieren el frutal (p < 0,001, R = 0,775), la viña de regadío (p = 0,017, R = 0,833) y frutales de secano (p < 0,001, R = 0,857). La mayoría de especies de caza presenta una relación positiva con la estructura del paisaje, especialmente sobre los índices fractal y de forma, y la agricultura tradicional basada en los cultivos de frutales en regadío y secano.

Palabras clave adicionales: agrosistema mediterráneo; clima semiárido; comunidad cinegética; estadísticos de caza; SIG.

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Abbreviations used: DI (dominance index); GIS (geographical information system); H (game diversity index); H' (Shannon landscape diversity index); LSI (landscape shape index); TD (total density).

Introduction

Hunting constitutes an important traditional economic activity in Spain. In the Alicante province, hunting areas represent more than 75% of the whole area of the province. Game zones constitute important, clearly delimited, units. Moreover, each type of game area works independently, presenting particular problems and concrete responses to these problems in order to improve management tasks. They are also characterised by different landscape structures and consequently, small game species present spatial distributions based on land use patches (Jiménez-García *et al*., 2006).

The monitoring of wildlife population is an essential component of any management program. It should be used to assess the population states for inclusion in conservation plans (Virgós *et al*., 2007). Nowadays, habitat fragmentation is a consequence of landscape change and strongly influences species survival, particularly in the case of area-sensitive species. Then, the availability of habitat patches is affected by fragmentation processes (Fahrig, 2003), that will lead to low dispersal capacity and to the loss of local populations (McGarigal *et al*., 2002).

Mediterranean basin landscapes are experiencing accelerated changes due to the increasing urbanization of coastal and inland areas, abandonment of traditional farming activities and expansion of modern intensified agricultural methods. Together, these changes are increasing the fragmentation of these landscapes (Serra *et al*., 2008). In this context, knowledge of the habitat features that may be limiting the numbers or distribution of a given species may be of paramount importance for its conservation in an increasingly human-altered landscape (Guisan and Zimmermann, 2000; Lehmann *et al*., 2002). In particular, slow-reproducing species which are often more sensitive to habitat alteration and disturbance may be largely affected by human-induced changes in the environment (Ontiveros *et al*., 2004; Brambilla *et al*., 2006).

The most important driving forces of land use change in semi-arid landscapes of southeastern Spain in the last decades have been identified by several authors (Martínez *et al*., 1997; Peña *et al*., 2007). One of these forces is the abandonment of traditional land uses, including wood or firewood extraction and traditional dry farming. The increasing availability of water resources and market demands has resulted in two other strong driving forces: intensification of agriculture and urbanization. Thus, the areas in which traditional farming has been abandoned have followed two opposite processes, the invasion of scrubland and pine forests on the one hand and the intensification of agriculture or spreading of housing developments (mainly urbanizations) and dispersed houses for tourism on the other.

Despite the effect of fires in the Alicante province, the forest land has increased during the last decades between 20% and 30% (Martínez *et al*., 1997; Peña *et al*., 2007). However, urbanized areas have increased much more, especially in coastal areas (Peña *et al*., 2007) rather than in non-coastal areas (Martínez *et al*., 1997).

In other regions where a similar process of forest recovery occurred, the population of this species has increased (Mañosa, 2003 and 2004), and we suppose that the abandonment of traditional land uses has favored the species in inland areas. In the Mediterranean provinces of south-eastern Spain, urbanization close to the coast has reached near-saturation, and therefore, an increasing number of housing developments are being projected in inland areas. This expansion of urbanization towards inland areas would have a detrimental effect on the game species community, especially if they are located close to mosaic of natural and agricultural patches. Thus, it is important to highlight the decline of dry crops, which in 1956 accounted for 35% of the territory but they have declined progressively to 10% currently (Arques *et al*., 2009). This is a consequence of fading economic power that the irrigated agriculture in Marina Baja held in the past. There has been an agricultural transformation from dry to irrigated crops and urban lands. The growth of pine tree areas (mainly *Pinus halepensis*) and scattered holm oaks is also significant. In 1956 these covered 18% of the surface, rising to almost 30% today. Finally, artificial hedges, principally urban land and infrastructures, have had a very marked increase, rising from 2 km^2 to 42 km^2 in 44 years, but only in around 7% of the zone (Peña, 2007).

The general aim of this study was to investigate large-scale patterns of wildlife community composition in Mediterranean areas. The focus was set on the landscape scale, covering a semi-arid region comprising approximately 580 km^2. The main goal of this study was to determine the main relationships between landscape structure and game species, using geographical information systems (GIS) and statistical analysis. The novel contribution that this analysis could make is the use of hunting data to make inference on species-habitat relationships. In this respect, our work is relatively new because it considers whole game species community and its biological groups at regional scale, with the recent population control group being specially interesting to avoid damage to crops and other wildlife species (Villafuerte *et al*., 2000). Thus, our main question was: how does the hunting wildlife community, including species distributions, relative abundance and hunting diversity, relate to land cover variation at the landscape scale in coastal regions of the South-East of Spain?

Material and methods

Study area

Marina Baja region is located in the southeast of the Iberian Peninsula, in the province of Alicante (Valencia Community). Its extension as an administrative unit covers about 580 km^2 and it is divided into mountainous and coastal sectors. It is composed of 18 municipalities, and Benidorm is the most distinguished due to its economic and population levels (Figure 1). As a part of Valencian territories is one of the Spanish areas with a greater territorial transformation rate in recent decades, not only in its structure and landscape dynamics, but also the spatial organization of land use (Martínez-Pérez, 2000).

Elevation ranges are from sea level to 1,558 m in the Aitana Mountain, which is also the highest elevation in the province of Alicante. As regards hydrography, the rivers Guadalest and Algar stand out for their watersheds. We can also highlight the Amadorio-Sella hydrological system, although it has a modular flow that is significantly lower.

The Marina Baja has a semi-arid Mediterranean climate, with mild temperatures, a prominent dry period in summer and rainfall that is concentrated in spring and autumn. The plant communities mainly belong to the superior and inferior thermomediterranean and mesomediterranean thermo-types (Rivas-Martínez and Usandizaga, 2004).

The territory is a good representation of the different landscapes in the province, from the mountains to the coast, including pieces of padded and thorny oromediterranean vegetation, deciduous forest interspersed between sclerophyll forests, pine forests, thermophilic garrigues, salt and semi-arid steppe communities (Peña, 2007).

Currently, the dominance of the natural matrix highlights the general distribution of land use; less important in order are irrigated crops, abandoned crops, dry crops and finally urban areas (Arques *et al*., 2009).

Cartography

In order to produce the land use maps, aerial photographs (scale 1:5000) from the ICV Flight (Instituto Cartográfico Valenciano, 2005) were geo-referenced (ERMapper®7.2 software), photointerpreted and digitized (Cartalinx®1.02 software). The borders of each

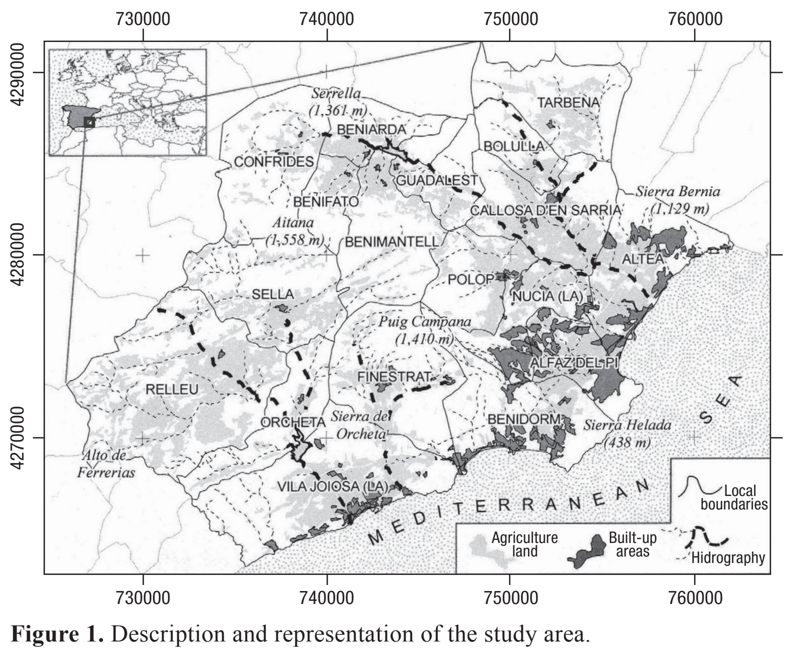

Figure 1. Description and representation of the study area.

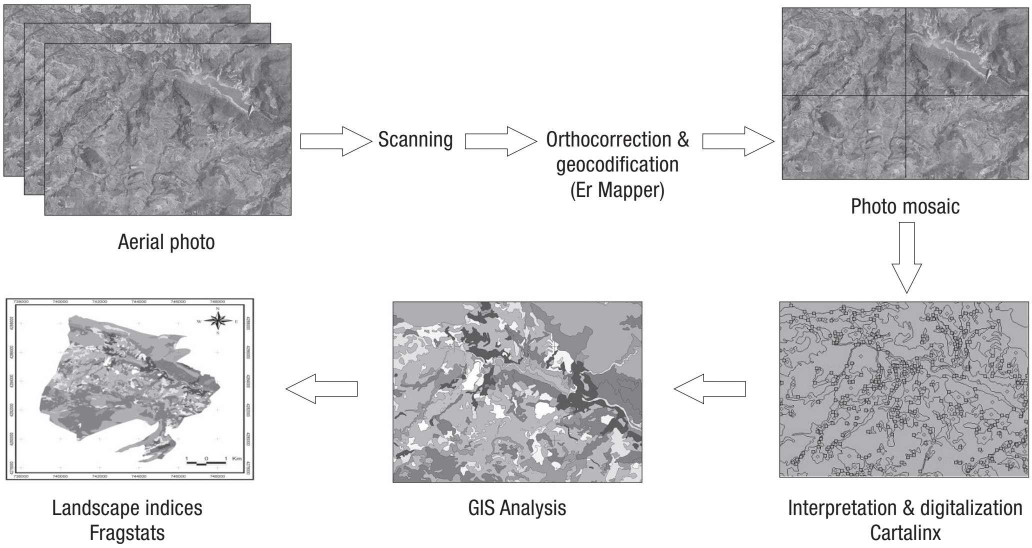

Figure 2. Thematic cartography generation process.

hunting area were obtained from Technical plans (wildlife management plans presented by hunters associations to the regional government). A coverage including hunting areas and land uses was built using ArcGIS 9.0.

This coverage was exported to raster format to perform the landscape analysis and management. The complete cartography building process is shown in Figure 2, created with Er Mapper. Land uses are composed by 34,942 polygons and 21 categories were selected (Table 1). These land uses are composed by natural uses (mainly by pine forest, shrubland and riparian), dry agricultural uses (mainly dry grove), irrigated areas (mainly fruit, and crop), abandonment uses (recent and old) and finally urban areas.

Landscape ecology metrics

In Europe, most studies have focused on highlighting species loss in forest fragments and examining the effects of factors operating on local scales, such as connectivity, shape and habitat structure within fragments (Santos *et al*., 2002). A Landscape Ecology basis is useful to obtain an extensive set of indicators to evaluate several processes related to environmental issues. The application of landscape metrics provided good results in environmental studies (Simoniello *et al*., 2004). Wildlife ecologists have often assumed that the most important ecological processes affecting wildlife populations and communities operate at local spatial scales. Vertebrate species richness and abundance are often considered to be functions of variation in local resource availability, vegetation composition and structure, and the size of the habitat patch (McGarigal *et al*., 2002).

Table 1. Surface of the landuses in Marina Baja Region

General categories	Landuses	Surface (ha)	Total area (ha)
Urban areas	Urban	4,402.79	4,583.12
	Road network	180.33	
Natural areas	Dense pine forest	3,162.42	32,138.54
	Clear pine forest	6,874.66	
	Holm-oak	258.13	
	Burned areas	421.60	
	Wooded shrubland	3,961.38	
	Dense shrubland	7,696.07	
	Clear shrubland	8,552.43	
	Riparian	1,105.35	
	Wetland	16.91	
	Dunes	89.59	
Dry crops	Dry fruit	5,134.94	5,734.89
	Dry vineyard	283.49	
	Cereal crop	316.45	
Irrigated crops	Greenhouse	313.53	6,553.77
	Irrigated fruit	4,354.02	
	Irrigated vineyard	411.53	
	Irrigated crop	1,474.68	
Agricultural abandonment	Recent abandonment	4,074.77	8,707.89
	Old abandonment	4,633.12	

Landscape ecology indices of hunting areas were obtained using FRAGSTATS® software (McGarigal *et al*., 2002). The main landscape indices used were selected as independent variables (see Annex 1), according to similar studies (Jiménez *et al*., 2006; Kong and Nakagoshi, 2006; Williams *et al*., 2007). Area, edge metrics, shape metrics, core areas, contagion and interspersion, connectivity and diversity are very common characteristics in ecological studies or when monitoring landscape changes (Yamaura *et al*., 2005; Jiménez *et al*., 2006).

The landscape metrics have gained popularity, yet there is much dispute about their ecological meaning, applicability, redundancy and sensitivity. Discarding indices on the basis of redundancy is improper due to the differences in their sensitivity to independent variables (Mateucci and Silva, 2005). Thus, the critical point of the redundancy of the indices is very valid. It is true that most of them have a high degree of correlation, which is logical because many of them are calculated from a pair of variables: length of perimeter and area of each land use polygon, and others from counting of types of contacts. However, there are several reasons to accept a priori the argument of redundancy. One is the degree of sensitivity, which varies between indices even if they are significantly correlated (Baldwin *et al*., 2004). It is not possible to reject landscape indices regardless of their discriminative ability (Mateucci and Silva, 2005).

Game species communities

Hunter associations annually report the number of hunted individuals per year to the regional government. The hunting bag data used in the present study was obtained from the regional government database (Generalitat Valenciana, 2008). According to this regional administration, there are 21 hunting areas, corresponding to 66.11 % of the Marina Baja region. The number of hunters in the area of study was 2,060, the average hunter density was quite high, 6 hunters/100 ha into a population of 180,768 inhabitants (INE, 2006).

The game communities are composed by at least three groups of wildlife species. The first is the "Small game" community that includes the wild rabbit (*Oryctolagus cuniculus*), hare (*Lepus granatensis*), red legged partridge (*Alectoris rufa*), wood pigeon (*Columba palumbus*), turtle dove (*Streptopelia turtur*), woodcock (*Scolopax rusticola*), and thrush species (*Turdus* spp.). The second is the "Big game" with only two species, wild boar (*Sus scrofa*) and aoudad (*Ammotragus lervia*). Finally, "Population Control" by hunting is composed of the red fox (*Vulpes vulpes*), collared dove (*Streptopelia decaocto*), starling species (*Sturnus* spp.) and the magpie (*Pica pica*). The control on this group is important to avoid damage to crops and other wildlife species. We used a complete register of hunting statistics for the period 2000-08 (Generalitat Valenciana, 2008). We calculated the mean values for density of each species (individuals/ 100 ha), richness (number of species), total hunting community density (individuals/ 100 ha), dominance index (DI) and Shannon diversity hunting index (H in bytes) (McGarigal *et al*., 2002) in different hunting areas for this period.

Statistical analysis

Models were built using stepwise regression analysis (SPSS® 15.0), based on (mean) hunting density, richness and diversity, land use and landscape indices for each one of 21 game preserves. Game community descriptors are the dependent variables and environmental (land use and landscape) factors are the independent variables. Game species were grouped for analysis into three distinct groups: "Small game", "Big game" and "Population Control". Thirteen game species, four community descriptors and three wildlife groups have been employed in the statistical analysis. Thus, basic coefficients of fit regression (F-variance), significance (p) and regression coefficient (R) were calculated. Results were considered highly significant when $p < 0.001$ and significant when $p < 0.05$. This method has frequently been used to predict relationships between habitat and wildlife (Dettmers and Bart, 1999; Jiménez *et al*., 2006; Merli and Meriggi, 2006).

Results

As for the hunting community (see Table 2), the group of "Small game" has the greatest richness (7 species) and density (76.80 individuals/100 ha). In this group, the most abundant species are thrushes (42.79 ind./-100 ha), wild rabbits (13.12 ind./100 ha), followed by the red legged partridge (12.69 ind./100 ha). In contrast, the least abundant species is the Iberian hare (0.27 ind./100 ha) and woodcock (0.19 ind./100 ha). The "Population Control" group has lower richness

Table 2. Hunted species density (mean 2000-2008 period) for three wildlife groups in the Marina Baja region

Wildlife group	Species	Mean density (individuals/100 ha)
Small game	Red legged partridge	12.69
	Wild rabbit	13.12
	Iberian hare	0.27
	Wood pigeon	5.74
	Turtle dove	1.99
	Thrushes	42.79
	Woodcock	0.19
Big game	Wild boar	0.44
	Aoudad	0.02
Population Control	Starlings	0.71
	Red fox	0.56
	Collared dove	1.36
	Magpie	0.63

(4 species) and density (3.26 ind./100 ha). In this category, the most abundant species is collared dove (1.36 ind./100 ha) versus the lowest density of red fox (0.56 ind./100 ha). Finally, the "Big game" group has the lowest richness (2 species), and density (0.46 individuals/100 ha). In this group, the most abundant species is wild boar (0.44 ind./100 ha).

Strong associations were seen between several wildlife groups ("Small game", "Big game" and "Population Control") and landscape/land use indices ($p < 0.05$). Basic coefficients of regression fit (F), significance (p) and regression coefficient (R), intercept value (a) and line slope (b) are shown (Tables 3 and 4). Thus, considering the associations between traditional land usages (Table 3) and game species, rabbits prefer the irrigated fruit, dry vineyard and landscape shape index. Hares were related with dry vineyard and the red-legged partridge with irrigated fruit, cereal crops and fractal dimension. The wood pigeon prefers dense pine and holm oak forests whereas the turtle dove chooses irrigated fruit, wooded shrubland, edge density and contagion zones. Woodcocks prefer oak woods, greenhouses and wooded shrubland. Thrushes exploit fruit groves, wooded shrubland, young abandoned fields and mean patch area. Wild boar is related to dense pine forest, oak wood, total core areas and disjunct core areas. Aoudad prefers dense pine forest, old abandonment, clear shrubland and total area. Magpie was related with fruit grove, dry vineyard, old abandoned fields, dense shrubland, cereal crops and landscape shape index. Collared doves opt for irrigated fruit, dry vineyard, edge density and perimeter-area fractal dimension. The red fox presents a relation with wooded shrubland, oak wood, irrigated vineyard and mean patch area. Finally, starling density is influenced by the irrigated fruit and landscape shape index.

As for the hunting community descriptors (Table 4), game species richness (S) is positively determined by the presence of crops landscape shape index, interspersion and juxtaposition index. The total density of species (TD) is influenced positively by fruit groves and wooded shrublands, but is influenced negatively by urban areas. The dominance index (DI) is determined by dry vineyard, wooded shrubland, irrigated fruit and edge density landscape index. Game diversity index (H) is related positively to fruit groves and cereal crops, instead of dense pine forest.

Referring to the different wildlife groups (Table 4), the "Small game" community is correlated to irrigated fruit and dry vineyard land uses and also with the landscape diversity index. "Big game" density is positively related to holm oak and dense pine forests and also with the total area landscape index. Finally, "Population Control" species prefer zones with irrigated fruit, dry fruit grove and irrigated vineyard land uses.

Discussion

This paper provides useful information on the interaction of wildlife with their habitat and other spatial variables. In this way, the relationship between game species and landscape structure is frequently used in biological conservation. However, in spite of its advantages, this relationship is scarcely assessed when monitoring game species (Whitfield *et al*., 2003; Jiménez *et al*., 2006). Wildlife managers need to take landscape structure into account in order to improve the management of game species in their territory. Thus, local governments and associations of hunters may encourage the conservation of crops and water holes.

We concluded that monitoring based on the cooperation of hunters, managers of protected natural areas and specialists in wildlife management is a valid source of information for the study of hunting mammals and birds (Peiró and Blanc, 1998; Rosell *et al*., 2004; Jiménez-García *et al*., 2006; Belda *et al*., 2008). Interviews and surveys carried out with hunting managers and rural inhabitants are an efficient source of information for obtaining data on natural resources, especially hunting species (White, 2005; Jiménez, 2007).

Table 3. Regressions between species hunting bags and land uses/landscape indices in the Marina Baja region (positive correlation in bold format and negative correlation in normal format)

Wildlife group	Dependent variable	Independent variable		b	a	F	p	R
Small game	Rabbit density	Land uses	**Irrigated fruit**	27.691	223.325	39.279	< 0.001	0.835
			Dry vineyard	1.518	179.184	10.408	0.005	0.904
			Old abandonment	–0.0966	156.196	6.056	0.026	0.933
		Landscape	**Landscape shape**	24.407	311.421	7.609	0.015	0.580
	Hare density	Land uses	**Dry vineyard**	0.134	3.429	7.890	0.012	0.763
	Red-legged partridge density	Land uses	**Irrigated fruit**	3.116	412.361	24.197	< 0.001	0.766
			Cereal crop	20.034	336.723	9.495	0.007	0.861
			Dense shrubland	–0.684	265.154	10.803	0.005	0.922
			Burned areas	–9.439	230.857	5.788	0.031	0.945
		Landscape	**Fractal dimension**	1.643	526.873	10.018	0.006	0.633
	Wood pigeon density	Land uses	**Dense pine forest**	1.974	137.682	35.863	< 0.001	0.824
			Oak wood	3.258	122.135	5.603	0.031	0.873
			Dense shrubland	–0.255	104.001	7.066	0.018	0.915
			Irrigated vineyard	–5.100	66.967	22.178	< 0.001	0.968
	Turtle dove density	Land uses	**Irrigated fruit**	0.738	64.032	54.318	< 0.001	0.873
			Wooded shrubland	2.568	46.654	9.064	0.009	0.943
			Dense shrubland	–0.118	57.215	5.292	0.035	0.906
		Landscape	**Edge density**	7.666	113.746	7.227	0.017	0.670
			Contagion	4.950	100.012	5.403	0.036	0.716
	Woodcock density	Land uses	**Oak wood**	0.225	8.560	10.348	0.005	0.615
			Greenhouse	0.361	6.460	13.851	0.002	0.817
			Wooded shrubland	0.068	5.780	4.987	0.041	0.866
			Dense pine forest	–0.034	5.189	4.610	0.050	0.901
			Wetland	–1.051	4.434	6.172	0.027	0.934
			Urban areas	–0.0149	3.629	7.402	0.019	0.960
		Landscape	Division	–1670.000	9.801	5.123	0.039	0.605
	Thrush density	Land uses	**Fruit grove**	11.618	2006.078	19.760	< 0.001	0.733
			Urban areas	–31.280	1484.052	15.063	< 0.001	0.873
			Wooded shrubland	11.254	925.641	26.128	< 0.001	0.956
			Young abandonment	31.635	790.418	6.571	0.023	0.970
		Landscape	**Mean patch area**	7349.316	2104.510	18.072	0.001	0.739
			Fractal dimension	–418712.162	690.422	125.368	< 0.001	0.977
Big game	Aoudad density	Land uses	**Dense pine forest**	0.007	1.408	13.593	0.002	0.667
			Wooded shrubland	–0.010	1.194	7.651	0.014	0.790
			Old abandonment	0.010	0.913	12.324	0.003	0.891
			Irrigated fruit	–0.005	0.771	7.030	0.019	0.929
			Clear shrubland	0.002	0.657	6.298	0.026	0.953
		Landscape	**Total area**	0.001	1.277	21.957	< 0.001	0.771
			Patch richness	–0.398	1.056	7.914	0.014	0.861
			Contagion	–0.018	0.894	6.549	0.024	0.910
	Wild boar density	Land uses	**Dense pine forest**	0.080	10.395	18.449	< 0.001	0.721
			Oak wood	0.211	8.899	7.195	0.016	0.818
		Landscape	**Total core areas**	0.007	7.760	47.118	< 0.001	0.871
			Nº disjunct core areas	0.001	4.922	23.279	< 0.001	0.954

Table 3 (cont.). Regressions between species hunting bags and land uses/landscape indices in the Marina Baja region (positive correlation in bold format and negative correlation in normal format)

Wildlife group	Dependent variable	Independent variable		b	a	F	p	R
Population control	Starling density	Land uses	**Irrigated fruit**	0.904	87.420	25.559	< 0.001	0.775
			Greenhouse	–2.326	76.911	5.963	0.027	0.842
		Landscape	**Landscape shape**	10.299	112.850	10.317	0.006	0.638
	Fox density	Land uses	**Wooded shrubland**	0.056	11.667	11.417	0.004	0.634
			Oak wood	0.259	10.480	5.066	0.039	0.739
			Irrigated vineyard	0.340	8.894	7.219	0.017	0.833
		Landscape	**Mean patch area**	49.572	13.180	6.758	0.020	0.557
			Aggregation	–2.260	8.915	18.787	0.001	0.840
	Collared dove density	Land uses	**Irrigated fruit**	0.798	93.670	36.387	< 0.001	0.826
			Dry vineyard	8.787	83.545	5.370	0.034	0.873
			Riparian	–1.588	73.667	5.578	0.032	0.909
		Landscape	**Edge density**	7.158	137.958	9.355	0.008	0.620
			Perimeter- fractal dimension	470.762	120.680	5.603	0.033	0.748
	Magpie density	Land uses	**Fruit grove**	1.494	10.774	46.837	< 0.001	0.857
			Dry vineyard	0.733	8.898	8.925	0.009	0.911
			Burned areas	–0.073	7.992	4.831	0.044	0.933
			Old abandonment	0.054	5.753	14.951	0.002	0.968
			Dense shrubland	0.014	4.341	11.593	0.005	0.983
			Dense pine forest	–0.039	3.235	11.407	0.005	0.991
			Cereal crop	0.269	2.762	5.460	0.039	0.994
		Landscape	**Landscape shape**	1.475	17.420	8.884	0.009	0.610

Techniques used to model species distribution, implemented in GIS tools, provide wide dissemination of geospatial information (Ferrier, 2002; Benito de Pando and Peñas de Giles, 2007) and allow modelling of their habitats (Park and Lee, 2003).

There are many statistical studies that use hunting bags to reflect the status of some game species and try to solve the problems which they cause (Galhano-Alves, 2004). Thus, population size and density estimates are commonly used as basic indicators in wildlife management and conservation (Morley and Van Aarde, 2007). Other studies, based on this information source, have analyzed the relationship between hunting communities and landscape structure (Jiménez-García *et al*., 2006; Wallgren *et al*., 2009). There are specific studies on landscape-habitat relationships or GIS-habitat selection for wild boar (Calenge *et al*., 2004; Monzón and Bento, 2004; Kaden *et al*., 2005; Hebeisen *et al*., 2008; Tsachalidis and Hadjisterkotis, 2008), the red-legged partridge (Peiró and Blanc, 1998; Nadal, 2001; Vargas *et al*., 2006), duck species (Duncan *et al*., 1999; Guillemain *et al*., 2008; Brochet *et al*., 2009), mouflon (Garel *et al*., 2005), wild rabbits (Schropfer *et al*., 2000; Virgós *et al*., 2007) and some predators (Rico and Torrente, 2000). They enable this information to be incorporated into a GIS and potential areas and appropriate management measures selected (Coulson *et al*., 2001). This information allows crop damage to be reduced, especially that caused by wild boar (Schley *et al*., 2008). They have also served to demonstrate the impact of birds of prey (Park *et al*., 2008) and mammalian predators (Schropfer *et al*., 2000; Kawata *et al*., 2008) on the game species, allowing establishment of the predator-prey relationship.

There are also studies based on questionnaires given to hunting managers, showing the actual conditions that hunting species have. Moreover, they provide appropriate management measures, which may make game an important resource for the economy of certain areas, based on ecotourism (Willebrand, 2009). These types of studies define preferred areas for hunting, based on the land use type (Kaltenborn and Andersen, 2009). Furthermore, the use of long-term series determines distribution areas, temporal

Table 4. Land use/landscape regression models on game community descriptors of three wildlife groups in the Marina Baja region (positive correlation in bold format and negative correlation in normal format)

Community descriptors		Independent variable	b	a	F	p	R
Richness (S)	Land uses	**Fruit grove**	15.412	2021.742	20.145	0.001	0.714
	Landscape	**Landscape shape**	10.368	183.817	4.587	0.034	0.612
		Interspersion /juxtaposition	0.152	0.963	12.206	0.002	0.567
Total density (TD)	Land uses	**Fruit grove**	11.748	2011.069	21.583	0.001	0.783
		Wooded shrubland	12.322	921.244	29.657	0.002	0.911
		Urban areas	–24.747	1457.009	14.503	< 0.001	0.844
Dominance index (DI)	Land uses	**Dry vineyard**	1.724	162.421	9.403	0.004	0.856
		Wooded shrubland	10.258	879.653	24.129	0.002	0.924
		Irrigated fruit	0.985	92.047	33.352	0.001	0.901
	Landscape	**Edge density**	8.203	129.654	8.267	0.041	0.705
Shannon Diversity (H)	Land uses	Dense pine forest	–0.236	2.004	12.356	0.003	0.692
		Fruit grove	2.452	9.767	40.324	0.011	0.872
		Cereal crop	18.071	320.346	7.462	0.024	0.827
Small game density	Land uses	**Irrigated fruit**	0.914	83.447	24.689	0.002	0.754
		Dry vineyard	0.167	2.917	6.930	0.021	0.839
	Landscape	**Shannon's diversity**	6.287	104.634	5.278	0.029	0.708
Big game density	Land uses	**Oak wood**	0.368	7.467	4.001	0.018	0.812
		Dense pine forest	0.230	9.334	16.927	0.001	0.849
	Landscape	**Total area**	0.087	1.236	20.904	0.011	0.921
Population control density	Land uses	**Irrigated fruit**	0.904	87.420	25.559	< 0.001	0.775
		Fruit grove	1.494	10.774	46.837	< 0.001	0.857
		Irrigated vineyard	0.340	8.894	7.219	0.017	0.833

evolution of some species and development of demographic models (Rico and Torrente, 2000; Tsachalidis and Hadjisterkotis, 2008).

Indirect methods based on written sources (interviews, hunting bags, etc.) present a series of problems: loss of documents, scattered files, incomplete series, different catch rates, etc. that may affect the final results, particularly in calculation of diversity indices. Thus, this information should be subjected to rigorous criticism of sources (Rico and Torrente, 2000), but they are quite valid (Arques *et al*., 2009) and at least represent reliable population trends (Virgós *et al*., 2007).

Although in our study have not been used, there are other studies that use variables derived from climate, topography or human pressure can be used as predictors in these models (Seoane *et al*., 2003; Williams *et al*., 2007). Indeed, a hierarchical scheme of environmental controls on species distributions has been suggested (but not demonstrated), in which climatic variables are large-scale determinants, followed by geology, land cover and topography, which moderate many of the effects of macroclimatic variables (Thuiller *et al*., 2004).

The Marina Baja region is largely occupied by the natural matrix (55.68%), crops (21.29%), abandonment (15.08%) and urban uses (7.94%). In this sense, crops are an excellent source of food. On the other hand, natural areas provide refuge and the abandonment matrix and urban areas play an important role as disturbance. In general, oak woods (*Quercus ilex* L.) and scrubland well interspersed with cereal crops (*Triticum aestivum* L.), and olive (*Olea europaea* L.) and almond groves (*Prunus dulcis* [Mill.] D.A. Webb), are the most important habitats for "Small game" in Spain (Gortázar *et al*., 2002). In our case, the positive relation between the richness of "Small game" species with irrigated crops and dry vineyards responds to low availability of natural and agricultural areas in an urban and transformed environment near the coast line with a high Shannon landscape diversity index (H' = 1.86) compared to hunting areas of interior (H' = 1.73). In fact, a mixture of landscape elements provides a wide range of spatial resources (breeding, nesting, resting, etc.).

Rabbit density in our study region is positively influenced by irrigated fruit and dry vineyards, which is in accordance with Jiménez *et al*. (2006). Rabbits avoid old abandonment with wooded shrubland, in contrast to other areas (Delibes-Mateos *et al*., 2008). Thus, crops provide the main food for rabbits while natural vegetation and field margins provide shelter and breeding sites. In other places, irrigated crops have never been suitable for rabbits (Calvete *et al*., 2004). However, regression models did not consider parameters such as cereal crops and dry fruit groves as feeding areas, which seem to be preferred by the rabbit in semiarid landscapes (Arques, 2000). Moreover, we did not consider the scrub structure of natural-vegetation as shelter and reproduction areas. A potential rabbit habitat is characterized by irregular and disaggregated areas according to the landscape shape index (LSI), which combine patches of fruit grove and dry vineyard in the natural matrix.

Hare density is positively influenced by the surface of dry vineyard areas, according to other authors (*e.g.* Duarte and Vargas, 1998). This relationship is due to availability of feeding areas. On the other hand, old abandonment areas are very homogeneous, presenting many colonizer species, used by the hare as food (Smith *et al*., 2005). Also, the evolving shrub layer provides refuge and resting areas. Thus, this species prefers a mosaic of low-density vegetation that presents a combination of open land and growing shrubs typically found in old abandoned fields (Jiménez *et al*., 2006).

The red-legged partridge is positively influenced by the surface of grove areas, according to other authors (Fortuna, 2002). This response shows a relative preference for cereal crops and irrigated fruits. This type of land use provides food. However, regression models did not consider categories such as shrublands, which seem to be preferred by the red-legged partridge as they provide cover and food (Peiró, 2003). Moreover, this species is positively related with the fractal dimension index, indicating that the partridge needs complex areas composed by irregular edges with a low level of human influence. In fact, fractal dimension is a measure, which reflects shape complexity across a range of spatial scales (patch sizes). Thus, the red-legged partridge prefers high richness and complex structure areas such as evolving shrubland and traditional groves (Jiménez *et al*., 2006).

Wood pigeon density is positively influenced by the forest areas, such as dense pine and oak wood forests, as in other places (Fernández, 2001). Thus, it needs large patches of Mediterranean forest areas and traditional agricultural fields. However, the wood pigeon avoids dense shrubland and irrigated vineyards in the study area, due to a lack of adequate shelter resources.

Turtle dove density is positively influenced by landscape edge density and the contagion index. This landscape parameter refers to a heterogeneous landscape and transitional areas with a huge suitability of resources. As in other places, this species needs patches with high connectivity (Jiménez *et al*., 2006). In fact, turtledoves prefer wooded shrubland matrix with irrigated fruit. However, they avoid dense shrubland due to a lack of adequate food resources.

Woodcock density is positively influenced by the holm oak forest, greenhouses and wooded shrubland. The biological response of this species is related to the availability of wooded zones combined with pasturelands, which are present in the category of recently abandoned areas, supporting a significant proportion of this duality (fruit trees with an herbaceous layer). The models discriminated other land uses that could be important habitat elements, for example, riparian, forest and irrigated areas (Hidalgo and Rocha, 2000). According to the landscape structure, this species prefers an unfragmented landscape with a small division index.

Thrushes are the most hunted species and their density is positively influenced by the fruit grove, wooded shrubland and recently abandoned fields, which provide food and shelter. This habitat selection is similar to another study, where thrushes exploit fruit, shrubland and dry groves (Jordano, 1993). On the other hand, thrushes are positively related with mean patch area and negatively with the fractal dimension index, indicating that the thrush needs homogeneous areas composed by regular edges with interaction between dry groves and natural areas.

The "Big game" group is correlated positively to high homogeneous forest areas, especially in the north of the region. Thus, hunting fences for big game management can generate a negative impact for several groups of terrestrial vertebrates (ungulates and endangered carnivores) similar to other linear infrastructures such as roads, railways and canals. This group is subject to less hunting pressure, due to reduced individual abundances in these species populations, because environmental resources are limited.

The area of dense pine forest and oak wood, which provides cover and refuge, influences the wild boar density positively. Natural areas have increased over the last decades (old abandonment) and this fact is contributing to the increase of populations in the region. However, regression models did not consider land uses such as cereal crops and dry groves as feeding areas, which seem to be preferred by wild boar in Mediterranean landscapes (Calenge *et al*., 2004). On the other hand, this species is positively influenced by the total core areas and number of disjunct core areas. Thus, the core area has proven to be a better predictor of habitat quality than patch areas for forest specialists (Temple, 1986).

Aoudad density is positively related to dense pine forest, clear shrubland and old abandoned fields. These locations correspond to the high mountain areas located within the study region. This species prefers large homogeneous areas (total areas). In Spain, the aoudad prefers forest, bare rock, shrublands, and natural grasslands. When there are human disturbances, it appeared that the aoudad was associated with less mountainous areas, with higher temperatures, and forest and dryland crop areas (Casinello *et al*., 2006).

The control population group is positively related to the presence of some crops, especially fruit grove, irrigated fruit and vineyards. This indicates the necessity of these species to exploit certain trophic resources. The management of such species is made especially to reduce the damage to these crops and to other wildlife species.

Starling density is positively influenced by irrigated fruit, but it avoids greenhouses in the agricultural matrix. A potential starling habitat is characterized by irregular and disaggregated areas (LSI), which combine patches of fruit grove in the agricultural matrix. However, in other places, starlings have higher population densities and breeding success in grass-covered fields than in cultivated fields (Olsson *et al*., 2002).

Fox density is positively related to wooded shrubland, oak wood and irrigated vineyards, which provide food and shelter. Shrublands increased in the last decades favouring red fox distribution and causing conflicts with hunters because both foxes and hunters compete to obtain the same prey species. As regards the landscape metrics, the red fox prefers large homogeneous areas (mean patch areas), but it needs a balanced distribution of landscape classes in order to obtain all natural resources (aggregation index). The red fox is an opportunistic species that can explore larger areas including woods and open field areas (Carvalho and Gomes, 2001).

Magpie density is positively influenced by the surface of dry cultivated lands (dry vineyard, cereal crop and fruit grove), old abandoned fields and dense shrubland. A potential magpie habitat is characterized by irregular and disaggregated areas (LSI), which combine agricultural and natural patches, avoiding burned areas and dense pine forest. In other places, it is very abundant especially in the lowlands. It is typically seen in fields, orchards, grasslands, or urban and rural villages (Eo *et al*., 2002).

The collared dove inhabits urban areas with gardens with trees or with forest patches, near urban settlement areas (which are preferred as nesting areas). A typical mosaic landscape in the Marina Baja includes agricultural lands (irrigated fruit and dry vineyards) near forest and urban patches. This mixture provides food, nesting and shelter areas. The increase of urbanization within dense afforested pine is favouring the collared dove density. Thus, this species is positively influenced by the edge density and fractal dimension, showing an affinity for landscape complexity.

In general, the game community presents a positive relation with landscape structure (core areas, patch richness, fractal dimension, perimeter-area ratio, etc.) and traditional agriculture (dry grove, irrigated areas and dry vineyard). Thus, crops play an important role in the hunting community, shown by descriptors. Game species richness is correlated with the juxtaposition and interspersion index of landscape, it refers to the fact that the game community depends on refuge and breeding areas. The landscape structure in the Marina Baja Region is suffering severe changes and the game species are adapting to landscape transformation. However, these human-made and human-maintained landscapes are richer in game biodiversity. In consequence, traditional working landscapes form an essential part of the ecological balance in this area. For this reason, it is very important to conserve these traditional landscapes with adequate management strategies in order to prevent biodiversity loss (Carter, 2001; Jiménez-García *et al*., 2006).

Our results provide a territorial ordination of hunting yields in southern Spain and have several potential applications in strategic planning for hunting activities and biodiversity conservation. Thus, the investigation of the effects of hunting, long-term monitoring and regional-scale analyses of the availability of habitat should be future research priorities.

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Appendix

Annex 1. Landscape indices used in the landscape analysis as independent variables (obtained and modified from FRAGSTATS)

Type of metrics	Indices	Description	Main formulae
Area Density Edge	Number of Patches (NP) Patch Density (PD) Total Edge (TE) Edge Density (ED) Landscape Shape Index (LSI)	These deal with the number and size of patches and the amount of edge created by these patches.	$PD = \frac{N}{A}(10{,}000) \quad (100)$, where: N = total number of patches in the landscape A = total landscape area (m^2).
Shape	Perimeter-Area Ratio (PARA) Perimeter-Area Fractal Dimension (PAFRAC) Perimeter-Area Ratio Distribution (PARA_MN) Shape Index Distribution (SHAPE_MN) Fractal Index Distribution (FRAC_MN)	The interaction of patch shape and size influence a number of ecological processes (eg. foraging strategies). The primary significance of shape in determining the nature of patches in a landscape is related to the 'edge effect'	$PAFRAC = \frac{2}{\frac{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\ln p_{ij} + \ln a_{ij}\right)\right] - \left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]}{\left(N\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^{2}\right) - \left(\sum_{i=q}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)^{2}}}$ a_{ij} = area (m^2) of patch ij. p_{ij} = perimeter (m) of patch ij. N = total number of patches in the landscape
Core areas	Total Core Area (TCA) Number of Disjunct Core Areas (NDCA) Disjunct Core Area Density (DCAD) Core Area Distribution (CORE_MN) Disjunct Core Area Distribution (DCORE_MN) Core Area Index Distribution (CAI_MN)	Area within a patch beyond some specified depth-of-edge influence (*i.e.,* edge distance) or buffer width. It is a better predictor of habitat quality than patch area. The primary significance of core area in determining the character and function of patches in a landscape is related to the 'edge effect.'	$TCA = \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}^{c}\left(\frac{1}{10{,}000}\right)$ a_{ij}^{c} = core area (m^2) of patch ij based on specified edge depths (m).

Annex 1 (cont.). Landscape indices used in the landscape analysis as independent variables (obtained and modified from FRAGSTATS)

Type of metrics	Indices	Description	Main formulas
Contagion and interspersion	Contagion (CONTAG) Aggregation Index (AI) Interspersion & Juxtaposition Index (IJI) Landscape Division Index (DIVISION)	Contagion is the tendency of patch types to aggregate. Interspersion refers to the intermixing of patches of different types and is based solely on patch (as opposed to cell) adjacencies. Both reflect the adjacency of patch types. Contagion reflects both the dispersion (*i.e.,* the spatial distribution) and intermixing of patch types, whereas interspersion reflects only the latter.	$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(p_i\right)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right) * \left[\ln\left(p_i\right)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)} \right]\left(100\right)$ P_i = proportion of the landscape occupied by patch type (class) i. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method. m = number of patch types (classes) present in the landscape, including the landscape border if present.
Diversity	Patch Richness (PR) Patch Richness Density (PRD) Shannon's Diversity Index (SHDI) Shannon's Evenness Index (SHEI)	These diversity measures are influenced by richness and evenness. Richness refers to the number of patch types present, evenness refers to the distribution of area among different types.	$SHEI = \frac{-\sum_{i=1}^{m}\left(p_i * \ln p_i\right)}{\ln m}$ P_i = proportion of the landscape occupied by patch type (class) i. m = number of patch types (classes) present in the landscape, excluding the landscape border if present.