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Decline of roller dung beetle (Scarabaeinae) populations in the Iberian peninsula during the 20th century

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Abstract

A historical compilation of data on roller dung beetle occurrence in the Iberian peninsula was examined for temporal changes between the first and second half of the 20th century. Analysis of changes in the relative frequency of database records, individuals and 10-km UTM cells where the beetles occurred showed a decline in the occurrence of nine of the eleven species. A comparison of latitudinal and longitudinal mid-points of the 10-km UTM cells where each species occurs indicated that the range of most roller dung beetles in the Iberian peninsula has also contracted. Before 1950 a significant, positive and curvilinear relationship was found between the number of roller dung beetles and the area of coastal environments (sea, dunes, beaches and marshes); while in the second half of the 20th century the number of "roller" species is positively correlated with artificial pastureland and scrub areas. It is suggested that urban development of the coastal zones for tourism since 1950 has probably contributed greatly to the disappearance of many roller populations. It is recommended that some of the more affected species of roller dung beetles should be considered for inclusion among protected invertebrates.

Keywords: Roller dung beetles; Iberian peninsula; Species declining

1. Introduction

Monitoring of any recent decline in population size or geographical range of some species is vital to understanding the mechanisms that promote extinction and the effects of anthropogenic changes (Lubchenco et al., 1991; Daily and Ehrlich, 1995). Early recognition of the threat to populations prior to irreversible reduction is particularly important for implementing effective conservation strategies (Hobbs and Mooney, 1998; Patton et al., 1998). However, long-term comparisons are required to detect population declines. Unfortunately, comparisons between past and present population sizes and range sizes over long periods of time are few, problematic and plagued by several methodological difficulties (Gaston, 1994; Samways, 1994; Patton et al., 1998).

Several studies have used historical data to identify species in decline, but most deal with plant or vertebrate species (see Kattan et al., 1994; Drayton and Primack, 1996; Hobbs and Mooney, 1998; Patton et al., 1998 and references therein). Information about insects is scarce and efforts have been directed mainly toward the butterflies and carabid beetles of North America and north and central Europe (see, for example, Pyle et al., 1981; Thomas et al., 1986; Turin and den Boer, 1988; Desender and Turin, 1989; van Swaay, 1990 and references therein). Reasonable evidence of the population and geographical decline of insect species is elusive because of our ignorance of insect life histories and distributions (Moore, 1991; Mound and Gaston, 1993).

With several notable exceptions (Cambefort, 1991), roller dung beetle species belong mainly to the tribe Scarabaeini of the subfamily Scarabaeinae (sensu Scholtz, 1990) and possess a specialised and complex trophic and nesting behaviour (Halffter and Edmonds, 1982), feeding on herbivore dung and making and rolling dung balls. According to Hanski and Cambefort (1991) there are around 115 genera and 1122 species of roller dung beetles, but only three genera (*Sisyphus*, *Gymnopleurus* and *Scarabaeus*) and 18 species occur in Europe, mainly in the Mediterranean region (Baraud, 1992). Eleven species with relatively large body size (between 10 and 40 mm) inhabit the Iberian peninsula.

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While the state of decline of non-roller dung beetles in northern and central Europe has been studied (Johnson, 1962; Leclerc et al., 1980; Väisänen and Rassi, 1990; Biström et al., 1991; Miessen, 1997), references to population decline in "roller" species are scarce (Leclerc et al., 1980, Lumaret, 1990; Lumaret and Kirk, 1991) and there are no studies based on compared data. The principal aim of this paper is to test if the probability of finding a roller dung beetle has decreased during the last 50 years in the Iberian peninsula, where the Mediterranean landscape has been considerably altered. Using an extensive database that incorporates historical information on the distribution and occurrence of Iberian Scarabaeinae species (BANDASCA; Lobo and Martín-Piera, 1991), changes in the number of database records, collected individuals and 10-km UTM cells where roller beetles have been recorded in the first and second half of this century were analysed. Subsequently, the Iberian geographic range of these species during each half century is examined for possible patterns in decrease in range of roller species. Finally, possible relationships between land use and numbers of species of roller dung beetles are sought in 50-km Iberian UTM cells, to obtain information on factors, including anthropogenic processes, which may be linked with decline in distribution and abundance.

2. Methods

The Iberian dung beetle database (BANDASCA) contains 13,285 records with date information of 93,911 individuals of the 55 Iberian dung beetle species (Veiga and Martín-Piera, 1988), of which 1273 records and 5874 individuals belong to the 11 Iberian roller species. Every record contains all available information structured in 22 fields, the most important of which are: number of individuals, sex, collector's name, locality (UTM coordinates), altitude, date of capture (day/month/year), type of habitat, and food resource. A database record is defined as a pool of specimens of a single species sharing identical information for all database fields previously mentioned. Therefore, any difference in the data conveyed by one or more database fields was taken as a new record for the same or different species regardless of the number of specimens representing that species.

Industrial and tourism development increased markedly in Spain around 1950 (Bosque Maurel and Vilà Valentí, 1990), and this date was, therefore, used as a cut-off in this study, as in other studies (Leclerc et al., 1980; Biström et al., 1991; Miessen, 1997). A comparison has been made only between the first and second half of this century because there is not enough data for each species to estimate trends in occurrence per decade (Turin and den Boer, 1988; McCarthy, 1997). The data are, therefore, divided into two groups, i.e. U50 for collections up to and during 1950 and L50 for later collections.

A classical two-way contingency table was used in order to compare the absolute frequency of database records, individuals and 10-km UTM cells of each roller species for both half-century periods. To test the independence of the two variables (roller versus non-roller and U50 versus L50) a Pearson Chi-square test, with Yates' correction for continuity was used (Sokal and Rohlf, 1981). An equal proportion of records, individuals and 10-km UTM cells with and without roller dung beetle species is expected between the two half-century periods. A significant difference indicates that species' abundance and presence in records or in UTM cells varies between periods.

The central location of each species' range in the first and second half of the century in Iberia was compared using the latitudinal and longitudinal mid points of occupied 10-km UTM cells and the non-parametric Sign test for dependent samples (Siegel and Castellan, 1988). The number of cells occupied as well as the latitudinal and longitudinal extent (the latitudinal or longitudinal distance between the two most distantly separated occupied cells) are simple methods of quantifying the geographic range size of species that do not take into account the degree of fragmentation of a species' range and the influence of outliers (Gaston, 1990; Quinn et al., 1996). The difference between the two periods in latitudinal and longitudinal scatter for each species was compared using the variance in latitude and longitude of the occupied 10-km cells and the Levene test for homogeneity of variances (Sokal and Rohlf, 1981).

For both half-century periods the relationship between the number of database records and the number of roller dung beetle species in the 255 Iberian 50-km UTM grid cells with $>15\%$ land area was analysed. According to Soberón and Llorente (1993) and Colwell and Coddington (1995) the negative exponential function relating the number of species (S_r) to the number of records (r) is given by:

$$S_r = S_{\max}[1 - \exp(-br)]$$

where $S_{\max}$, the asymptote, is the estimated total number of species per 50-km UTM cell, and b is a fitted constant that controls the shape of the curve. The curvilinear model was fitted by the quasi-Newton method. To reach 100% richness would require an infinite number of records, so the number of records (r) that would be required for a rate of species increment $\leqslant 0.01$ was calculated (i.e. one added species for every additional 100 records; $r_{0.01}$). According to Soberón and Llorente (1993):

$$r_{0.01} = 1/b\ln(1 + b/0.01)$$

The 67 50-km UTM grid cells (17 in the 1900–1950 period and 55 in the second half of this century) with a number of records equal to or greater than $r_{0.01}$ were considered to be well surveyed. The number of roller dung beetle species in these well-surveyed cells in both periods was compared using the non-parametric Mann-Whitney U test (Siegel and Castellan, 1988).

For all 50-km UTM grid cells 12 land-cover variables were provided by the European Environment Agency raster information (282 m resolution) for Spain and Portugal (CORINE Programme 1985–1990), namely areas of sea, urban and industrial land, cultivation, artificial pastureland, natural pastureland, forest, scrub, scattered natural vegetation, forest-scrub transition, dunes and beaches, marsh and land use diversity. The area of land covering variables in each 50-km UTM cell was calculated by overlaying polygons of the UTM cells on the digital map of land covering categories using a geographic information system (GIS: Idrisi 2.0, 1998). Grid cell land use diversity was estimated using the Shannon diversity index (Magurran, 1988; $H' = -\Sigma p_i \log_2 p_i$), where p_i is the relative frequency of the land cover categories.

The number of roller dung beetle species in the well-surveyed cells (the dependent variable) and land cover categories (the independent variables) were analysed using multiple linear regression. The 13 independent variables were stepwise forward selected with the predictor variables being added sequentially, according to their statistical significance (Sokal and Rohlf, 1981). As a multiple regression stepwise procedure does not necessarily yield the optimal set of variables (of two highly correlated variables only one is likely to be included in the set; Legendre and Legendre, 1983), the nonparametric Spearman rank correlation coefficient (r_s) between the number of species and each of the land cover categories was also calculated. Finally, the relation between the number of species and the statistically significantly correlated variables was explored.

3. Results

The relative frequency of records, individuals and 10-km UTM cells containing roller dung beetles depends on the date period (Table 1). Twenty-eight percent of all records prior to 1950 referred to rollers, while only 7% of the records from the second half of this century did so. The decrease in the number of collected individuals is similar (from 24 to 6%) while the number of 10-km cells where rollers were present declined from 48 to 29%.

Ten of the 11 roller species show a significant fall in the relative frequency of records and relative number of individuals in the second half of the century (Table 1). Only *Scarabaeus typhon* had a non-significant increase in % records, and only *S. cicatricosus* has a significant increase in % of individuals. Again, all except these two species show a significant reduction in % occupancy of surveyed 10-km cells.

In examining species distributions, only *S. semipunctatus* shows a significant change in its latitudinal centre between the first and second half of this century (Table 2) due to a northward retreat from the Mediterranean coast (Fig. 1). And only in *Gymnopleurus flagellatus* does the variance in latitude differ significantly, suggesting a contraction in the northern limit of its Iberian distribution (Fig. 1). The 10-km cell longitude differs significantly for *Scarabaeus laticollis, S. sacer*, *S. semipunctatus*, *G. flagellatus* and *G. sturmi* (Table 2) due

Table 1
1900–1950 and 1951–1999 database records, number of individuals and number of 10-km UTM cells in the Iberian peninsula for 11 Iberian roller dung beetle species. Information provided by an extensive database on Iberian Scarabaeinae (BANDASCA; Lobo and Martín-Piera, 1991)[a,b]

	Records			Number of individuals			10-km UTM cells		
	Before 1950	After 1950		Before 1950	After 1950		Before 1950	After 1950	
Scarabaeus cicatricosus (Lucas, 1849)	22(1.22)	56(0.49)	*	34(1.09)	3227(3.55)	*	11(3.13)	16(1.53)	
S. laticollis L., 1767	81(4.51)	141(1.23)	*	108(3.48)	251(0.28)	*	49(13.96)	77(7.35)	*
S. pius (Illiger, 1893)	6(0.33)	6(0.05)	*	9(0.29)	7(0.01)	*	5(1.42)	1(0.10)	*
S. puncticollis (Latreille, 1819)	29(1.61)	14(0.12)	*	37(1.19)	35(0.04)	*	17(4.84)	10(0.95)	*
S. sacer L., 1758	57(3.17)	121(1.05)	*	71(2.29)	258(0.28)	*	42(11.40)	67(6.39)	*
S. semipunctatus Fabricius, 1792	52(2.89)	49(0.43)	*	91(2.93)	121(0.13)	*	23(6.55)	27(2.58)	*
S. typhon Fischer-Waldheim, 1823	2(0.11)	30(0.26)		2(0.06)	34(0.04)		2(0.57)	21(2.00)	
Sisyphus schaefferi (L., 1758)	53(2.95)	99(0.86)	*	62(2.00)	607(0.67)	*	37(10.54)	62(5.92)	*
Gymnopleurus flagellatus (Fabricius, 1787)	104(5.79)	182(1.58)	*	189(6.08)	489(0.54)	*	67(19.09)	97(9.26)	*
G. sturmi MacLeay, 1821	70(3.90)	46(0.40)	*	102(3.28)	78(0.08)	*	45(12.82)	30(2.86)	*
G. mopsus (Pallas, 1781)	30(1.67)	23(0.20)	*	32(1.03)	30(0.03)	*	21(5.98)	18(1.72)	*
Total with roller dung beetle data	506(28.16)	767(6.68)	*	737(23.72)	5137(5.66)	*	168(47.86)	301(28.72)	*
Total in the database	1797	11488		3107	90804		351	1048	

[a] Percentages of database totals in parentheses.
[b] Significant difference ($P < 0.05$) between the pre and post 1950 data, using the Pearson Chi-square test, with Yates' correction for continuity (Sokal and Rohlf, 1981)

Table 2
Results of the Sign test for dependent samples (Siegel and Castellan, 1988) to compare the Iberian central location of each species' latitude and longitude between the first and second half of this century, and results of the Levene test for homogeneity of variances (Sokal and Rohlf, 1981) to compare the species' variance in latitude and longitude for the two half-century periods

	Central latitude[a]	Latitude variance	Central longitude	Longitude variance
Scarabaeus cicatricosus	0.60, NS[c]	0.00, NS	0.02, NS	1.93, NS
S. laticollis	0.86, NS	0.53, NS	3.14**	20.20***
S. pius[b]	–	–	–	–
S. puncticollis	0.32, NS	3.25, NS	0.95, NS	7.65**
S. sacer	1.70, NS	1.09, NS	2.93**	36.89***
S. semipunctatus	3.21**	0.29, NS	3.35***	0.43, NS
S. typhon	0.71, NS	3.39, NS	0.71, NS	4.91*
Sisyphus schaefferi	0.66, NS	1.62, NS	0.02, NS	28.38***
Gymnopleurus flagellatus	1.49, NS	5.14*	20.90***	48.42***
G. sturmi	1.48, NS	0.01, NS	5.29***	7.39**
G. mopsus	0.71, NS	2.27, NS	0.71, NS	71.76***

[a] The latitude and longitude are those of the 10-km UTM cells in which each of the species appear.
[b] *Scarabaeus pius* data are not considered because only one 10-km UTM cell has information for the second half of this century.
[c] NS, not significant; *$P<0.05$; ** $P<0.01$; *** $P<0.001$.

to the westward displacement of their central distributions during the second half of this century (Fig. 1a and b). Except for *S. cicatricosus* and *S. semipunctatus,* longitude variances differ between the two periods. The general pattern is an inward contraction in the Iberian peninsula distribution area, and a decrease in occurrence in Mediterranean and Atlantic boundary cells (Fig. 1a and b). The only exception is *S. typhon*, which has extended its distribution toward those same boundaries.

The number of roller dung beetle species in well-surveyed 50-km cells declined significantly between the two periods from 4.58±0.50 (mean±standard error) in 1900–1950 to 3.20±0.23 in 1951–1999. (Mann-Whitney U test, $Z = 2.47$; $P<0.05$; $n_1 = 17$; $n_2 = 55$).

In the data before 1950 a significant and positive relation was found between the number of roller dung beetles and the area of dunes and beaches in 50-km cells. Roller species richness in the first half of the century is also positively correlated with marsh area and sea area, but negatively correlated with forest-scrub transition area and land cover diversity (Table 3). The stepwise multiple regression shows that the sea area is the only significant explanatory variable ($F_{(1,15)=}16.51$; $R^2 \times 100 = 52.40\%$; $P<0.01$), probably because sea area summarises the extent of coastal environments in cells with land area $>15\%$. The variables positively correlated with the species number are not linearly related (Table 3 and Fig. 2), showing that the increase in the number of roller dung beetle species is lower with greater sea areas, and that species richness is maximum when there is an intermediate amount of dunes and beaches or marshes. On the other hand, forest-scrub transition area and land cover diversity are linearly related with species richness.

In contrast, in the second half of this century, the number of roller species is positively correlated with areas of artificial pastureland and scrubs, but negatively correlated with cultivated area (Table 3). Stepwise multiple regression indicates that the only significant explanatory variable is the cultivated area in 50-km cells ($F_{(1,53)=}12.07$; $R^2 \times 100 = 18.55\%$; $P<0.01$). The variables positively and negatively correlated are linearly or logarithmically related with numbers of species (Fig. 2).

4. Discussion

It seems evident that the probability of finding a dung roller species in the Iberian peninsula has decreased notably during the second half of this century and that a decline in the occurrence of some species has taken place. Only *S. cicatricosus* appears to have maintained its populations and distribution range. It is restricted to the Atlantic coastal and sandy regions of the south-west of the Iberian peninsula, being very numerous here (130 individuals per pitfall-trap, $n=24$; Lobo et al., 1997). *S. typhon* was, until 1940, a subspecies of *S. sacer* (Janssens, 1940), so that its distribution and abundance is difficult to specify in the period before 1950.

The decline of roller dung beetle populations has led to a significant decrease in the number of species that can be collected in a 50-km cell in Iberia during the second half of this century, whilst the geographic range of many roller species has contracted substantially over the course of the past century. Moreover, the decrease in roller beetle distribution range seems to follow a clearly defined geographical pattern: roller species becoming rarer or absent from coast localities and restricting their presence to the inner Iberian peninsula. Hence, the higher species richness during the 1900–1950 period occurs in those cells with both coastal and non-coastal landscapes.

Coastal zones have been subjected to severe human impact and are often favoured for urban development in

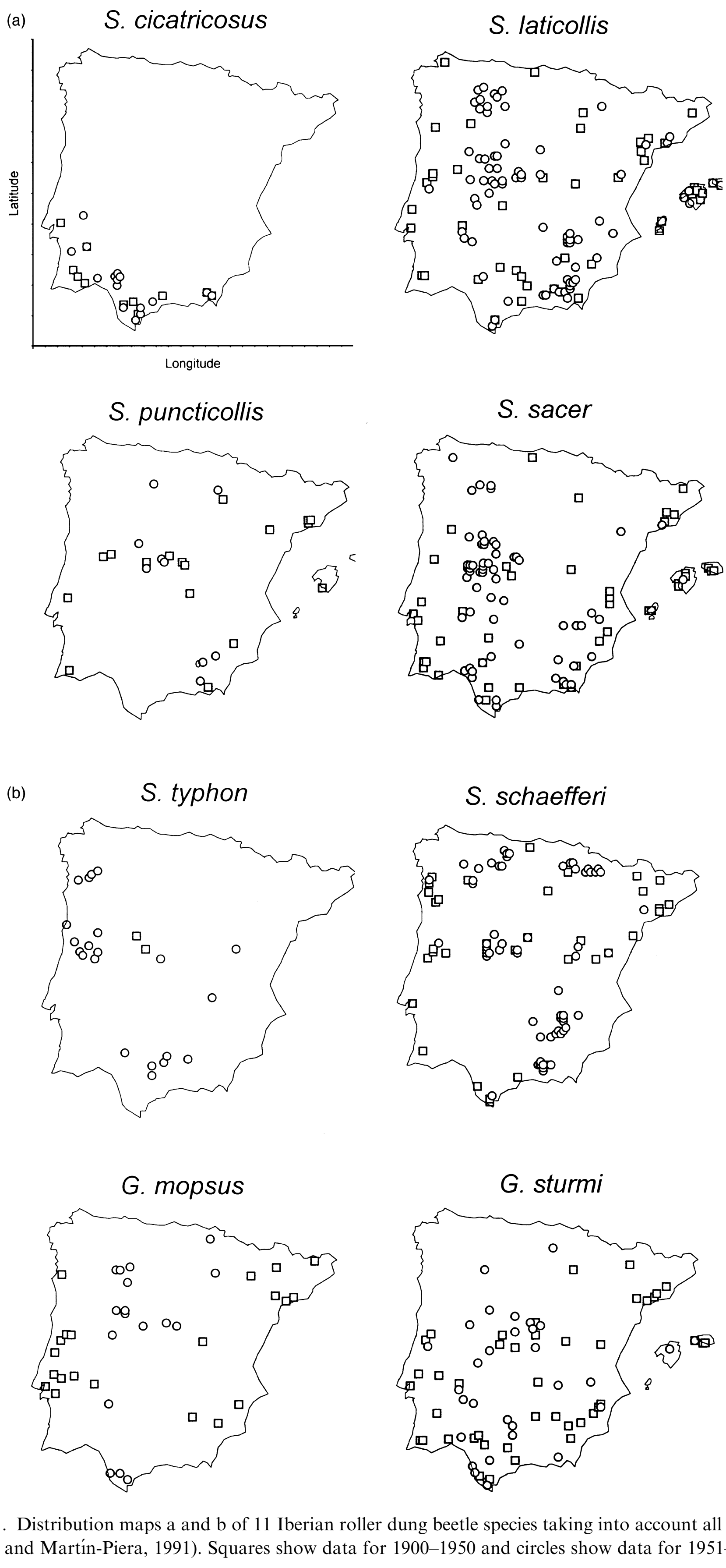

Fig. 1. Distribution maps a and b of 11 Iberian roller dung beetle species taking into account all the available information (BANDASCA database; Lobo and Martín-Piera, 1991). Squares show data for 1900–1950 and circles show data for 1951–1999.

Table 3
Land cover categories significantly correlated with the number of roller dung beetle species in the two half-century periods; type of relation between the number of species and each of the explanatory variables. Spearman rank correlation coefficient (r_s), and coefficient of determination ($R^2 \times 100$; percentage of explained variance) for these relationships[a]

	Before 1950			After 1950		
	r_s[b]	Relation type	R^2	r_s	Relation type	R^2
Dunes and beaches area	0.716***	Parabolic	42.49	–	–	
Marsh area	0.558*	Parabolic	36.83	–	–	
Sea area	0.556*	Logarithmic	77.79	–	–	
Forest-scrub transition area	−0.512*	Linear	24.56	–	–	
Land cover diversity	−0.544*	Linear	30.42	–	–	
Cultivated area	–	–	–	−0.452***	Linear	18.54
Artificial pastureland area	–	–	–	0.284*	Logarithmic	13.81
Scrub area	–	–	–	0.282*	Linear	6.01

[a] Land cover data in each 50-km UTM cell from the European Environment Agency raster information (CORINE Programme 1985–1990).
[b] * $P<0.05$; *** $P<0.001$.

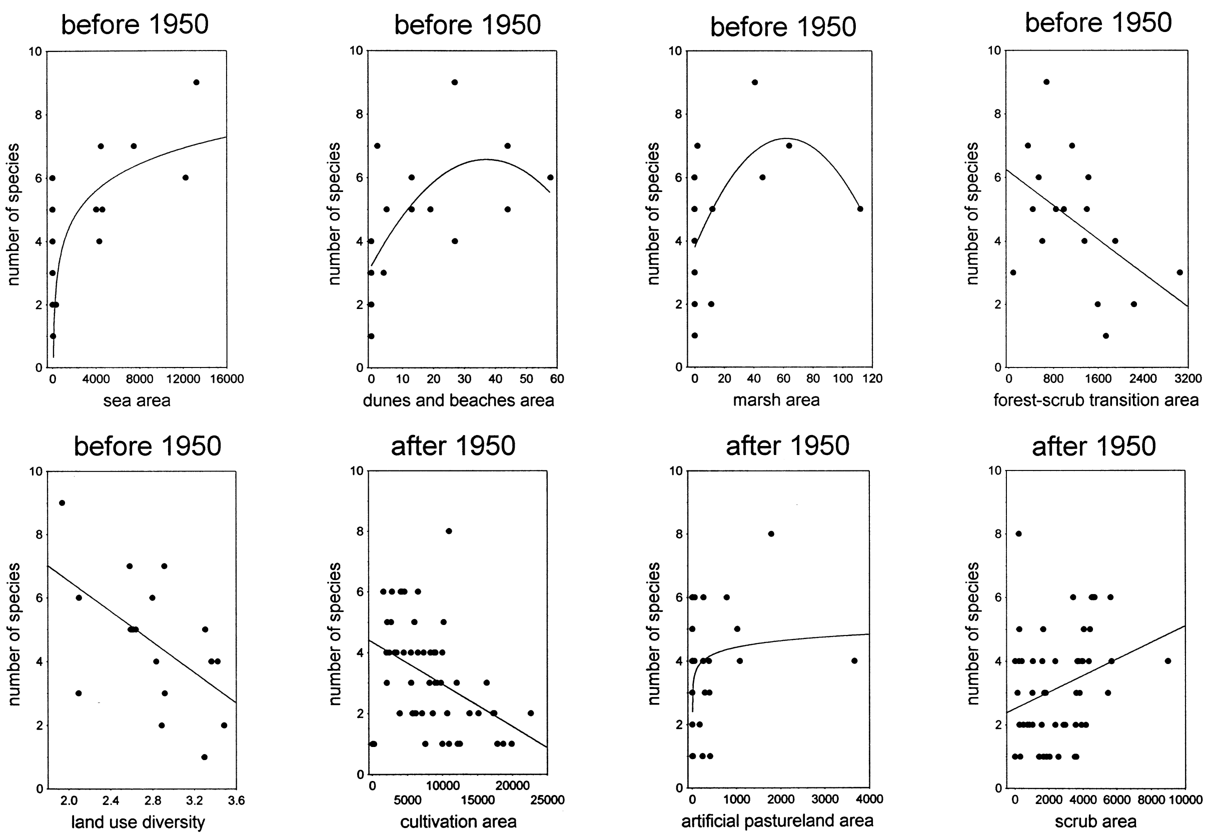

Fig. 2. Relationship between the number of Iberian roller dung beetle species and eight significantly correlated land cover variables for the two periods (see Table 3), with fitted lines: straight line ($y = a + bx$), logarithmic ($y = a + b\log x$), or parabolic ($y = a + bx + cx^2$).

locations that include biotopes for rare and localised species (Pyle et al., 1981; Balleto and Casale, 1991; Gray, 1991). Dunes and sandy coastal zones are one of the main habitats for some western Mediterranean roller dung beetles, and they are still one of the most characteristic faunistic elements there (Lumaret, 1978–1979; Lobo and Martín-Piera, 1993; Lobo et al., 1997). However, in the west Palaearctic region, pastureland and other open biomes are the habitats where most of Scarabaeinae dung beetles occur (Lumaret, 1983; Lumaret and Kirk, 1991). The disappearance of coastal roller species has led to a relative increase in the contribution of pastureland roller species to the total richness.

The profound alteration of the coastal zones in the Iberian Mediterranean area from 1950 for tourism has probably contributed most to the disappearance of many roller populations and the consequent decrease of species richness. The negative correlation between cultivated areas and species richness in the second half of this century also suggests that it is highly likely that any further increase in intensive agriculture could have a negative consequence for roller dung beetle populations.

The geographical distributions of European roller dung beetle species are limited to the Mediterranean basin (Baraud, 1992). The results of this study highlight the need for detailed scientific studies to obtain information to improve our biological knowledge of the decline of Mediterranean roller species and to favour their survival. It is especially important to monitor roller dung beetle populations, mainly in the coastal areas, in order to: (1) determine if the protected territories in these biotopes can assure the survival of these species in the Iberian peninsula; and (2) ascertain the utility of roller dung beetles as monitors of the quality of coastal ecosystems.

Compared with northern European countries, insect conservation is still a long-neglected issue in the Mediterranean countries (Balleto and Casale, 1991). The threatened insect lists of the Mediterranean countries are limited to a very few species. For example, there are 141 and 303 Coleoptera species in the Red Data list of Finland and Sweden, respectively (Mikkola, 1991); but only 47 in Spain (Rosas et al., 1992), a country that probably possesses >40,000 insect species (Martín-Piera, 1999). It is difficult and controversial to compile an all-European list of endangered species (Mikkola, 1991) and Spain needs to continue efforts to elaborate a much more rigorous, scientific and useful list of threatened insect species. In the specific case of Iberian roller species this study suggests that some of the more affected species of roller dung beetles (e.g. *S. pius* and *G. mopsus*) should be considered for inclusion among Spanish invertebrates listed as vulnerable (Rosas et al., 1992) (i.e. with a high risk of extinction in the wild in the medium-term future) according to the 1996 IUCN red list of threatened animals (see http://iucn.org/themes/ssc/96anrl/intro.htm).

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