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Inferring species decline from collection records: roller dung beetles in Italy (Coleoptera, Scarabaeidae)

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ABSTRACT

The decline of roller dung beetles (Coleoptera, Scarabaeidae) in Italy, at national and regional level, was described using a database of both literature and unpublished data, since the late of 19th century. The probability of finding roller species was assessed for each decade of the 20th century in order to detect changes in their distribution and status. An analysis of decline was performed using a complementary approach of different extinction indexes, according to IUCN criteria. During the 20th century, both the absolute number of records and the UTM cells where roller beetles were found increased clearly as a consequence of the escalation of entomological surveys. Nevertheless, comparing R species (rollers) with all the scarab dung beetles from the first to the last quarter of the 20th century, the relative frequency of roller records decreased by 31%, while the relative number of occupied UTM cells dropped by 23%. Six roller species showed a significant decline in Italy from the first to the second part of the 20th century, and nine in the last 30 years. Other two species disappeared from the majority of the northern regions. Finally, the values of all the extinction indexes were strongly correlated and detected a high risk of extinction in Italy for six species. A gradual change in land use during the last three decades, consisting of a reduced extension of grasslands in favour of either intensive agriculture or reforestation after abandonment of livestock raising, was likely the main factor inducing decline and local extinction of roller species.

Keywords

Conservation biogeography, decline, extinction index, Italy, land use change.

INTRODUCTION

Insect conservation is still a long-neglected issue in the Mediterranean countries, in comparison with northern Europe (Balletto & Casale, 1991; Mikkola, 1991; Gaston *et al.*, 1993; Kotze & O'Hara, 2003; Samways, 2005).

The threatened insect lists of the Mediterranean countries are limited to a very few species. For example, there are, respectively, 141 and 303 Coleoptera in the Red Data list of Finland and Sweden (Mikkola, 1991), but only 47 in Spain (Rosas *et al.*, 1992), a country that probably possesses nearly 10,200 beetle species (Martin-Piera, 1999; Galante & Verdú, 2000). The Italian Red List of Invertebrates quoted only 12 of 12,000 beetle species occurring in the country (Cerfolli *et al.*, 2002). More recently, the Checkmap Project (Ministry of Environment, Italy) brought to gather a massive information on over 10,000 terrestrial and aquatic animals in order to create a georeferenced database, with the aid of 68 specialists (Ruffo & Stoch, 2005). More than a half

of these species were Coleoptera (5035), and 684 of them (about 13%) were considered threatened (endangered + vulnerable) by the specialists (Bologna, 2005).

A decline in biodiversity can be assessed estimating the decrease in species richness and abundance, evidencing the extinction of some species, at local or global level. Some interesting attempts to evaluate biodiversity and numerical trends of some taxonomic groups in a defined geographical area were based on a rough estimate of their populations by museum records and/or national databases (Turin & den Boer, 1988; Desender *et al.*, 1994; Guralnick & Van Cleve, 2005).

In Italy, in the framework of the Checkmap Project, Brandmayr *et al.* (2005) carried out a chronogeonomic analysis of the records referred to *Osmoderma eremita*, a saproxylic scarab beetle (Coleoptera Scarabaeidae; *sensu* Browne & Scholtz, 1999) included in the Habitat Directive, in order to give a population dimension to distributional data, and clustered the records into three groups (before 1940, between 1941 and 1980, and after 1980).

In the present paper, we attempt a more detailed chronogeonomic analysis of a group of dung-eating scarab beetles named 'rollers' (Scarabaeidae; *sensu* Browne & Scholtz, 1999) that seem to experience a severe decline in Italy during the last decades.

Among dung beetles, three major feeding strategies (characterized by a different reproductive behaviour) were developed in order to compete for the same resource (Halffter & Edmonds, 1982; Scholtz, 1990; Hanski & Cambefort, 1991; Davis *et al.*, 2002; Finn & Gittings, 2003):

Tunnellers (T): Coprinae subfamily (*Copris*, *Onitis*, *Euoniticellus*, *Caccobius*, *Onthophagus*) and some Aphodiinae digging chambers more or less directly underneath the pat, for feeding or breeding;

Rollers (R): Scarabaeinae subfamily (*Scarabaeus*, *Gymnopleurus*, *Sisyphus*) forming a ball of dung that can be rolled away from the pat and buried for feeding or breeding;

Dwellers (D): Many representatives of the Aphodiinae subfamily (*Aphodius sensu lato*), which feed in the dung pat as adults and lay eggs within or under the dung mass where they undergo larval development (other Aphodiinae are detritivorous).

In the present paper, we compare data referred to rollers (Scarabaeinae) with those related to rollers and tunnellers together (Scarabaeinae + Coprinae), and use, respectively, the acronyms R and RT. The definition of these two categories (R and RT) allowed us to compare our data with those from the Iberian peninsula, reported by a previous paper (Lobo, 2001). Dwellers (Aphodiinae), which include a high number of small sized and less known species, were always excluded by our analysis.

According to Hanski & Cambefort (1991) there were around 115 genera and over 1120 species of rollers (this number is surely increased in the last years). Nevertheless, only three genera (*Sisyphus*, *Gymnopleurus*, and *Scarabaeus*) and 18 species occur in Europe, mainly in the Mediterranean region (Baraud, 1992). A study conducted in South Africa recognized a role as bioindicators of habitat changes to roller and tunneller species (McGeoch *et al.*, 2002).

Studies on the decline of dung beetles are very scarce. Data on this subject can be found in some papers concerning dung beetles from northern and central Europe (Johnson, 1962; Leclerc *et al.*, 1980; Lumaret, 1990; Lobo *et al.*, 2001; Carpaneto *et al.*, 2005a). Recently, Lobo (2001) observed a decline of roller populations in the Iberian Peninsula, where the Mediterranean landscape had been considerably altered, by testing if the probability of finding a R species had decreased between the first and the second part of the 20th century. In the Padana Plain (northern Italy), Barbero *et al.* (1999) considered as 'virtually extinct' at least one species of *Scarabaeus* and three of *Gymnopleurus*, which were common and widespread at the beginning of the 20th century. In north-eastern Italy (Carso Triestino, Friuli Venezia Giulia), Benasso (1985) considered as extinct the species of *Scarabaeus*.

The aims of the present study are (1) to describe the trend in the records of R species along time in the Italian territory, and (2) to understand the main causes of decline in the populations of R species.

METHODS

Data source

A database of Italian scarab beetles (Scarabaeinae and Coprinae), including 6149 records, was compiled by our research group during the Project 'CheckMap' (see Carpaneto *et al.*, 2005b), promoted by the Italian Ministry of Environment. For each species, all the collection localities were listed together with the related information (year, altitude, region, province, UTM coordinates, bibliographical source, etc.). As 'single record' we intend all the individuals collected by the same person in the same date and locality. The range of records lasts from 1865 to 2004 and includes all the literature data, implemented by 1413 unpublished records from private and public collections. The database is the most exhaustive tool to represent the scarab beetle diversity in Italy, for all the 20 administrative regions (Fig. 1).

The number of bovine heads in Italy for each decade was obtained by a work produced by CNR (the Italian National Research Centre) (Rognoni & Pagnacco, 1983) between the 1870–79 decade and the 1980–89 decade, integrated by the official data on the agricultural trends during the first half of the 20th century (Angelini, 1939). The dynamic extension of pastures in Italy was obtained by an allochronic GIS analysis conducted by Falcucci *et al.* (2007).

Record analysis

The methods of analysis adopted for the present paper were chosen to align with the study conducted by Lobo (2001) on the R species decline in the Iberian peninsula, in order to compare data. Therefore, a comparison was made between the first and the second half of the 20th century and between consecutive quarters (25 years). Data were analysed for decades, for quarters and for the two halves, i.e. U50 for data recorded up to 1950 and L50 since 1951.

A Time Series Data Analysis was conducted in order to assess the trends in the variation of numbers of records between the decades. In particular, such analysis for decades has been based on data since 1890–1999.

A two-way contingency table was utilized in order to compare the total number of records and the partial numbers for each species, between the two half-century periods and between consecutive quarters. The same contingency table was also utilized to compare the number of 10-km UTM cells either for all the R species or for each R beetle species, between the two half-century periods (cf. Lobo, 2001) and between consecutive quarters. To test the independence of the two variables (R species vs. RT species and U50 vs. L50, or first quarter vs. second quarter and so on), a Pearson χ^2 test, with Yates' correction for continuity was used (Sokal & Rohlf, 1981; cf. Lobo, 2001). The null hypothesis consists of an equal proportion of records and UTM cells with and without R species between the two half-century periods or between consecutive quarters. Because of the different number of records among the two periods of the century, the expected frequency for the four categories (i.e. U50 or first quarter R species,

Figure 1 The 20 administrative regions of Italy and the number of R species (rollers) occurring in them.

U50 or first quarter RT species, L50 or second quarter R species, and L50 or second quarter RT species) was calculated by multiplying the total of each column for the total of each row and dividing for the global total. A significant difference indicates that species occurrence in records or in UTM cells varies between the two periods.

The geographical distribution of each R species in Italy has been deduced from the records available for each half or quarter of the century in order to evaluate a possible variation in the range extension or at least in their area of occupancy (cf. Mace & Lande, 1991). A chorotype (zoogeographical distribution pattern) was assigned to each R species, according to the terms defined by Vigna Taglianti *et al.* (1993, 1999) for the Palearctic Region.

The Italian range of the species was defined by all the latitudinal and longitudinal mid-points of the occupied UTM cells, to compare the first and second half of the century and the four quarters. Such a comparison concerned both the location of the distributional core area, using a *t*-test for independent samples (Gaston, 1990; Quinn *et al.*, 1996; Lobo, 2001), and its amplitude, using the Levene test for homogeneity of variances (Sokal & Rohlf, 1981).

Only the 513 Italian UTM grid cells with > 15% land area were analysed to relate the number of records referred to R species and the number of R species through the 20th century. Such a relation between the number of species (S_r) to the number of records (r) is given by the following negative exponential function:

$$S_r = S_{\max}(1 - e^{-br})$$

where $S_{\max}$, the asymptote, is the estimated total number of species per UTM cell, and b is a fitted constant that controls

the shape of the curve (Soberón & Llorente, 1993; Colwell & Coddington, 1995; Lobo, 2001). The curvilinear model was estimated 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 ≤ 0.01 was calculated (i.e. one added species for every additional 100 records: $r_{0.01}$) (cf. Lobo, 2001). According to Soberón & Llorente (1993):

$$r_{0.01} = \frac{1}{b \ln\left(1 + \frac{b}{0.01}\right)}.$$

The 282 UTM grid cells (79 in the 1900–50 period and 208 in the 1951–99 period) with a number of records equal to or greater than $r_{0.01}$ were considered to be well surveyed. The nonparametric Wilcoxon matched-pairs test was used to compare the number of R species in these well-surveyed cells in both the two half-century periods (Siegel & Castellan, 1988).

In order to estimate the probability that R species are still extant, some indexes of decline were calculated and a trend analysis was accomplished (see also Solow, 1993a,b; McCarthy, 1998; Roberts & Solow, 2003; Solow, 2005; Van der Ree & McCarthy, 2005; Roberts & Kitchener, 2006). A complementary utilization of these indexes can help to assess the conservation status of species according to IUCN criteria (see Robbirt *et al.*, 2006).

The Solow's equation (Solow, 1993a): this index estimates the probability that a species is still extant.

$$p = \left(\frac{t_n}{T}\right)^n$$

where n is the number of times the species was recorded between time 0 and time T , and t_n is the time at which the species was last recorded. The equation gives the probability that the n records would all occur prior to time t_n , if records were equally likely to occur between time 0 and T . The probability equals the chance that the observed run of absences at the end of the observation period would occur by chance alone. This index assumes a constant pre-extinction sighting rate. All other things being equal, a small probability value ($P < 0.05$) would imply a decline in population size and/or range size of the species; under the assumption of a species extinction, an unbiased estimate of the extinction time is (Solow, 2005):

$$\hat{T}_E = \frac{n+1}{n} t_n$$

associated with an upper bound T_E^u of a $1-\alpha$ confidence interval for $\hat{T}_E$:

$$T_E^u = t_n / \alpha^{1-n}$$

the Burgman's equation: a modification of the Solow's equation to account for multiple collection efforts within a time period (Burgman *et al.*, 1995). The period (t_0, T) may be partitioned into C_T years, and the number of years between the start of the observation period and the last collection is C_e . In each year, a multiple number of records may be recorded. Considering a random distribution of the N records along the C_T years, the probability that a species has not become extinct since the last observation is equal to:

$$p = \left(\frac{C_e}{C_T} \right)^N$$

The above equation will be referred to as the Burgman's equation. If the collection effort does not vary over time, this equation reduces to Solow's equation.

The sighting rate: this index produces an index unbiased by different periods of initial sightings (McInerny *et al.*, 2006). The probability that another sighting will occur can be generated given the previous sighting rate, n/t_n , and the time since last observation, $T-t_n$, by the following:

$$p = \left(1 - \frac{n}{t_n} \right)^{T-t_n}$$

The probability of sighting rate meets a correspondence with the IUCN Red list categories (McInerny *et al.*, 2006), and a low likelihood value (at least $P < 0.5$, see McInerny *et al.*, 2006) means a low probability of discover another record for the species at the previous sighting rate. This probability is a useful indicator for rarefaction of species discovered by short time. A low sighting rate could be both an evidence for a recent decline or for rarity.

The runs test: this test permits to detect some runs of absences near the end of the recording period, which are a symptom identifying declining species. A probability is calculated of not

recording a species for as long or longer than the longest observed run of absence (see Bradley, 1968), as follows

$$p = \binom{C_T}{n_0}^{-1} \sum_{k=1}^{\lfloor n_0/r \rfloor} (-1)^{k+1} \binom{n_1+1}{k} \binom{C_T-rk}{n_1}$$

where: n_0 = number of years without records

n_1 = number of years with records

k = all the most recent sighting times for the species

r = the length of the longest run of years without records

The Solow and Roberts nonparametric equation (Solow & Roberts, 2003): this test bases the assessment of significance on the behaviour of the sighting record in the vicinity of the most recent sighting. In particular, there is no need to specify either the beginning of the observation period or even the number of sightings in the observation period. An approximate P -value in testing H_0 vs. H_1 is simply the ratio of the interval between the second most recent sighting and the most recent sighting, to the time interval between the second most recent sighting and the end of the observation period, as shown by the equation:

$$p = \frac{t_n - t_{n-1}}{T - t_{n-1}}$$

The Solow (2005) equation: this equation is based on an estimate of the shape parameter of the Weibull extreme value distribution, $\hat{\nu}$:

$$\hat{\nu} = \frac{1}{k-1} \sum_{i=1}^{k-2} \log \frac{T_1 - T_k}{T_1 - T_{i+1}}$$

deriving an approximate P -value for testing for extinction

$$p = \exp \left(-k \left(\frac{T - t_n}{T - t_{n-k+1}} \right)^{1/\hat{\nu}} \right)$$

Finally a cross-correlation analysis was done in order to understand the possible role of two leading factors, i.e. the number of grazing animals and the number of bibliographic sources, in explaining the variation of roller records along time. The observed number of roller records for each decade was compared with the number of roller records estimated by the linear regression equation in relation to these two factors.

RESULTS

Rollers' distribution in Italy

Through the revision of all the literature and unpublished data, 11 R species have been recorded in Italy. All these species are included in the subfamily Scarabaeinae and three tribes, each one represented by a single genus: Scarabaeini (*Scarabaeus*, 6 species), Gymnopleurini (*Gymnopleurus*, 4 species), and Sisyphini (*Sisyphus*, 1 species). The regional boundaries of each Italian region and the number of R species occurring in them were reported in Fig. 1.

An analysis of the Spearman Rank correlation test was conducted between the percentage distribution of records for each

species and the percentage distribution of records for all the species in the administrative regions. This analysis shows that these variables are significantly correlated (always $P < 0.05$), except for *Gymnopleurus geoffroyi*, *Scarabaeus variolosus*, and *Sc. pius* (see Table 1).

The values of relative abundance of each species were compared (Table 2): three species (*Gymnopleurus flagellatus*, *G. geoffroyi*, *Sc. pius*) are represented by a percentage of records lower than the 25th percentile (121 records); two species (*Gymnopleurus sturmi*, *Sc. laticollis*) are represented by a percentage of records higher than the 75th percentile (272 records); and the other species fall within the 25th and the 75th percentiles range.

According to available data on regional distribution (Table 1), the less recorded R species in Italy are distributed as follows:

- 1 *G. flagellatus* is a Centralasiatic–Mediterranean species, sparse, and localized in the Mediterranean Basin; in Italy it was captured mainly in a restricted coastal area of Latium (about 69% of records), and in some scattered localities of Tuscany and southern regions (Campania, Basilicata, Calabria, Apulia), always in the coastal belt.
- 2 *G. geoffroyi* is a Turanian–Mediterranean species that in Italy occurs only on mountain pastures, from almost all the Italian regions but the highest number of records comes from central (Abruzzi, Latium, Tuscany) and northern (Friuli-Venezia-Giulia, Piedmont) regions of Italy.
- 3 *Sc. pius* is a Mediterranean species, rare in all the western part of its range (Spain, southern France, Italy). In Italy, this species was recorded only in the past decades from some inner localities of northern regions, mainly in Emilia Romagna (about 40% of the records), Veneto (26%), and Liguria (13%) and secondly in Piedmont, Tuscany, Trentino Alto Adige, and Lombardy (some of these records are considered uncertain).

Scarabaeus laticollis and *G. sturmi*, the most recorded R species of Italy are distributed as follows (Table 1):

- 1 *Sc. laticollis* has a western Mediterranean range, with the eastern border in peninsular Italy, and was mainly recorded from Latium (51% of the records) and Sardinia (37%), and secondly in Abruzzi, Liguria, Tuscany, and Sicily, where it is still common and widely spread on plain and hill pastures.
- 2 *G. sturmi* is a Mediterranean species, formerly common and widespread in almost all the Italian regions, mainly in the central regions as Latium (25%) and Sardinia (16%) and in Sicily (23%).

The other species in Italy are distributed as follows (Table 1):

- 1 *G. mopsus* has a Centralasiatic–Mediterranean range and was formerly common and spread in central regions of Italy (principally in Latium and Sardinia, with, respectively, 31% and 13% of the total records; secondly in Tuscany and Abruzzi) and southern regions (mainly in Apulia, Sicily, and Calabria, respectively, 12%, 12% and 6%), with some scattered records in northern regions (Friuli-Venezia Giulia, Liguria, Veneto, and Piedmont).
- 2 *Sc. semipunctatus* is a western Mediterranean species strictly related to sand beaches, mostly recorded from the Tyrrhenian coast of Latium (18%), Sardinia (13%), and Sicily (19%), and reaches marginally the northern regions (Liguria, Emilia Romagna, Veneto, Friuli-Venezia-Giulia).

3 *Sc. sacer* has a wide Mediterranean range extending to western Asia (Sind); in Italy, it was recorded from the sandy soils along the seashore, with a higher occurrence along the Tyrrhenian coast, mainly in Latium (16%), Sardinia (37%), and Sicily (22%), secondly in Apulia, Basilicata, Campania, and Calabria.

4 *Sc. typhon* has a Centralasiatic–Mediterranean range and was recorded from many Italian regions, mainly in the central ones, as Latium (26% of the total records) and Sardinia (24%), and secondly from Piedmont to Veneto and southwards to Sicily.

5 *Sc. variolosus* is a Mediterranean species, mostly recorded from Sicily (57%) and secondly from other southern Italian regions (Campania, Basilicata, Apulia, Calabria); it was also recorded from scattered mountain localities of central regions (Marche, Emilia Romagna, Umbria, Abruzzi, Latium). Such irregular pattern of ecological distribution of *Sc. variolosus* in central Italy (where it is restricted to mountains) is probably due to an ecological competition with *Sc. laticollis*, where the two species occur together.

6 *Si. schaefferi* is an European–Mediterranean species widely distributed in central and southern regions; it was mainly recorded from Latium (32%), Sicily (17%), and Sardinia (15%), secondly in Abruzzi, Umbria, Tuscany, Marche, Calabria, Basilicata, Apulia, Molize; only old and scattered records are from the north (Emilia Romagna, Friuli-Venezia-Giulia, Liguria, Lombardy, Piedmont, Trentino Alto Adige, Veneto).

Rollers' occurrence during the 20th century

The database arranged for this study contains 6870 records on the whole: 1871 (27.2%) of R species and 4999 (72.8%) of T species. Of the total number of records, 1336 (19.4%) were referred to the first half of the 20th century and 5534 (80.5%) were referred to the second one. A significant reduction in data referred to R species from the first (34.28%) to the second part (25.53%) of the 20th century was observed (Table 3).

Notwithstanding the increased number of records for all the R and T species, six of the 11 roller species show a significant fall in the relative frequency of records in the second half of the century (Table 3): *G. geoffroyi*, *G. mopsus*, *G. sturmi*, *Sc. pius*, *Sc. sacer*, and *Sc. typhon*. Three species, *Sc. laticollis*, *Sc. variolosus*, and *Si. schaefferi*, show a significant increase in the relative frequency.

Despite a general increase in the number of investigated grid cells by the time, the number of grid cells where R species were present declined from 50% to 31.03% (Table 3). A significant increase in the mean number of investigated grid cells by each literature source for RT species (Wilcoxon matched-pairs test, $Z = 26.37$; $P < 0.01$) was also registered.

An evident increase in the percentage values of the total number of records (RT) was registered from the first to the fourth quarter of the 20th century (Table 4). An overall significant reduction in the number of records of R species was observed along all the 20th century by -31.41% , but the most incisive reductions were observed from the first to the second quarter (-13.2%) and from the third to the fourth quarter (-14.36%) (Table 4).

Despite the increased number of records for all the R and T species, nine of the 11 roller species show a significant drop in the

Table 1 Percentage distribution of records of roller species in the 20 Italian administrative regions. Values of the Spearman rank correlation (r_s) and its associated probability (P) between the percent occurrence of the species in Italy and in each region.

	<i>Gymnopleurus flagellatus</i>	<i>Gymnopleurus geoffroyi</i>	<i>Gymnopleurus mopsus</i>	<i>Gymnopleurus sturmi</i>	<i>Scarabaeus laticollis</i>	<i>Scarabaeus semipunctatus</i>	<i>Scarabaeus variolosus</i>	<i>Scarabaeus pius</i>	<i>Scarabaeus sacer</i>	<i>Scarabaeus typhon</i>	<i>Sisyphus schaefferi</i>	Total
Abruzzi	0.0	13.4	0.9	0.7	1.3	1.4	7.4	0.0	0.0	0.5	4.9	2.3
Aosta Valley	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apulia	12.5	3.0	12.2	8.9	0.0	7.9	10.8	0.0	3.4	8.6	3.8	6.5
Basilicata	4.2	6.0	2.3	3.6	0.0	1.8	2.3	0.0	6.9	2.4	9.4	3.5
Calabria	8.3	1.5	5.9	3.0	0.0	5.8	9.1	0.0	6.3	9.0	2.6	4.6
Campania	2.1	0.0	0.0	0.3	0.0	5.8	4.5	0.0	2.3	1.0	0.0	1.5
Emilia Romagna	0.0	0.0	1.4	1.6	0.0	6.1	1.1	39.5	0.0	1.0	1.5	2.3
Friuli Venezia Giulia	0.0	11.9	5.0	3.6	0.0	0.7	0.0	0.0	0.0	1.9	3.0	2.1
Latium	68.8	11.9	31.2	24.7	50.9	18.3	4.0	0.0	16.0	26.2	31.6	27.2
Liguria	0.0	1.5	2.7	1.6	5.9	2.5	0.0	13.2	0.0	2.9	1.9	2.6
Lombardy	0.0	0.0	0.5	0.3	0.0	0.0	0.0	2.6	0.0	0.0	0.4	0.2
Marche	0.0	7.5	0.0	0.0	0.0	0.7	2.3	0.0	0.0	0.5	0.8	0.7
Molize	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.1
Piedmont	0.0	9.0	2.3	3.3	0.0	0.0	0.0	7.9	0.0	1.4	0.8	1.4
Sardinia	0.0	3.0	13.1	16.4	37.2	13.3	0.0	0.0	36.6	24.3	15.0	18.6
Sicily	0.0	1.5	12.2	23.4	1.6	19.1	56.8	0.0	21.7	8.6	17.3	17.1
Trentino Alto Adige	0.0	7.5	3.2	1.3	0.0	0.0	0.0	5.3	0.0	0.0	3.4	1.3
Tuscany	4.2	10.4	5.4	5.3	3.1	8.6	0.0	5.3	5.7	8.6	1.9	5.0
Umbria	0.0	6.0	0.0	0.7	0.0	0.0	1.7	0.0	1.1	1.4	0.4	0.7
Veneto	0.0	6.0	1.8	1.0	0.0	7.9	0.0	26.3	0.0	1.9	0.8	2.3
Italy	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
r_s	0.562	0.274	0.868	0.883	0.665	0.904	0.413	-0.059	0.766	0.924	0.792	
P	0.01	0.242	< 0.001	< 0.001	0.001	< 0.001	0.07	0.804	< 0.001	< 0.001	< 0.001	

Table 2 Species richness, number of records referred to all the RT species (rollers + tunnellers) and to each R species (rollers), and value of the decline indexes for each decade.

	Records	Species	<i>G. flagellatus</i>	<i>G. geoffroyi</i>	<i>G. mopsus</i>	<i>G. sturmi</i>	<i>S. laticollis</i>	<i>S. semipunctatus</i>	<i>S. variolosus</i>	<i>S. pius</i>	<i>S. sacer</i>	<i>S. typhon</i>	<i>S. schaefferi</i>
1870–1879	5	3	0	0	0	0	0	2	0	0	1	2	0
1880–1889	8	5	0	0	1	3	2	1	0	1	0	0	0
1890–1899	46	10	1	7	11	10	2	4	0	1	1	1	8
1900–09	78	11	3	4	7	13	7	4	3	3	12	20	2
1910–19	45	9	0	2	8	15	1	4	2	6	2	5	0
1920–29	43	8	0	6	5	14	7	2	0	1	0	6	2
1930–39	112	11	2	10	19	20	9	15	2	2	13	14	6
1940–49	153	11	3	4	34	36	22	13	7	3	9	14	8
1950–59	213	11	15	2	36	34	21	32	10	9	27	16	11
1960–69	374	11	8	14	46	58	50	69	30	2	41	24	32
1970–79	491	11	8	11	32	60	106	60	55	1	48	48	62
1980–89	190	9	1	0	3	10	40	30	28	0	10	11	57
1990–99	172	10	1	1	0	11	43	13	26	1	7	24	45
Total	1930	11	42	61	202	284	310	249	163	30	171	185	233
Percentage	100		2.2	3.1	10.6	15.2	16.2	13.2	7.9	1.6	9.1	9.9	11.1
Solow <i>P</i> (1993a)			0.034	0.041	< 0.001	1.000	1.000	0.022	0.197	0.133	0.001	0.053	1.000
Burgman's <i>P</i>			0.028	0.037	< 0.001	1.000	1.000	0.012	0.192	0.066	0.001	0.036	1.000
Year for last record			1995	1998	1987	2004	2004	2002	2003	1994	1999	2002	2004
T_E -Solow (1993a)			1998	2000	1988	–	–	2003	–	1999	2000	2003	–
T_E -upper boundary Solow (1993a)			2003	2004	1989	–	–	2004	–	–	2001	2004	–
Sighting rate <i>P</i>			0.097	0.073	< 0.001	1.000	1.000	0.235	0.505	0.175	0.055	0.153	1.000
Runs test <i>P</i>			*	0.008	< 0.001	*	*	*	*	0.099	*	*	*
Solow and Roberts <i>P</i>			0.625	0.760	0.227	1.000	1.000	0.333	0.500	0.697	0.375	0.333	1.000
Solow <i>P</i> (2005)			0.918	0.996	0.465	1.000	1.000	0.92	0.981	0.964	0.846	0.95	1.000

*The longest run of absences for the species occurred in the first half of the observation period, decreasing concerns about low *P*-values generated by Grimson's run test.

Table 3 Percentage values of roller (R) records with respect to the total number of rollers and tunnellers (RT) for each half of the 20th century. Significant difference (* $P < 0.05$, ** $P < 0.01$) between the two periods of the century, using the Pearson χ^2 test, with Yates' correction for continuity (Sokal & Rohlf, 1981); ns = not significant value.

	Number of records						Number of 10-km UTM cells					
	Before 1950		After 1950		χ^2	P	Before 1950		After 1950		χ^2	P
<i>Gymnopleurus flagellatus</i> Fabricius, 1787 ^c	9	0.67	32	0.58	0.11	ns	8	3.70	16	3.57	0.43	ns
<i>Gymnopleurus geoffroyi</i> (Fuessly 1775)	26	1.95	28	0.51	27.54	**	21	9.72	23	5.13	5.28	*
<i>Gymnopleurus mopsus</i> (Pallas 1781)	74	5.54	116	2.10	46.7	**	52	24.07	81	18.08	3.41	ns
<i>Gymnopleurus sturmi</i> (MacLeay 1821)	99	7.41	172	3.11	51.93	**	58	26.85	113	25.22	2.61	ns
<i>Scarabaeus laticollis</i> (Linnaeus 1767)	46	3.44	260	4.70	4.15	*	23	10.65	115	25.67	15.64	**
<i>Scarabaeus semipunctatus</i> (Fabricius 1792)	43	3.22	199	3.60	0.52	ns	32	14.81	126	28.13	12.86	**
<i>Scarabaeus variolosus</i> (Fabricius 1787)	15	1.12	148	2.67	11.59	**	12	5.56	82	18.30	16.76	**
<i>Scarabaeus pius</i> (Illiger 1893)	19	1.42	9	0.16	40.24	**	11	5.09	3	0.67	DD	DD
<i>Scarabaeus sacer</i> (Linnaeus 1758)	48	3.59	121	2.19	8.54	**	42	19.44	77	17.19	2.18	ns
<i>Scarabaeus typhon</i> (Fischer-Waldheim 1823)	61	4.57	121	2.19	23.1	**	51	23.61	87	19.42	4	*
<i>Sisyphus schaefferi</i> (Linnaeus 1758)	18	1.35	207	3.74	19.9	**	16	7.41	113	25.22	23.1	**
Total of R records	458	34.28	1413	25.53	41.44	**	108	50.00	139	31.03	275.11	**
Total RT records	1336		5534				216		448			

Table 4 Percentage values of roller records (R) with respect to the total number of rollers and tunnellers (RT) for each quarter of the 20th century. Significant difference (* $P < 0.05$, ** $P < 0.01$) between the consecutive quarters of the century, using the Pearson χ^2 test, with Yates' correction for continuity (Sokal & Rohlf, 1981). DD = data deficient (the frequency of expected records for this species was less than 5.0, then χ^2 test was not applied); ns = not significant value.

	1900–24	1925–1949	1950–1974	1975–1999	First to second		Second to third		Third to fourth	
					χ^2	P	χ^2	P	χ^2	P
<i>Gymnopleurus flagellatus</i>	0.79	0.46	0.75	0.03	DD	DD	1.38	ns	45.18	**
<i>Gymnopleurus geoffroyi</i>	2.10	1.65	0.44	0.14	0.26	ns	17.52	**	8.61	**
<i>Gymnopleurus mopsus</i>	4.46	5.14	2.67	0.10	0.36	ns	16.53	**	136.35	**
<i>Gymnopleurus sturmi</i>	9.44	5.69	3.21	0.59	6.15	*	14.41	**	115.12	**
<i>Scarabaeus laticollis</i>	3.41	3.03	3.33	1.77	0.11	ns	0.31	ns	27.47	**
<i>Scarabaeus semipunctatus</i>	2.62	2.57	3.31	0.98	0.03	ns	1.67	ns	77.38	**
<i>Scarabaeus variolosus</i>	1.31	0.83	1.80	1.08	DD	DD	5.56	*	10.04	**
<i>Scarabaeus pius</i>	2.62	0.46	0.29	0.01	DD	DD	DD	DD	DD	DD
<i>Scarabaeus sacer</i>	3.67	2.02	2.53	0.42	2.95	ns	1.08	ns	96.83	**
<i>Scarabaeus typhon</i>	7.87	2.66	1.75	0.73	19.31	**	3.51	ns	24.2	**
<i>Sisyphus schaefferi</i>	0.79	1.38	1.94	1.82	DD	DD	1.74	ns	0.2	ns
Total of R records	39.08	25.88	22.02	7.67	23.62	**	7.21	**	471.39	**
Total RT records	3.04	8.68	32.78	55.51						

relative frequency of records during the 20th century (Table 4). From the first to the second quarter, the drop of records occurred for only two species, *G. sturmi* and *Sc. typhon*. From the second to the third quarter, three species decreased significantly, i.e. *G. geoffroyi*, *G. mopsus*, and *G. sturmi*, while the records belonging to *Sc. variolosus* doubled. From the third to the fourth quarter, nine species decreased significantly, i.e. *G. flagellatus*, *G. geoffroyi*, *G. mopsus*, *G. sturmi*, *Sc. laticollis*, *Sc. semipunctatus*, *Sc. variolosus*, *Sc. sacer*, and *S. typhon*.

The number of investigated UTM grid cells increased by the time passing from the first to the third quarter of the 20th century, and decreased from the third to the last quarter (respectively,

between two adjacent quarters, $\chi^2_{1-2} = 15.58$, $P < 0.01$; $\chi^2_{2-3} = 109.5$, $P < 0.01$; $\chi^2_{3-4} = 83.87$, $P < 0.01$). On the contrary, the number of UTM grid cells where R species were present declined from the first to the last quarter of the 20th century, from 49.13% to 25.28% (respectively, between two adjacent quarters, $\chi^2_{1-2} = 16.31$, $P < 0.01$; $\chi^2_{2-3} = 109.1$, $P < 0.01$; $\chi^2_{3-4} = 47.49$, $P < 0.01$) (Table 5). No significant increase occurred in the mean number of the investigated grid cells by each literature source for RT species among the four quarters of the 20th century (mean UTM/source for first quarter = 1.52, second quarter = 2.06, third quarter = 2.25, fourth quarter = 1.8; Wilcoxon matched-pairs test, $0.6 < Z < 1.75$; $0.08 < P < 0.54$).

Table 5 Percentage values of UTM cells that present roller (R) records with respect to the total number of UTM cells presenting both rollers and tunnellers (RT) for each quarter of the 20th century. Significant difference (* $P < 0.05$, ** $P < 0.01$) between the consecutive quarters of the century, using the Pearson χ^2 test, with Yates' correction for continuity (Sokal & Rohlf, 1981). DD = data deficient (the frequency of expected records for this species was less than 5.0, then χ^2 test was not applied); ns = not significant value.

	1900–24	1925–1949	1950–1974	1975–1999	First to second		Second to third		Third to fourth	
					χ^2	P	χ^2	P	χ^2	P
<i>Gymnopleurus flagellatus</i>	1.73	1.50	1.36	0.23	DD	DD	26.6	**	233.36	**
<i>Gymnopleurus geoffroyi</i>	4.62	4.20	1.45	0.91	1.09	ns	31.26	**	29.77	*
<i>Gymnopleurus mopsus</i>	8.67	11.41	7.65	0.80	2.69	ns	33.16	**	67.97	**
<i>Gymnopleurus sturmi</i>	15.61	11.11	8.91	3.30	4.1	*	35.16	**	55.59	**
<i>Scarabaeus laticollis</i>	6.94	4.80	7.07	7.86	1.75	ns	73.84	**	34.15	**
<i>Scarabaeus semipunctatus</i>	4.05	7.21	9.78	5.24	2.12	ns	39.31	**	62.17	**
<i>Scarabaeus variolosus</i>	2.89	2.10	5.23	4.56	DD	DD	17.94	**	6.46	*
<i>Scarabaeus pius</i>	3.47	0.90	0.48	0.00	DD	DD	DD	DD	DD	DD
<i>Scarabaeus sacer</i>	8.09	6.01	6.97	2.16	1.69	ns	6.9	**	38.37	**
<i>Scarabaeus typhon</i>	15.03	7.51	5.13	4.56	10.6	**	9	**	185.57	**
<i>Sisyphus schaefferi</i>	1.73	3.90	4.94	8.43	1.86	ns	6.51	*	18.66	**
Total of R records	49.13	39.64	31.95	25.28	6.47	*	7.51	**	13.69	**
Total RT records	100.00	100.00	100.00	100.00						

Rollers' distribution in the 20th century

From the first to the second half of the 20th century, a significant decrease in percentage occupancy of grid cells was shown by *G. geoffroyi* and *Sc. typhon*. Otherwise, *Sc. laticollis*, *Sc. semipunctatus*, *Sc. variolosus*, and *Si. schaefferi* increased their occupancy (Table 3; Fig. 2). Seven species show a significant change of the geographical location of records towards south and two species show a significant change towards west (Table 6). In fact, an increase of records was registered from southern regions of Italy for several species, as for *G. geoffroyi*, *G. mopsus*, *G. sturmi*, *Sc. semipunctatus*, *Sc. sacer*, *Sc. typhon*, and *Si. schaefferi* (Fig. 2). On the other hand, *Sc. laticollis* shows a significant increase of records in the western part of the country. A significant decrease in latitudinal range was observed for *Sc. sacer*. No species revealed a significant decrease in longitudinal range (*Sc. pius* is at a border line confidence), while a significant increase was observed for *G. geoffroyi*, *G. mopsus*, *Sc. laticollis*, and *Si. schaefferi*.

The variation in the mean number of R species in well-surveyed UTM cells was not significant between the two periods: it passed from 2.43 ± 0.12 (mean $\pm$ SE) in the first half of the century to 2.5 ± 0.08 in the second half of the 20th century (t -test, $t = -0.445$; $P = 0.65$; d.f. = 285). That is to say, changes concerned a decrease in record abundance but not in species richness per UTM cell.

From the first to the last quarter of the 20th century, a significant decrease in the percent occupancy of grid cells was shown by *G. sturmi* and *Sc. typhon* (Table 5; Fig. 2). Since the second to the last quarter of the 20th century, a continuous significant drop in percentage occupancy was shown by *G. flagellatus*, *G. geoffroyi*, and *G. mopsus*. Other species increased their occupancy from the second to the third quarter, and dropped from the third to the last quarter: *Sc. semipunctatus*, *Sc. variolosus*, and *Sc. sacer*. Finally, *Sc. laticollis* and *Si. schaefferi* increased continuously their occu-

pancy from the second to the fourth quarter of the 20th century.

The mean number of R species in well-surveyed UTM cells increased significantly from the second to the third quarter of the 20th century (mean $\pm$ SE: from 3.68 ± 2.21 to 7.46 ± 1.64 ; t -test, $t = -5.912$; $P < 0.001$; d.f. = 47); on the other hand, it decreased significantly from the third to the fourth quarter (from 7.46 ± 1.64 to 4.24 ± 1.56 ; t -test, $t = 5.786$; $P < 0.001$; d.f. = 47).

The variation, for each decade, of the data referred to RT species on the whole, is aligned with the variation of the data referred to R species only ($r_s = 0.934$, $P < 0.001$) and with the data referred to each R species (excepted for *Sc. pius*) (Pearson product moment always significant: $P < 0.05$). The number of roller records from 1870 to 1979 increased clearly (except for a slight drop between the first three decades of the 20th century) (Table 2). After 1979, the number of records began to fall. From the decade 1970–79 to the last one, the number of records of RT species on the whole dropped of 19.2% (a linear regression showed a direction coefficient = -0.0463), while the number of records referred to R species dropped of 64.97% (a linear regression showed a direction coefficient = -0.227) (Fig. 3).

Examining the trend in the number of records for each R species, three chronological patterns of reduction can be observed (Fig. 4): species that started to decrease clearly in the decade 1960–69: *G. flagellatus*, and *Sc. pius* (Fig. 4a); species that started to decrease clearly in the decade 1970–79: *G. geoffroyi*, *G. mopsus*, and *Sc. semipunctatus* (Fig. 4b); and species that started to decrease clearly in the decade 1980–89: *G. sturmi*, *Sc. laticollis*, *Sc. sacer*, *Sc. typhon*, *Sc. variolosus*, and *Si. schaefferi* (Fig. 4c).

Extinction process

The probability that an R species is still extant in Italy, calculated by the Solow and the Burgman indexes, ranges between 0 and 1

Figure 2 Distribution maps of the Italian R species (rollers) along the years. ○ ≤ 1924 data, □ 1925 ≤ data ≤ 1949, ● 1950 ≤ data ≤ 1974, ■ ≥ 1975 (UTM 32 projection).

Table 6 Results of the *t*-test for independent samples (Siegel & Castellan, 1988) to compare the centres of distribution (latitudinal and longitudinal) in Italy of each species from the first (U50) to the second half (L50) of the 20th century, and results of the Levene test for homogeneity of variances (Sokal & Rohlf, 1981) for the same periods (log-transformed data). (SD = standard deviation; var = variance; d.f. = degree of freedom; *P* = probability of the *t*-test; Levene *F* = ratio between variances; *P* = probability of the Levene test).

N-Latitude	Mean U50	Mean L50	<i>t</i> -value	d.f.	<i>P</i>	SD U50	SD L50	Levene <i>F</i>	<i>P</i> -var
<i>G. flagellatus</i>	6.662	6.662	-0.091	39	0.928	0.005	0.010	0.601	0.443
<i>G. geoffroyi</i>	6.684	6.671	2.483	51	0.016	0.015	0.022	2.320	0.134
<i>G. mopsus</i>	6.666	6.656	2.991	178	0.003	0.023	0.021	0.216	0.642
<i>G. sturmi</i>	6.673	6.648	8.694	264	< 0.001	0.020	0.024	3.375	0.067
<i>S. laticollis</i>	6.668	6.663	0.525	299	0.600	0.026	0.024	1.899	0.169
<i>S. semipunctatus</i>	6.668	6.656	2.822	235	0.005	0.026	0.024	0.023	0.879
<i>S. variolosus</i>	6.640	6.639	0.203	161	0.839	0.026	0.020	2.856	0.093
<i>S. pius</i>	6.695	6.693	0.410	24	0.685	0.007	0.005	3.125	0.090
<i>S. sacer</i>	6.653	6.646	2.388	164	0.018	0.0212	0.0157	4.513	0.035
<i>S. typhon</i>	6.666	6.654	3.967	179	< 0.001	0.018	1.456	3.281	0.072
<i>S. schaefferi</i>	6.674	6.655	3.856	220	< 0.001	0.015	0.021	2.588	0.109
E-Longitude	Mean U50	Mean L50	<i>t</i> -value	d.f.	<i>P</i>	SD U50	SD L50	Levene <i>F</i>	<i>P</i> -var
<i>G. flagellatus</i>	5.9695	5.9345	1.2939	39	0.203	0.081	0.069	1.18	0.285
<i>G. geoffroyi</i>	5.8928	5.8841	0.2463	51	0.806	0.091	0.154	4.26	0.044
<i>G. mopsus</i>	5.908	5.904	0.222	188	0.824	0.108	0.142	10.307	0.002
<i>G. sturmi</i>	5.870	5.892	-1.292	264	0.198	0.127	0.139	3.727	0.055
<i>S. laticollis</i>	5.892	5.797	6.004	299	< 0.001	0.039	0.106	266	< 0.001
<i>S. semipunctatus</i>	5.866	5.898	-1.470	235	0.143	0.126	0.128	0.273	0.602
<i>S. variolosus</i>	5.9690	5.9791	-0.6848	161	0.494	0.056	0.054	0.03	0.874
<i>S. pius</i>	5.7863	5.8403	-1.8615	24	0.075	0.074	0.029	4.16	0.053
<i>S. sacer</i>	5.855	5.857	-0.070	164	0.944	0.144	0.151	0.473	0.493
<i>S. typhon</i>	5.8482	5.8756	-1.2864	179	0.200	0.126	0.140	1.31	0.254
<i>S. schaefferi</i>	5.8743	5.9031	-1.0111	220	0.313	0.057	0.119	6.81	0.010

(Table 2). A significant probability of extinction ($P \leq 0.05$) was observed by both these indexes for *G. flagellatus*, *G. geoffroyi*, *G. mopsus*, *Sc. semipunctatus*, *Sc. sacer*, and *Sc. typhon*. According to the extinction time calculated for the Solow index, all the species were expected to be disappeared from Italy from 1 to 3 years from their last sighting with an associated upper confidence interval from 2 to 8 years from the last sighting.

Gymnopleurus flagellatus, *G. geoffroyi*, *G. mopsus*, *Sc. semipunctatus*, *Sc. pius*, and *Sc. typhon* shared a low probability of sighting rate ($P < 0.5$) so their status should be considered alarming. *Sc. variolosus* and *Sc. sacer* are at a border line ($P = 0.5$).

According to the Runs test, the significant longest runs of absences occurred in the second part of the 20th century for *G. geoffroyi* and *G. mopsus*, while for the majority of other species a run occurred in the first part of the century.

The nonparametric indexes of extinction formulated by Robson and Whitlock and by Solow were not significant for any species. The trends of all the extinction indexes for all the species were strongly correlated ($r_s \geq 0.638$ and always $P < 0.05$).

Leading factors for rollers' trends

A positive correlation was observed between the number of roller records, calculated for each decade in Italy, and the

number of roller records estimated considering two parameters as leading factors: (1) the number of bibliographic sources for each decade and (2) the number of bovine heads (Fig. 5). A cross-correlation permitted to associate in the best way the number of records to the leading indicators, in order to obtain the best correlation joining the two variables. In particular, both the leading indicators (the number of bibliographic sources and the number of bovine heads) were better accorded with the logarithm of the number of records (to avoid non-stationary series) at the same decade (i.e. they forecasted at their best the number of records in the same period). A significant linear regression between these parameters and the number of roller records was calculated (for bibliographic sources: $F_{1,11} = 190.678$, $P < 0.001$; for bovine heads: $F_{1,10} = 101.881$, $P < 0.001$).

In 1960, pasture areas represented 18.8% of the total Italian territory, but reduced to 9.2% in 1990 and 8.7% in 2000. The percentage occurrence of R species in 1960 respect to all the RT species was calculated as a mean of the records from the two adjacent decades: 1950–59 and 1960–69. In the same way, the percentage occurrence of R species in 1990 was calculated as a mean from the decades 1980–89 and 1990–99. In 1960, the occurrence was 45.72%, and in 1990, the occurrence was 18.33%. Assuming a proportional relation between the pasture cover and

Figure 3 General trend for all the RT species (rollers + tunnellers) and for the R species (rollers) (log-transformed data).

the occurrence of R species, the occurrence of these in 1990 should be equal to 22.37%.

DISCUSSION

Past and present distribution of rollers in Italy

The relative abundance of almost all the R species in the administrative regions of Italy reflects the distribution of the total sampling effort of the country. Nevertheless, it is clear that all these species are mostly represented in central and southern regions, including the large islands (Sardinia and Sicily); their occurrence in northern regions has ever been marginal, also in the past decades. On the contrary, in central and southern regions, the rollers' occurrence dropped only from the third to the last quarter of the 20th century. This distribution pattern could be explained by the tropical and subtropical origins of this taxonomic group which is influenced by a climatic gradient with increasing temperature values from north to south.

From the first to the second half of the 20th century, the relative frequency of roller records has reduced, indicating that the probability of finding an R species in Italy has significantly decreased (−8.75%). Moreover, the marked reduction in the number of UTM cells where R species were present (−18.97%) shows that a decline in the occurrence of some species has taken place. These probabilities reduce strongly passing from the first to the last quarter of the 20th century: −31.41% of relative frequency for roller records and −23.85% of cells with R species. For a comparison, the probability of finding an R species in the Iberian Peninsula decreased by 21.48% and the number of UTM cells where R species were present decreased by 20.04% (Lobo, 2001).

A general increase in the number of surveyed UTM cells was registered for RT species until the third quarter of the 20th century when a drop occurred, while the R species decreased continuously along the whole 20th century.

Passing from the first to the second part of the 20th century, three species of *Gymnopleurus* (*G. geoffroyi*, *G. mopsus*, and *G. sturmi*), and three species of *Scarabaeus* (*Sc. pius*, *Sc. sacer*, and *Sc. typhon*) show a significant decline. *S. typhon* and *S. sacer* began its decline passing from the first to the second quarter of the 20th century; *G. geoffroyi* and *G. mopsus* began their decline passing from the second to the third quarter, while *Sc. semipunctatus*, *Sc. variolosus*, *G. flagellatus*, and *G. sturmi* began their decline passing from the third to the fourth quarter.

Data from southern Italy show an increase from the first to the second half of 20th century, but it is probably due to the intensification of entomological researches in those regions after the World War II. *Gymnopleurus geoffroyi* and *Sc. typhon* resulted to be the only species showing a net reduction of their occurrence in Italy from the first to the second part of the century. Two species, *G. sturmi* and *Sc. typhon*, decreased their occupancy from the first quarter until nowadays. Three species decreased their occupancy from the second quarter until nowadays (*G. flagellatus*, *G. geoffroyi*, and *G. mopsus*) and other three species dropped from the third to the fourth quarter (*Sc. semipunctatus*, *Sc. variolosus*, and *Sc. sacer*). The stronger decline in occurrence and occupancy (addressed by high χ^2 values) was generally observed in the last quarter of the 20th century. The general increase in the latitudinal and longitudinal ranges for the other species was probably a consequence of the increase of entomological surveys during the second part of the 20th century.

The stability in the mean number of R species in well-surveyed cells of the country, despite their rarefaction, is probably explained by the increased number of UTM cells in which these species were collected in the second part of the century. However, a relevant reduction of the rollers' diversity appeared from the third to the fourth quarter of the 20th century.

The positive increase of records observed both for RT and R species along the decades of the 20th century may be a consequence of the increase in entomological research. However, a net reduction of records for both RT and R species occurred in the last 30 years. The first category shows a slight fall while the R species showed a severe decline (Table 2; Fig. 3). The species firstly influenced by this decline are *Sc. pius* and *G. flagellatus*, both ever represented by a scarce number of records in the database. All the other species started to decrease since 1970–89.

Figure 4 General trend for the number of records of each R species over decades (log-transformed data).

Extinction process

The integrated application of different extinction indexes let us evaluate the real decline and eventually the extinction processes for the R species in Italy. Moreover, each index corroborates each other. *Gymnopleurus flagellatus*, *G. geoffroyi*, *G. mopsus*, *Sc. semipunctatus*, *Sc. sacer*, and *Sc. typhon* are all species sharing a large number of records: these wide series exclude the hypothesis that even little runs of absences at the end of the observation period could only be due to chance. According to the time series, these species are expected to have strongly declined in the Italian territory. For all these species, including also *Sc. pius*, future new records should be considered an uncommon event.

The long run of absences for many species in the first part of the century can be a result of scanty collections and of a little number of active entomologists in that period. On the contrary, in the second part of the century, *G. mopsus* and *G. geoffroyi* experienced a severe decline.

The non-significant values of the Solow & Roberts (2003) equation are due to the short time between the two last records of

the series for each species that implied a not influent reduction of the sighting rate. On the other hand, the non-significant values for the Solow equation (2005) are probably dependent on the choice of including all the records in the k most recent sightings, but today there is no clear indication of what we must consider as 'the most recent sightings' in a time series (see Solow, 2005).

Causes of the rollers' decline

According to the predicted curves, both the number of bovine heads and the number of bibliographic sources are important leading factors for trends in roller records. The number of bibliographic sources describes better the trend in number of roller records with respect to the number of bovine heads. In particular, it should be considered that both these models predicted a fall of records from the 60s (1960–69) to the 70s (1970–79). So, the reduction of roller records since the 60s could be a consequence firstly of the reduction in the number of entomologists collecting R species in the Italian territory and, secondly, of the reduction in the number of bovine heads in each decade. This

Figure 5 Variation in the number of roller records (—) and variation in the number of estimated roller records (---) considering (a) the number of papers published for each decade and (b) the number of grazing animals, as the only factors influencing this parameter (log-transformed data). Linear regression coefficients (R) and linear regression equations for the two models: (a) $R = 0.972$; estimated number of roller records = $1.437 \times$ best number of bibliographic fonts $+0.06092$; (b) $R = 0.954$; estimated number of roller records = $4.445 \times$ best number of bovine heads -15.109 .

assertion on the decreasing of scarab collectors in Italy was deduced by the decreased number of faunal articles on this group, as appeared on local bulletins.

The number of bovine heads reported for Italy considers both the free-ranging livestock and the stabled one. The first consists of animals left in open grasslands or woodlands from dawn to dusk, which leave their dung directly on the ground, while the second one is usually kept in stalls and their dung is used as manure. The latter is hardly used by dung beetles, especially by *R* species. Only the excrement of free ranging animals represents a food resource available for dung beetles, while the dung of stalled animals is generally added to cultivated fields when it is too dry and unsuitable for dung beetles. We do not know which quote of grazing animals for each decade was effectively free ranging, but the total number variation of bovine heads describes very well

the trend of roller records at all. In general, reconversion from traditional pastoralism to intensive farming of stabled animals in Italy began in northern Italy and only recently reached the southern regions, with a gradual process from the 50s to 90s. This consideration can explain the early start of rollers' decline in northern regions respect to central and southern regions.

In Italy, 16% of the land which was cultivated in the 1950s reverted to forests or to early seral stages in the 1980s (Di Cocco, 1988). Large sectors of the Maritime Alps and Apennines, once grazed by large herds of cattle and sheep, became poorly grazed and extensively covered by beech forest regrowth. Zunino (1982) suggested that these ecological changes as factors reducing local biodiversity.

A rapid conversion between pastures, intensive cultivations, and forests occurred in Italy from 1960 to 2000, as recently assessed for Spain in the same period (Zamora *et al.*, 2007). In particular, forest increased both in total area and in patch size. On the contrary, pasture dramatically decreased in the same period, and pasture patches became smaller, while the total agriculture surface remained mostly unchanged (Falcucci *et al.*, 2007). On the whole, an overall clear reduction of 49.30% was recorded for pasture areas from 1960 to 2000, accompanied by a decrease in traditional grazing of sheep and cattle (Falcucci *et al.*, 2007). From 1960 to 1990, notable are the changes occurred to pastures because 43% of their 1960s surface changed to forest. From 1960 to 1990, the clear reduction of pasture areas (-53.90%) was accompanied by a clear reduction in the occurrence of *R* species (-27.39%) in Italy. However, the most important changes occurred from 1990 to 2000, because a quarter of pasture surface changed to forest. The main reduction in pasture surface was observed in lowlands all over the country, in the Apennines and Sardinia. A drastic decrease of pastures in Sardinia followed the decrease of traditional grazing and it represents an important issue for wildlife conservation, not only for dung beetles. In fact, some birds associated to open wild areas, such as the little bustard (*Tetrax tetrax*) and the griffon vulture (*Gyps fulvus*), became very rare also in Sardinia, which was their last stronghold in Italy (de Juana & Martinez, 2001; Wolff *et al.*, 2001; Slotta-Bachmayr *et al.*, 2004). Griffon vultures are strongly dependent on traditional grazing practices and therefore have drastically dropped in number. Recently, Lunt & Spooner (2005) recognized the role of historical anthropogenic disturbance to understand patterns of biodiversity in fragmented agricultural landscapes, in order to determine biodiversity patterns. Nowadays, loss of habitat caused by changes in land use is considered the second most important factor affecting loss of biodiversity in the Mediterranean basin (cf. Sala *et al.*, 2000). Samways (2006) recognized the role of extensive land transformation for the extinction of extremely common species, and our data fit with this scenario of a fast alteration of habitat features (open grasslands with free-ranging livestock) followed by a rapid extinction of previously common species.

Some studies stressed the negative influence of helminthicides (e.g. ivermectin) and antibiotics on the dung beetle populations (Fincher, 1992; Holter *et al.*, 1994; Floate, 1998; Lumaret & Errouissi, 2002). Anyway, the observed decline and local extinction

of R species cannot be only explained by the increased use of these medicals in livestock because their effects should be shared by either R and T species. The first species have a clearly larger body size with respect to the latter and their apparent vulnerable status must depend on other factors. Kotze & O'Hara (2003) observed that the most declining beetles of North Europe are large species, associated to open grasslands, and imputed this decline to their biological cycle (*K*-selection, lower fecundity, etc.). A further factor being adverse to rollers (rather than to tunnellers) could be the enormous increase in the populations of the hooded crow (*Corvus corone cornix*), in Europe and particularly in Italy, in the last decades. Such an omnivorous corvid that forages in grasslands and feeds on large insects is actually considered a big menace for scarab beetles in general (Horgan & Berrow, 2004) and particularly for slow-moving and large-sized R species, as suggested by Carpaneto *et al.* (2005a).

CONCLUSIONS

As for the Iberian peninsula and other European countries (Belgium and France), Italy is affected by a decline of R species (*Scarabaeus*, *Gymnopleurus*, and *Sisyphus*), considering both the number of records and their area of occupancy. Such a reduction in roller occurrence was assessed notwithstanding the increased number of records and literature sources on scarab beetles in Italy during the second part of the 20th century, especially in the 70s.

Three species of *Gymnopleurus* (*G. geoffroyi*, *G. mopsus*, and *G. sturmi*) and three species of *Scarabaeus* (*Sc. pius*, *Sc. sacer*, and *Sc. typhon*) showed a significant decline in Italy, particularly in the last 30 years. Other two species disappeared from the majority of the northern regions (*Sc. typhon* and *Sc. pius*).

In particular, *Sc. typhon* and *Sc. pius*, were strongly affected by a reduction of their area of occupancy, with a complete disappearance in, respectively, one-third and two-fifth of the administrative regions. *Sc. typhon* encountered a local extinction in north-western regions (Liguria, Piedmont, Tuscany), remaining well represented in the other regions, while *Sc. pius* completely disappeared from almost all the northern regions (Liguria, Lombardy, Piedmont), but remained in some localities of Veneto and Emilia Romagna.

Decline occurred at first for 'weak' species, i.e. the species showing a low number of records in the Italian territory: *Sc. pius* and *G. flagellatus*. Moreover, finally, six species were recognized to be affected by a high risk of extinction in Italy: *G. flagellatus*, *G. geoffroyi*, *G. mopsus*, *Sc. semipunctatus*, *Sc. sacer*, and *Sc. typhon*. Among them, *G. mopsus* can be considered as practically extinct in Italy.

Possible factors that induced the roller decline in Italy are (1) a dramatic reduction of rangelands since 1960, due to either an increase of spontaneous reforestation or an intensive agriculture practices, and (2) a reduction of free-ranging livestock, particularly of bovine heads since the decade 1960–69, associated with an increase of stalled animals.

Some conservation practices can be encouraged in order to preserve scarab beetle diversity in pasture habitats, particularly R species:

- (1) enlarging bonuses for wild stock-farming practices in order to reduce stalling;
- (2) financing new investigations to define the carrying capacity of grasslands in order to favour the whole animal community of open areas, without a damage for plant cover; and
- (3) controlling population density of crows, by the removal of unauthorized dumps to reduce their basic food supply.

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