Species ecological preferences predict extinction risk in urban tenebrionid beetle guilds

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Abstract
A number of studies have attempted to investigate which species traits influence species proneness to extinction in vertebrates. By contrast, studies involving insects are scarce, because of difficulties in obtaining complex assessments of species extinction risk and measures of species traits. In this paper, a simple (binary) codification based on literature data and field observations was used to determine the importance of various traits (notably ecological preferences) in determining species vulnerability of the tenebrionid beetles inhabiting urban Rome (Italy). Vulnerability scores were calculated from measures of geographical, habitat and population rarity. Vulnerable species were distributed with similar proportions among different tenebrionid guilds, which suggests that conservation programs in urban ecosystems should be more addressed to the development of species-oriented actions than to the identification of priority ‘habitats’. Species traits accurately predicted species assignment to vulnerability classes, with some traits being particularly important in determining species vulnerability. Species associated with ruins and cellars, and which are typically fairly common in Rome, tend to be moderately or middle vulnerable. The identification of important sites for these species and definition of measures for population management would be useful strategies to preserve them.

Keywords
Coleoptera; rarity measures; Tenebrionidae; urban ecology; vulnerability

Introduction
Predicting the fate of species and correctly managing those that appear to be particularly prone to extinction are among the most ambitious tasks of conservation biology. A number of studies have attempted to investigate which species traits
influence species proneness to extinction. Research has been mainly focused on plants (e.g., Mills and Schwartz, 2005), fishes (Angermeier, 1995), birds (Kattan, 1992; Manne and Pimm, 2001), and mammals (Laurance, 1990; Dobson and Yu, 1993), whereas only few papers have investigated species ecological correlates of extinction risk in invertebrate taxa (e.g., Thomas, 1994; Koh et al., 2004; Driscoll and Weir, 2005; Shahabuddin and Ponte, 2005). These studies have typically involved both complex assessments of species extinction risk and particular measures of species traits, such as body size, mobility, trophic level, host specificity, larval and adult behaviours, etc. (Koh et al., 2004; Driscoll and Weir, 2005; Shahabuddin and Ponte, 2005). These measures are, however, difficult to obtain for most invertebrate taxa for several reasons (including the scarce attention currently paid to natural history and ecological studies based on broad sampling programs), which typically prevented their use in conservation studies (see Cardoso et al., 2011).

Rarity is often a precursor to extinction, and measures of different aspects of rarity (e.g., range extent, habitat specialization and population size) can be combined into measures of species vulnerability which are relatively easy to also obtain for insects (Fattorini, 2008a, 2010a, 2010b, 2011a; Fattorini et al., 2012). In addition, for most insect groups (at least in the best investigated geographical areas) there is a lot of information about their ecological traits. However, this information is typically qualitative (i.e., it is available in a descriptive, not quantitative form), anecdotal and dispersed in local and specialized literature. How can this precious information be used to study relationships between species ecological traits and their vulnerability?

The aim of this paper was to investigate the importance of various ecological traits (notably ecological preferences) in determining species vulnerability of the tenebrionid beetles inhabiting urban Rome (Italy) as an example of how anecdotal data dispersed in specialized literature can be used for similar purposes. In particular, I investigated which species ecological traits are important predictors of species vulnerability derived from rarity measures. Identification of major correlates of species vulnerability was then used to infer some conservation suggestions for tenebrionids in urban Rome.

For about two millennia, the area currently covered by the city of Rome was largely occupied by a semi-natural landscape, the so-called Campagna Romana. But with the beginning of the 20th century, the city started to expand into the Campagna Romana threatening the loss of natural biotopes of insects. Urban development is expected to have a deleterious impact on insect populations, if only because the construction of buildings in expanding suburbia reduces the area of natural and semi-natural biotopes within the city and their possible connections with other biotopes in the country surrounding the urban area. The quality of residual habitats may also be adversely affected by various forms of pollution (Tiple et al., 2007; Van Dyck et al., 2009) and inappropriate management of green areas (e.g., removal of attacked or dead trees essential for saproxylic species).

In general, there are several motivations for urban biodiversity conservation, including, among others, preserving local biodiversity, creating stepping stones
to non-urban habitats, understanding and facilitating responses to environmental change, conducting environmental education, providing ecosystem services, fulfilling ethical responsibilities, promoting individual’s environmental sensitivity, and improving human well-being (Dunn et al., 2006; Dearborn and Kark, 2009; Sanford et al., 2009). However, insect conservation in urban areas has received little attention (see Fattorini, 2011a, 2011b).

Currently, the city of Rome includes a large number of sites that contain biotopes suitable for insects, including several protected areas (Fattorini, 2011b). Tenebrionid beetles are a very diversified insect group, comprising some 1500 species and subspecies in Europe, and some 175 in mainland Italy (Fattorini, unpublished data). They are an important insect group for ecosystem functioning in Mediterranean areas, with high proportions of endemic and endangered taxa (Fattorini, 2008b). However, tenebrionid beetles are relatively poorly known, when compared with other groups, for which ecological data are much more detailed and abundant, such as butterflies and ground beetles, and are therefore an overlooked group in insect conservation. Many authors have stressed the importance of considering non-charismatic, little known taxa in conservation biology (Pearson and Cassola, 1992; Pimm and Gittleman, 1992; Dunn, 2005), and the present study qualifies for this purpose.

**Material and methods**

**Study area and taxa**

Urban Rome was defined here as the territory of the town encompassed by the great motorway ring that circumscribes an area of about 360 km² (see Fattorini, 2011b). Approximately one-half of this area is covered by built-up surfaces, whereas the other half is occupied by ruins, historical villas, archaeological sites, meadows, grasslands, gardens, parks, and suburban uncultivated grounds.

Tenebrionid occurrence in Rome has been investigated in another paper (Fattorini, 2011a), where primary data were published. These data were derived from: (1) an extensive literature survey of entomological papers on tenebrionids in Italy; (2) the examination of material preserved in various insect collections, which were the most complete for the study area; and (3) personal field research conducted through the entire study area from 1985 to 2000. Species that are strictly associated with man, and which are proved or suspected to be recent introductions, such as *Alphitophagus bifasciatus*, *Gnatocerus cornutus*, *Latheticus oryzae*, *Tribolium castaneum*, *Tribolium confusum*, and *Alphitobius diaperinus*, all associated with stored food, were not considered because entomologists rarely collect these pests. A total of 37, non-synanthropic species were then considered in this study. Further details and primary data can be found in Fattorini (2011a).
Species rarity

In order to fulfil Hartley and Kunin’s (2003) recommendations of considering different aspects of rarity, species rarity was assessed here using a multidimensional characterization that takes into account: (1) geographical distribution (wide/narrow distribution), (2) habitat specificity (broad/restricted habitat specificity) and (3) abundance (abundant/scarcely population; see Rabinowitz, 1981; Rabinowitz et al., 1986; fig. 1). Such a multidimensional characterization of species rarity has been previously applied to both vertebrates (e.g., Kattan, 1992; Dobson and You, 1993; Manne and Pimm, 2001) and arthropods (Fattorini, 2008a, 2010a, 2010b, 2011a; Fattorini et al., 2012).

Estimating the geographical rarity of a species depends on the spatial scale of analysis (Abellán et al., 2005; Fattorini et al., 2012). The use of the entire range size as a measure of geographical rarity would imply an excessively large scale for a study that is focused on species vulnerability at local scale. Thus, in this study species distribution in Italy was considered a more appropriate scale. Geographical rarity was therefore measured as the number of Italian administrative regions from which each species is known. Habitat specificity (Hughes et al., 2000) was evaluated by assessing species distribution across the 15 main phytoclimatic units occurring in Latium and defined on the basis of climatic indexes and vegetational settings (Blasi, 1994). In this case, the assumption is that the larger the number of phytoclimatic units occupied by a species, the wider the species ecological tolerance. On the basis of the examination of some 1800 museum specimens collected in urban Rome, the

![Flow-chart illustrating the methodological approach used in this paper.](image-url)
number of specimens collected for each species was considered a measure of local rarity, assuming contactability as a proxy for population size (cf. Strayer, 1999).

The very large sampling efforts made throughout more than a century by a number of collectors interested in different insect groups and who used any kind of collecting methods (hand searching, pitfall traps, aerial traps, soil examination, etc.) ensures that these data collectively form a ‘random’ sample, not affected by biases due to collector preferences for certain biotopes, sites or species. Further details about rationale and protocols used in this paper to assess species rarity can be found in Fattorini (2011a).

Based on these three rarity measures, an index of vulnerability was calculated for each species using Kattan’s (1992) approach. For this, an eight-celled model is created that reflects different types of rarity and commonness. Species were dichotomized into two groups (common and rare) according to whether they were above or below the median of the aforementioned three rarity measures and then assigned to a cell (cf. Arita et al., 1990). Species that fall in the cell ‘wide geographical distribution-broad habitat specificity-high abundance’ are ‘common’ in three dimensions (vulnerability index: 1), while those falling in the cell ‘narrow distribution-restricted habitat specificity-low abundance’ are ‘rare’ in three dimensions and are supposed to be the most vulnerable to extinction (vulnerability index: 8). Of the remaining six cells, three are rare in two dimensions and three are rare in one dimension (vulnerability index values 7-2). To rank these cells, species with narrow geographical distribution are more vulnerable at a global/regional level, and species with restricted habitat specificity are more vulnerable regardless of their abundance. This led to the following categorization: 1, species that are not rare; 2, scarce species (i.e., species rare for abundance); 3, species with narrow habitat specificity; 4, restricted species (i.e., species rare by range); 5, scarce species with narrow habitat specificity (i.e., species rare for both habitat specificity and abundance); 6, scarce and restricted species (i.e., species rare for both geographical range and abundance); 7, restricted species with narrow habitat specificity (i.e., species rare for both habitat specificity and geographical distribution); 8, restricted and scarce species with narrow habitat specificity (i.e., species rare for geographical distribution, habitat specificity and abundance). Fattorini (2011a) provides further details about the rarity measures and vulnerability index used here.

Species ecological preferences

Species ecological preferences were assessed on the basis of extensive literature reviews and personal observations. In general, I used data coming from personal observations made in urban Rome, but for species for which no sufficient data from Rome were available, I referred to data from Central and Southern Italy. Literature data were extracted from titles listed in Fattorini (2011a). Utility resources (sensu Dennis, 2010), biotope occupancy, soil preferences, and trophic habits, were defined using a binary (0-1) coding (fig. 1, supplementary table S1).
This corresponds to common practice of defining “habitat” preferences and species guilds using presence-absence data (e.g., Telfer and Eversham, 1996; Huges et al., 2000; Shreeve et al., 2001; Dennis, 2010) and is probably safer than the use of quantitative data, especially for rare species. In fact, presence-absence data tend to better explain habitat relationships of rare species than abundance data (Cushman and McGarigal, 2004). Moreover, using binary state attributes is more conservative than abundance-based indices: for example, a species that is distributed in some biotopes but which is concentrated in only one of them, would appear to be very rare if abundance data were used, and less rare if only the number of occupied biotopes is considered.

The following 12 utility resources (environments) were scored in the present paper: stones; barks (without preferences for tree species); beech bark; chestnut bark; oak bark; elm bark; poplar bark; olive bark; plane tree bark; willow bark; pine bark; strawberry bark.

The same approach was used to score 15 biotopes used by tenebrionids: ruins; gardens; cellars; livestock buildings; uncultivated arid land and garrigues; arable fields; wet areas; sand dunes and banks; lower maquis; high maquis; broadleaves woods; coniferous woods; caves; fungi; ant nests.

Based on preferences for soil characteristics, species were scored for sandy soils, rocky soils and organic soils (i.e., soils with abundant litter and/or humus). Finally, based on trophic habits, species were scored for the following five types of food: plants (phytophagous); fungal matters (mycophagous); decaying matter (detritivorous); dung (coprophagous); dying animals (subpredator). For simplicity, all variables will be referred to as ‘ecological preferences’. Species ecological preferences are summarized in table S1.

**Local guild identification**

The term ‘local guild’ is used here to identify a group of species that share a common resource and occur in the same community (Dennis, 2010). Local guilds were identified using the whole set of ecological attributes reported in table S1. Guilds were identified using cluster analysis (cf. Krasnov and Shenbrot, 1998) (fig. 1). Because ecological preferences were expressed by binary variables, a similarity coefficient for binary data was used. A large number of coefficients that use binary data to measure association between objects is presently available. On the basis of Shi’s (1993) review, Jaccard, Dice, Simpson, Kulczynski #2, and Ochiai coefficients were utilized in this research. Pairwise similarities were then clustered using the average linkage rule (UPGMA). This technique seems to minimize the distortion of an original data matrix better than other available amalgamation techniques (McGarigal et al., 2000). To test if data actually contain clusters, the cluster matrix was correlated with a cophenetic value matrix of the original data. If the two matrices produce high cophenetic correlation coefficient (CPCC) they actually have the same clustering patterns (Rohlf, 1993). In general, all the aforementioned indices produced similar dendrograms. On the basis of the highest cophenetic correlation
coefficient, results with Jaccard coefficient were preferred (CPCC = 0.876). Cluster analyses were undertaken using PAST software (Hammer et al., 2009).

To identify the appropriate number of clusters (corresponding to meaningful guilds), I followed the method suggested by McGarigal et al. (2000). The fusion level (dissimilarity values) was plotted against the number of clusters, and the resulting curve used to evaluate the appropriate number of clusters to retain. The point at which the curve first begins to straighten out is considered to indicate the maximum number of clusters to retain. This led to the identification of four main clusters (guilds) at a cut-off value of about 0.7.

To assess if the frequency of the vulnerability categories differed among guilds, a G-test was applied to a contingency table. The G-statistic corresponds to the \( \chi^2 \) likelihood ratio, obtained using the maximum likelihood method (see Sokal and Rohlf, 1995). A significant result indicates association between the rows and columns in a contingency table.

**Discriminant analysis**

To assess if species ecological preferences are good predictors of species vulnerability, discriminant analyses were performed (fig. 1). First, on the basis of vulnerability scores obtained using Kattan’s approach described above, species were grouped into four classes of vulnerability: highly vulnerable species (vulnerability scores 8-7); medium vulnerable species (vulnerability scores 6-5); fairly vulnerable species (vulnerability scores 4-3); not vulnerable species (vulnerability scores 1-2). This classification into four categories was preferred to the eight category classification for two reasons: first, it is more conservative; second, it reduces the number of categories which cannot be very numerous because of the relatively small number of cases (37 species). A first discriminant analysis was then performed to assess whether ecological preference data are able to predict species vulnerability category. The following variables were excluded from the analysis as completely redundant (tolerance < 0.0001; tolerance is \( 1 - R^2 \), where \( R^2 \) is the square of the multiple correlation): organic soil, rocky soil, sand soil, ant nests, fungi, pine bark, olive bark, willow bark.

Discriminant function analysis can be applied to binary data to identified patterns, but in this case it is suspected to produce less rigorous outcomes than for continuous data (McGarigal et al., 2000). Moreover, because of the large number of variables, significance of Wilks’ lambda can be seriously affected by colinearity between variables. Thus, I did not focused on statistical significance of canonical roots, but on the percentage of correct classifications as a measure of the discriminant efficiency of the variables. For this, I have calculated the percentage of correctly classified cases (species). Here, the approach was that of testing if the species trait variables are adequate predictors of vulnerability, so the focus was on their ability to correctly classify the species, not on their statistical significance. For this second purpose (i.e., to identify important variables), I used another approach.
I performed a stepwise (forward) discriminant function ($F$ to enter $= 1.00$; $F$ to remove $= 0.00$) to remove redundant variables and isolate those that most contributed to discrimination. This reduce the number of species which will be correctly classified, but remove the effects of collinearity, thus increasing statistical significance. Structure coefficients (within-groups correlations of variables with the respective discriminant (canonical) functions) were then examined to identify the most important variables among those selected by the stepwise method. To assess if there was an association between vulnerability categories and species characteristics selected by discriminant analysis, a contingency table was analysed with $G$-test (see Koh et al., 2004 for a similar approach). Both discriminant analyses were performed using Statistica 6 software (Statsoft, 2001). An overview of the methodological approach used in this paper is given in fig. 1.

Results

Species vulnerability and ecological preferences are reported in table S1. Figure 2 shows tenebrionid guilds identified on the basis of ecological preferences. As a whole, cluster analysis showed a basic separation between ground dwelling species and arboreal species. Ground dwelling species are then subdivided into two main groups. The first group (cluster 1 in fig. 2) includes species associated with open dry areas with various soil types (Pedinus meridianus, Gonocephalum spp. and Catomus rotundicollis) and two species with sand soils (Melanimon tibialis and Tentyria grossa). The second group is more numerous and is in turn subdivided into two subgroups: one (cluster 2 in fig. 2) including species associated with ruderal areas (Akis spp., Blaps spp., Scaurus striatus, and Asida luigionii), and the other (cluster 3 in fig. 2) including species which can also be found under bark (Stenosis spp.), under stones in open and dry areas (Cossyphus tauricus, Opatrum sabulosum, Tentyria italica), or which are associated with ants (Oochrotus glaber, a strictly myrmecophilous species, and Dichillus minutus, which is not strictly myrmecophilous).

Among the arboreal species, Diaperis boleti, a mycetophagous species, is well apart. Other distinct species are Platydema violaceum (associated with wet areas) and Corticeus spp. (subpredators feeding on scolitid beetles). The other arboreal species are grouped into a well defined group (cluster 4 in fig. 2), including both phytophagous species (Accanthopus velikensis, Colpotus strigosus, Helops caeruleus, and Scaphidema metallicum) and more phyto-saprophagous species (Nalassus spp., Neatus noctivagus, Palorus depressus and Uloma culinaris). With a cut off level at a distance of about 0.7, four guilds, corresponding to clusters 1-4, can be recognized. No significant association was found between guilds and vulnerability categories ($G = 15.763, df = 9, P = 0.072$).

A discriminant function showed that ecological preferences can adequately predict species vulnerability. A scatterplot of species distribution in the space defined by the first two discriminant functions indicates a good separation of the four vulnerability categories (fig. 3). Only three species (8.11%) were incorrectly classified:
Figure 2. Dendrogram yielded by hierarchical cluster analysis of tenebrionid species based on ecological preferences reported in table S1. Numbers refer to main guilds, corresponding to well defined clusters.
Figure 3. Results of discriminant analysis (first two canonical axes). Abbreviations for species based on first genus letter and first three species letters (see table S1 for species names). Vulnerability categories: A, not vulnerable; B, fairly vulnerable; C, middle vulnerable; D, highly vulnerable.

*Cossyphus tauricus* (a priori classification: B; a posteriori classification: C), *Dendrarus coarcticollis* (a priori classification: A; a posteriori classification: C) and *Gonocephalum granulatum* (a priori classification: A; a posteriori classification: C). However, because of the large number of variables, Wilks’ lambda ($\lambda$) was not significant ($\lambda = 0.155, P = 0.506$).

Using a stepwise procedure, the following variables were retained in the final model, which was significant ($\lambda = 0.216, P < 0.017$; variance explained by the first two canonical roots: 82.4%): oak bark, beech bark, ruins, cellars, broadleaves woods, coniferous woods, uncultivated arid land and garrigues, livestock buildings, decaying matter. Examination of structure coefficients associated to these variables for the first two discriminant functions, reveals that the most important variables were ruins, cellars, broadleaves woods, oak bark, beech bark, and decaying matter. A significant association was found between these six ecological traits and vulnerability categories ($G = 28.989, df = 15, P = 0.016$).

**Discussion**

This study was essentially correlative. I used a first set of rarity variables (range size, habitat distribution and population abundance) to derive vulnerability scores for each tenebrionid species inhabiting urban Rome. A completely different set of variables, reflecting species ecological preferences, were then used in a discriminant analysis to explore if they were able to place the species into the same vulnerability
classes obtained by rarity measures. These ecological variables (comprising species diet, soil preferences, biotopes and resources used by the species) were based on data (literature records and personal observations) which were not collected specifically for this study and reflect, in general, a very rough knowledge. Nevertheless, they were efficient in predicting species allocation into vulnerability classes. As such kind of information is typically available for most insect groups, this result suggests that similar good findings can be expected for other groups.

The same ecological variables were able to classify species into well defined guilds. However, there was no clear association between guild membership and vulnerability class; in other words, vulnerable species tend to be distributed with similar proportions among guilds. Thus, there is no particular functional group of species that is more vulnerable than others. Many conservation programs, especially for invertebrates, are based on the identification of priority ‘habitats’ (see Fattorini, 2010a, 2010b). Results obtained in this study should suggest more caution against attempts of selecting priority ‘habitats’ for species protection, because vulnerable species tend to do not cluster into the same class, at least in the case of highly fragmented and human modified ecosystems as those of cities. Thus, insect conservation programs in urban ecosystems should be more addressed to the development of species-oriented actions than to the identification of priority ‘habitats’ (cf. Dunn et al., 2006; Hunter and Hunter, 2008).

Because of the very large number of variables originally considered in this study, a stepwise procedure was applied to prune predictors. This allowed the identification of a set of characteristics which can be considered particularly important in predicting species vulnerability. Focusing on these predictors, there is a significant association between selected species characteristics and vulnerability classes. In particular, while species with saprophagous feeding habits are the most represented in all four vulnerability classes, species associated with ruins tend to be more frequent in the fairly vulnerable and middle vulnerable categories, and those associated with broadleaves woods are more frequent in the highly vulnerable category. These results suggest that the most vulnerable species are to be found among the few species which tend to be restricted to the few, sparse and small remnants of broadleaves woods present in the city. However, these results should be considered very provisional and merely suggestive, because of the very small number of species included in the analysis. Species associated with ruins and cellars (see Aliquò et al., 2006), and which are typically fairly common in Rome, such as *Asida luigionii*, *Akis bacarozzo*, *Blaps* spp., tend to be moderately or middle vulnerable. A complex epigean system, coupled with many monumental, ruderal and archaeological areas widespread through the entire city (including suburbs), may enable the maintenance of relatively large populations of these anthropophilous species, confirming the importance of archaeological sites for insect conservation (Fattorini, 2011a). Because most archaeological sites are already protected because of their historical importance, insect conservation measures in these areas should be easier. Thus, the identification of important sites and definition of measures for population
management would be useful strategies to preserve these species that find suitable biotopes in the urban area (cf. Dunn et al., 2006; Hunter and Hunter, 2008).

Because of the exploratory purposes of the statistical analyses adopted in this study, it is not possible to infer the true mechanisms underlying the observed patterns. However, the results obtained here clearly indicate that species ecological characteristics are in some way associated with, and likely responsible for, vulnerability.

Supplementary material

See table S1 as supplementary material in the online edition of this journal, which can be accessed via http://www.brill.com/ab.

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