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# Insect extinction by urbanization: A long term study in Rome

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ABSTRACT

Previous studies deduced negative effects of urbanization on insect conservation from decline in species richness with increasing built-up areas. This is the first study that investigates insect extinction determined by urbanization using a long-time temporal data set from hidden literature data and museum collections. Analyses were conducted for four insect groups in urban Rome: butterflies, coprophagous scarabaeids, non-coprophagous scarabaeids and tenebrionids. A reconstruction of extinction trends from 1885 to 1999 indicates impressive declines in species richness, with differences according to the ecological characteristics of each insect group. Results obtained in this study suggest that insect conservation programs should involve a thorough assessment of which species of conservation concern benefit from green spaces in urban areas, and then the identification of important sites and appropriate measures for population management.



## 1. Introduction

Biodiversity conservation in urban areas is a debated issue. Although Hunter and Hunter (2008) and Dearborn and Kark (2009) highlighted several reasons to support conservation programs in urban areas, other conservationists claim that designation of protected areas within towns may divert public opinion, and hence founds, from more important, natural biodiversity reservoirs (Battisti and Gippoliti, 2004). However, the debate has been mainly driven by experiences on plant and vertebrate conservation, because detailed studies on the effects of urbanization on invertebrate persistence, and on the possible role of urban green spaces in maintaining residual local biodiversity are rare (see Zapparoli, 1997a; Gaston et al., 2005; Hunter and Hunter, 2008; Dennis, 2010 for reviews). A few researches have investigated insect species loss in urban areas (e.g. Rickman and Connor, 2003; Ishitani et al., 2003; Ferreira and Tidon, 2005; Sanford et al., 2008). However, in these researches, a negative impact of increasing urbanization on insect persistence has not been observed on a temporal basis, but deduced by a decrease in insect diversity from peripheral (non-urbanized) areas to city centre. Thus, temporal patterns of insect extinctions induced by increasing urbanization remain obscure. This situation is not limited to urban areas, but reflects a more general state of affairs. Studies aimed at the identification of the ecological correlates of extinction proneness in insects have an invariably snap-shot scale of observation, because of the difficulty of obtaining sufficiently accurate information about insect species persistence over long periods (e.g. Koh et al., 2004; Shahabuddin and Ponte, 2005).

Urban Rome offers an intriguing opportunity for a long time study because of various favourable conditions:

(1) Rome is one of the oldest cities in the world, continuously inhabited for more than 2500 years.
(2) For about two millennia Rome area was largely occupied by a semi-natural landscape, the so-called ‘Campagna Romana’ (Zapparoli, 1997a), with built-up covering a very small proportion of current city area. Thus, urban expansion in the XX century took place on an area that had been practically uninhabited.
(3) Modern urbanization proceeded in a jeopardized fashion, with relicts of Campagna Romana embedded in the urban tissue, sometimes as green enclaves completely surrounded by built-up areas.
(4) Thanks to a longstanding entomological tradition, with large collections dating from the end of the XX century, it is possible to trace changes in local insect faunas from the initial phase of modern urbanization to current times.

To study patterns of species extinction by urbanization, I selected four insect groups with different ecological characteristics among the best investigated in urban Rome: butterflies (Lepidoptera Papilionoidea: 60 species), tenebrionid beetles (Coleoptera Tenebrionidae: 37 species), coprophagous scarabaeids (Coleoptera Scarabaeoidea: Geotrupidae, Hybosoridae, Ochodaeidae,

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Aphodiidae, Scarabaeidae: 87 species) and non-coprophagous scarabaeids (Coleoptera Scarabaeoidea: Glaphyridae, Melolonthidae, Rutelidae, Dynastidae, Cetoniidae: 39 species).

Butterflies are the most popular insect group in biological conservation and are typically seen as the invertebrate counterparts to birds. Butterflies have relatively good dispersal ability, but are also particularly sensitive to environmental characteristics of green urban areas because they feed on plants as both larvae and adults (Dennis, 2010).

Tenebrionids (both adults and larvae) are primarily saprophagous, feeding on a variety of dead plant and animal matter. Adults of xylophilous species can be found under barks, whereas soil dwelling species are usually encountered under stones (Fattorini, 2010). Soil dwelling tenebrionids are generally wingless and have limited dispersal ability. This family includes a number of anthropophilous species associated with ruderal areas (Fattorini, 2001).

Both larvae and adults of coprophagous scarabaeids typically feed on mammal dung. Adults of non-coprophagous scarabaeids feed on leaves, flowers or fruits, while their larvae feed on roots or decaying woods. The conservation of dung beetle communities in green urban areas is strongly affected by reduction to complete disappearance of grazing herbivores (Carpaneto et al., 2005), whereas inappropriate garden policy management may have negative effects on the persistence of saproxylic species (Carpaneto et al., 2010).

For these four insect groups I used data spanning from 1885 to 1999 to model extinction patterns. From these patterns I derived some considerations about how urbanization affects insect species persistence and some recommendations for insect conservation in the urban environment.

## 2. Material and methods

### 2.1. Study area

Until 1860–1870, when Rome was annexed to the Italian Kingdom, the city was about 14 km$^2$ wide (with just one third of the town occupied by built-up areas) and had 200,000 inhabitants. The surrounding 'Campagna Romana' (3500 km$^2$ wide, 4 inhabitants/km$^2$) was characterized by a very pristine environmental condition, because economic and social conditions, coupled with the presence of malaria, prevented an effective colonization. Most of this territory was occupied by wild grazing and wheat areas (Zapparoli, 1997a). Today, Rome is Italy's largest city, with a population of about 3,000,000 inhabitants. As in other researches (see Zapparoli (1997a,b) for review), urban Rome was defined here as the territory of the town encompassed by the great motorway ring that circumscribes an area of about 360 km$^2$. 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. The Tevere and Aniene rivers occupy an area of about 25 km$^2$.

### 2.2. Data sources

Data were taken from Carpaneto and Piattella (1997) for scarabaeids, and from Zilli (1997) for butterflies. A list of tenebrionid species occurring in the study area and their temporal occurrence has been derived from: (1) an extensive literature survey of entomological papers on tenebrionids in Italy (including the 311 titles reported in Fattorini, 2010, plus further four titles); (2) the examination of material preserved in various insect collections (see Acknowledgements and Appendix A – Supplementary material), which were the most complete for the study area; and (3) personal field research conducted through the entire study area from 1986 to 1999. Field research was particularly addressed to establish the persistence of rarely sampled species, and involved accurate hand searching under barks (in forest biotopes) and under stones (in open biotopes) in the most important archaeological sites, urban parks and historical villas of the city, including all the 12 preserves of the RomaNatura network (the largest system of protected areas in Rome, covering about 14,000 hectares).

Tenebrionids include certain cosmopolitan species, such as *Alphitophagus bifasciatus*, *Gnatocerus cornutus*, *Latheticus oryzae*, *Tribolium castaneum*, *Tribolium confusum*, and *Alphitobius diaperinus*, which are associated with stored food. Entomologists rarely collect these species because they are common pests and their occurrence in urban Rome is as obvious as poorly understood. Therefore, they were not considered in the analysis. No alien species has been recorded among scarabaeids. By contrast, a butterfly, *Cacyreus marshalli*, has been introduced into Rome in 1996 and it was excluded from the analyses.

Taxonomy follows Zilli (1997) for butterflies, Carpaneto and Piattella (1997) for scarabaeids and Löbl and Smetana (2008) for tenebrionids.

### 2.3. Statistical analyses

#### 2.3.1. Species persistence through time

To study species loss through time, I applied an approach similar to that used by Fattorini (2008). First, I divided the study period into decades. The present-day presence and distribution of insect species in the study area is typically relictual (Zapparoli, 1997a). Therefore, discovery of new species through decades has to be regarded as a collection of species previously present but not sampled, not as additions to the local fauna by immigration. Thus, the latest decade in which a species has been found was considered as the decade in which the species disappeared from the study area, i.e. the decade in which the species was lost (Fattorini, 2008). Species were therefore considered as continuously present in the study area from the first period considered in this study (1880–1889) to the decade of the most recent record(s), even if actually not recorded in some decades included in this range. Rare species might appear to go extinct sooner than common species, simply because rare species are less often sampled. It is difficult to account for this possible bias. However, this bias is probably reduced by the very large sampling efforts made through each decade and notably in recent years. Decades from 1900 to 1949 were grouped because of the dearth of data for the oldest periods. Thus, species persistence was evaluated for six temporal intervals: (1) 1900–1949, (2) 1950–1959, (3) 1960–1969, (4) 1970–1979, (5) 1980–1989, (6) 1990–1999 (Appendix B – Supplementary material).

#### 2.3.2. Percentages of cumulative number of extinct species per decade

To make all groups fully comparable, I considered not the cumulative raw number of extinct species per decade (Nex), but the percentage of cumulative number of extinct species per decade [%ex = (Nex/Ntot) × 100]. Temporal trends of percentages of cumulative number of extinct species per decade (%ex) for the decades 1950–1999 were modelled using several functions: linear, exponential, power, and logistic. For each insect group, alternative models were compared using the $R^2$ statistics as measures of goodness-of-fit.

#### 2.3.3. Relative percentage of extinct species

It is obvious that the aforementioned method gives a monotonically increasing pattern, because extinctions necessarily increase through time. Thus, to investigate variations in the rate of extinction, I adopted another approach. For each decade, I considered the relative percentage of extinct species (%rex) as the percent number of extinct species with reference to the species present in the previous decade [%rex = $(\mathrm{Nex}_i/\mathrm{Nt}_{i-1}) \times 100$, where $\mathrm{Nex}_i$ is the number of species extinct in the *i*-decade, and $\mathrm{Nt}_{i-1}$ is the total number of species still present in the $(i-1)$-decade].

*2.3.4. Trends in species decline*

I used the number of species assumed as still present in each decade (from 1950 to 1999) to estimate how sharply species were lost. The aim here was to obtain the best predictive function which relates the number of species per decade to the progressive number of decades, without reference to any theoretical model. For this purpose I used polynomial approximations. When selecting a polynomial approximation, I started with the lower power of the independent variable (decade number). Degree of the polynomial function was then increased until about 95% of variance was explained.

*2.3.5. Cross-group comparisons*

Correlations between temporal variations in %ex and %rex among groups were tested using a Spearman correlation coefficient ($r_s$). Differences in the overall proportions of extinct species among groups were tested using a contingency table.

The last decade (1990–1999) was incomplete for butterflies and scarabaeids because I referred to papers published in 1997. However, no additional species was collected or observed from 1997 to 1999 during personal field research, thus this did not alter the calculation of %ex and %rex. In all tests, a minimum probability level of $P < 0.05$ was accepted. I made many tests on the same data set, thereby increasing risk of significant results occurring by chance. Although the sequential Bonferroni has become the standard method of dealing with multiple statistical tests, I believe that decreasing the significance level would have resulted in an even higher risk of ignoring real relationships. Thus, in accordance with the suggestions of Moran (2003), I did not apply the Bonferroni correction, but focused on *P*-values and consistence of results.

## 3. Results

Species persistence through decades is reported in Appendix B (Supplementary material). Temporal variations in percentages of cumulative number of extinct species per decade (%ex) and relative percentages of extinct species (%rex) in the four investigated insect groups are reported in Fig. 1. For the tenebrionid beetles, %ext increases with time according to an exponential function ($y = 4.850e^{0.375x}$, $R^2 = 0.945$). Extinction of coprophagous scarabaeids was also well modelled by an exponential function ($y = 31.99e^{0.144x}$, $R^2 = 0.994$), but a simple linear function provided a comparable fit ($y = 7.191x + 28.764$, $R^2 = 0.988$). Extinction of non-coprophagous scarabaeids followed a similar pattern ($y = 31.11e^{0.1192x}$, $R^2 = 0.985$ for the exponential model, $y = 5.385x + 28.974$, $R^2 = 0.976$ for the linear model). Butterflies were best modelled by an exponential function ($y = 31.106e^{0.0677x}$, $R^2 = 0.800$), but the percentage of explained variance was relatively moderate.

Overall, variations in %ext for tenebrionids indicate an accelerated accumulation of extinct species, while in scarabaeids (both coprophagous and non-coprophagous) extinction proceeded at a more constant rate. In the butterflies, a large number of extinctions occurred before 1950, no extinction was recorded from 1960 to 1979, but a few extinctions occurred after 1979. An analysis of %rex reveals that in tenebrionids, no species disappeared before 1950, whereas %rex was relatively constant from 1950 to 1989, but increased in 1990–1999. By contrast, in the scarabaeids, a relatively high number of species disappeared before 1900, and values of %rex were highly variable, with a peak of relative extinctions in 1950–1959 (about 32% of the coprophagous species and 27% of non-coprophagous still present before 1950).

The number of butterfly species assumed as still present in each decade was well fitted by a 3-degree polynomial function ($y = 0.167x^3 - 2.071x^2 + 5.762x + 35$, $R^2 = 0.955$). A projection using this equation shows a virtual stop of extinctions in the next 10–20 years. In the case of tenebrionids, a parabolic (2-degree polynomial) function was sufficient to explain >95% of variance. The fitted equation ($y = -0.5x^2 + 0.7x + 34$, $R^2 = 0.986$) predicts the extinction of all species within the decade 2030–2039, i.e. within the next 30 years. In the case of the two groups of scarabaeids, a linear function was sufficient to explain >95% of variance. The fitted equation for the coprophagous scarabaeids ($y = -6.4x + 63.4$, $R^2 = 0.988$) predicts the extinction of all species within the decade 2040–2049), i.e. within the next 40 years, whereas the fitted equation for the coprophagous scarabaeids ($y = -2.1x + 27.7$, $R^2 = 0.976$) predicts the extinction of all species within the decade 2070–2079, i.e. within the next 70 years.

Temporal variation in %ex followed a similar pattern in the three groups ($r_s > 0.941$, $P < 0.01$ in all cases). By contrast, values of %rex were correlated between butterflies and non-coprophagous scarabaeids ($r_s = 0.928$, $P < 0.001$), but not among other groups ($P > 0.05$). Proportions of extinct species in the four insect groups were significantly different ($\chi^2_{(3)} = 13.293$, $P < 0.01$).

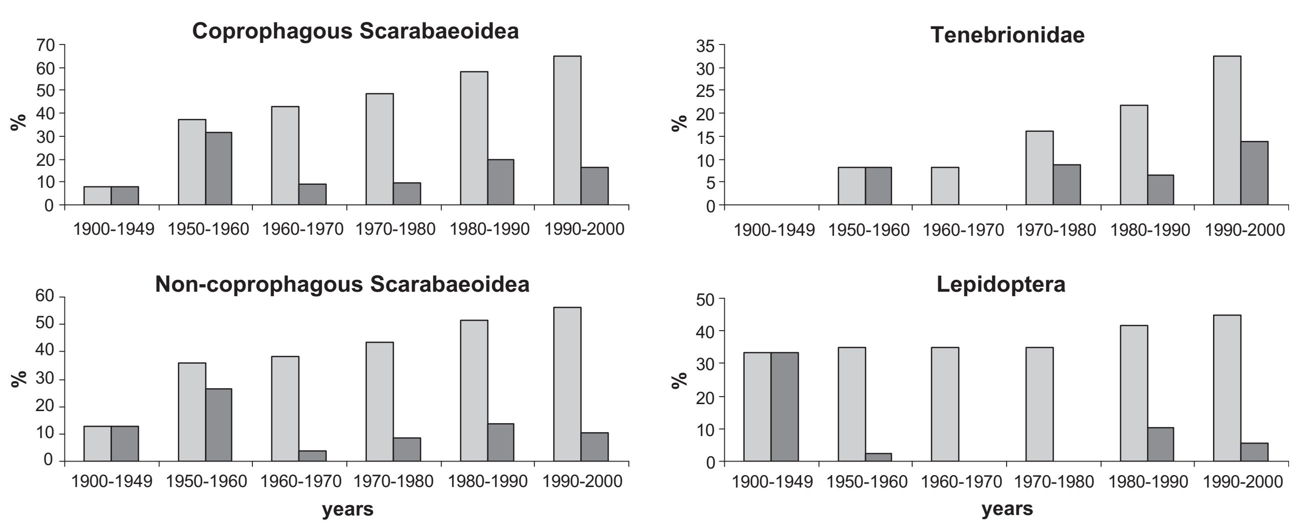


**Fig. 1.** Temporal trends in percentages of extinct species (%ex, light gray) and relative percentages of extinct species (%rex, dark gray) for four insect groups in urban Rome.

## 4. Discussion

Peaks of insect extinction in urban Rome are distinctly related with the urbanization process. Between 1871 and1930 many green spaces associated with the largest historical villas were destroyed or deeply modified (Zapparoli, 1997a,b). Extinction of most of the scarabaeid species that disappeared earlier, occurred as an obvious consequence of these changes, and involved the most specialised species. For example, the extinction of sand-dwelling scarabaeids, such as *Scarabaeus sacer*, *Scarabaeus semipunctatus*, *Rhyssemus plicatus* and *Rhyssemus sulcatus*, which were associated with the sandy banks of Tevere and Aniene rivers, has been determined by the serious alteration of the banks of these rivers to solve the problem of periodical floods occurring in the city.

The percentage of extinct species was higher in coprophagous (65%) than in non-coprophagous (56%) scarabaeids (see Fig. 1), a consequence of the almost complete disappearance of grazing even in suburban Rome after the 1960s. Among the coprophagous species, there are several cases of insects which are really scarce and localised in the entire Apennine range, and which were already rare in urban Rome, such as *Geotrupes mutator*, *Trypocopris pyrenaeus*, *Aphodius biguttatus*, *Aphodius brevis*, *Aphodius distinctus, Aphodius lugens*, *Aphodius reyi*, *Onthophagus andalusicus*, *Onthophagus nuchicornis*, and *Gymnopleurus flagellatus*. These beetles were collected in urban Rome only occasionally, typically at the beginning of the XX century. By contrast, other coprophagous scarabaeids, such as *Gymnopleurus mopsus*, *Copris lunaris*, *Chironitis irroratus*, *Chironitis furcifer* and *Euoniticellus pallipes*, now disappeared, were once common in Rome, as testified by the large number of specimens collected from several localities in the city until 1970. Although the urban area of Rome still contains several grazing areas which might host rich communities of coprophagous scarabaeids, lack of appropriate dung (e.g. sheep dung) is an important cause of extinction (Carpaneto et al., 2005). In particular, loss of some large-sized species, such as *Scarabaeus laticollis* and *Thorectes intermedius*, may be a result of the incapacity of dog scats to sustain large sized beetles. By contrast, dog scats may favour some rare species, such as *Onthophagus coenobita* and *Aphodius johnsoni*, which prefer the dung of omnivorous animals (Carpaneto et al., 2005).

Among non-coprophagous species, flower-visiting beetles, such as *Liocola lugubris*, *Potosia fieberi* and *Potosia opaca*, became extinct at the beginning of the XX century, whereas *Eupotosia mirifica* occurred until the 1940s and *Anthypna carceli* and *Trichius rosaceus* until the 1950s. The high percentages of scarabaeid extinctions occurred in the period 1950–1960, when compared to those of the period 1900–1950, suggests that the main factors which contributed to scarabaeid loss were those associated with the chaotic and uncontrolled urbanization occurred between 1950 and 1960. Many of the non-coprophagous scarabaeids are today very rare and confined to semi-natural environments in the largest historical villas or in some enclaves of the 'Campagna Romana' in the built-up area. Some saproxylic species, such as *Oryctes nasicornis* or *Osmoderma eremita*, are however present on their host plants even if these are out of their natural plant associations, as in historical villas and sometimes along the urban streets, but are endangered by garden policy management, such as the removal of dead trees or interventions made on attacked trunks (Carpaneto et al., 2010).

As regards the tenebrionid beetles, most of the early extinctions were recorded among sand dwelling species associated with Tevere's and Aniene's banks. In particular, *Cnemeplatia atropos* disappeared before 1900 and *Melanimon tibialis* before 1950, whereas the highest percentage of extinction was recorded at the end of the 1980s, when ground-dwelling species associated with arid and sandy soils, such as *Tentyria italica*, *Gonocephalum obscurum*, *Opatrum sabulosum* and *Cossyphus tauricus*, disappeared. On the whole, tenebrionids had a lower percentage of extinct species (32%) compared with scarabaeids (62.5%) and butterflies (45%). This lower percentage of lost species in tenebrionids can be explained by the occurrence of several arboreal, but eurytopic species (such as *Colpotus strigosus*, *Dendarus coarcticollis*, *Catomus rotundicollis*, *Accanthopus velikensis*, *Nalassus* spp.), able to survive in the largest parks of the city, as well as some anthropophilous species, associated with ruderal and archaeological sites, such as *Asida luigionii*, *Scaurus striatus*, *Akis bacarozzo*, *A. italica*, *Blaps* spp.

Butterflies showed an even more different pattern of species loss. No extinction occurred before 1900. Ecological changes occurred in 1900–1949 were, in contrast, particularly serious for butterflies, because 33% of species were lost in this period, and an additional 2.5% of species disappeared in 1950–1960, whereas no further extinction occurred in 1960–1980. Most of the species that disappeared early (such as *Lycaena tityrus*, *Thecla quercus*, *Cupido alcetas*, *Aricia agestis*, *Boloria dia*, *Apatura ilia*, *Melanargia arge* and *Pyronia tithonus*) are really scarce and localised in their entire Apennine range (Prola et al., 1978), and were therefore never common in urban Rome. In most cases, destruction of suitable biotopes (namely woodlands) is probably the major cause of extinction. For example, loss of *Zerynthia polyxena* before 1950 can be associated with the disappearance of suitable habitats with the host plant *Aristolochia rotunda* L. Increasing isolation of patches of suitable biotopes could be an additional factor responsible for the decline of certain species. For example, the extinction of *Melanargia arge* in urban Rome was considered by Verity (1953) as a result of biotope alteration due to urbanization, but according to Zilli (1998) spatial isolation is a more important cause of extinction, because suitable xeric biotopes are still present in the study area. Other species disappeared between 1980 and 1999, but with decreasing relative percentages of extinct species. This suggests that the most sensitive species disappeared early, and that the remaining fauna was composed of so tolerant species that further ecological changes had a limited impact on them. For example, butterfly species with high dispersal power and metapopulation dynamics, such as *Papilio machaon*, *Pieris rapae* or *Vanessa atalanta*, tend to be less affected by urbanization and are widespread in urban Rome, because they are able to survive even in very scattered and small patches of suitable biotopes. In some cases, habitat alteration caused by urbanization favoured certain species which are more abundant in urban Rome than in the adjacent rural areas, such as *Polygonia egea* (associated with *Parietaria judaica* L., which is a common plant on walls and ruins) or *Papilio machaon* (which feeds on carrots and fennels growing in disturbed sites and even along the edges of streets). Another species' habit that may increase the probability of persistence in the urban area is the ability of using different biotopes at different development stages. For example, nymphalids, such as *Inachis io* and *Vanessa atlanta*, use garages, cellars, warehouses to overwinter as adults (Zilli, 1998).

Cross-taxon positive correlation in percentages of cumulative number of extinct species per decade is a rather trivial result because cumulative curves are inherently increasing, but in the butterflies the pattern was not monotonic as in other groups. By contrast, relative percentages of extinct species were correlated between scarabaeids and butterflies, which showed a decreasing relative extinction rate in the last decades, whereas tenebrionids had a monotonically increasing relative percentage of extinct species. Overall, trends in species loss indicate that scarabaeids and butterflies lost most species in an initial phase, and that the species that survived after the 1980s were so tolerant that further extinction was less probable. By contrast, tenebrionids were characterized by a high rate of species loss even in the last decades. Thus, they appear to have a 'delayed' response to urbanization. This can be explained by the fact that this group of beetles includes a number of moderately tolerant species that were able to survive for longer time, and which have been disappeared only recently.

Different dispersal abilities and food needs are important factors affecting species decline. One of the most important aspects of urbanization is the increasing isolation of urban green spaces from semi-natural ecosystems surrounding the city. Effects of fragmentation are expected to be more serious for species with lower dispersal capability. A low percentage of extinct species in butterflies can be explained by their relatively good dispersal ability. Butterflies can easily flight from suburban areas into the city. Small green spaces, and even flowerpots on balconies and terraces in intensively built-up areas, may assist them as stepping stones, allowing connectivity between rural areas and urban parks, even when there are no more 'natural' corridors. Both adults and larvae of butterflies can easily feed on cultivated or adventitious plants. For example, adult females of *Papilio machaon* are good dispersers, able to fly over streets and buildings, searching for the host plants of their caterpillars. By contrast, obliteration of corridors affected less mobile species such as coprophagous scarabaeid species. Although most species are able to fly on long distance as adaptation to find dung pads in a discontinuously grazed landscape, they require the presence of dung, thus lack of connectivity makes difficult re-colonization of urban parks from non-urban populations.

Finally, a further cause of insect decline in urban Rome is the increased density of insect-eating bird populations. Urbanization promotes bird density (e.g. Manganaro et al., 1999; Salvati et al., 1999a,b, 2002) and insects are an important food for many bird species. Predation by omnivorous and opportunistic species, such as the hooded crow, *Corvus corone cornix* Linnaeus 1758, and the starling, *Sturnus vulgaris* Linnaeus 1758, has been considered a possible factor that reduced the urban populations of certain coprophagous scarabaeids (Carpaneto et al., 2005). Detailed studies on the trophic niche of raptors proved that insects may be an important food resource for these birds in urban Rome (Fattorini, 2001). Urban Rome harbours large breeding populations of four raptors: the kestrel *Falco tinnunculus* Linnaeus, 1758, the barn owl *Tyto alba* (Scopoli, 1769), the little owl *Athene noctua* (Scopoli, 1769) and the tawny owl *Strix aluco* Linnaeus, 1758. With the exception of the barn owl, which rarely takes insects, all other raptors feed on beetles in urban Rome. In particular, although some tenebrionid species have obnoxious secretions which reduce their predation by kestrels (Fattorini, 2000), tenebrionids accounted for 2.2% of the total prey (7.2% of the beetles) in kestrel diet, for 2.0% of the total prey (3.1% of the beetles) in little owl diet, and 0.5% of total prey (but 3.7% of the beetles) of tawny owl diet (Fattorini, 2001). Thus, tenebrionids appear to be an important food resource for the kestrel in urban Rome, representing an important prey also for the little owl.

## 5. Conclusions

Previous studies in urban insect conservation have deduced a negative effect of urbanization on insects from spatial variations in species richness (Rickman and Connor, 2003; Ishitani et al., 2003; Ferreira and Tidon, 2005; Sanford et al., 2008). This is the first study that investigates insect extinction determined by urbanization using a long-time temporal data set. Although insect extinctions are typically considered difficult to document (Dunn, 2005), this study shows how data hidden in museum collections or published in local faunal inventories can be profitably used to trace insect loss through time. This approach allowed a reconstruction of extinction trends during more than one century in Rome, thus providing important insights for future conservation actions.

For all insect groups considered in this study, a quite large percentage of species loss has been occurred in urban Rome. Although the decade of extinction of certain species might be incorrectly assessed, the emerging pattern clearly shows an impressive decline, typically with increasing rate after the 1950s. However, differences among groups indicate that the effects of urbanization varied according to species' ecology. Most of the early extinctions were recorded among specialized species, and insect groups with reduced dispersal ability were more affected by urbanization.

Many entomologists claim that urban areas may be important biodiversity reservoirs (see references in Hunter and Hunter, 2008). In the case of urban Rome, it seems that the city hosts a considerable proportion of the entire species richness of Italian tenebrionids (about 15%), coprophagous scarabaeids (about 39%), non-coprophagous scarabaeids(about 29%) and butterflies (about 25%). However, this is an incorrect view, because most of the species quoted from the city are actually extinct. Moreover, because rarer species are typically those that disappear early, urban fauna will be mainly composed of most tolerant species, which are typically common also in rural areas. Thus, urban areas are not good candidates to preserve biodiversity. On the other hand, urban Rome is an important hold for certain species of conservation concern, such as the endemic tenebrionids *A. luigionii* and *Akis italica*, and the imperilled scarabaeid *O. eremita*, the latter included in the European Habitat Directive (ECC Directive 92/43). *A. italica* is restricted to archaeological sites, whereas *O. eremita* is restricted to old oak trees in a few sites within the city. Paradoxically, it is seriously threatened by interventions done to protect these planted trees.

These observations suggest that insect conservation programs in an urban area should be not addressed to protection of as many areas as possible, but to a thorough assessment of which species of conservation concern benefit from the urban environment and then to the identification of important sites and definition of measures for population management (cf. Dunn et al., 2006; Hunter and Hunter, 2008).

Temporal analysis of persistence of individual species suggests that the effects of urbanization are various, including biotope alteration, population fragmentation, increasing predation, etc. As in any retrospective study, these inferences, albeit reasonable, were not based on direct experiments, but deduced by relating the eco-ethological traits of a species with the time at which it was lost in concomitance with urban changes. Thus, comparative analyses, extended to other taxa and geographical contexts, would be particularly useful to assess the straightness of these results.

Methods used in this study can be easily adapted to other urban areas for which less data are available (see Fattorini, 2006 for a temporal analysis based on pivotal dates). Other Mediterranean metropolises, such as Athens (for which there are historical collections, Kühnelt, 1965), might offer the opportunity for similar analyses. Because of the importance of the Mediterranean Basin for insect conservation (Balletto and Casale, 1991), results achieved in cities which underwent a long history of urbanization might offer recommendations for insect conservation in other, recently fast growing Mediterranean metropolises.


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## Appendices A and B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.09.014.

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