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The effects of a sudden urbanization on micromammal communities: a case study of post-earthquake L'Aquila (Abruzzi Region, Italy)

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Abstract
The earthquake that occurred in L'Aquila (Abruzzi Region, Italy) on 6 April 2009 caused the destruction of many buildings and the deaths of 309 people. In summer 2009, new settlements were built in rural areas near L'Aquila to host part of the population whose houses were uninhabitable or had been totally destroyed. Our study is focused on the impact of these "new towns", analyzing the variation of the micromammal community, from 2002 to 2013, through a barn owl pellet analysis. The study area is a 3-km buffer plot sited in the northwest of L'Aquila and affected by the so-called Progetto CASE ("Complessi Antisismici Sostenibili ed Ecocompatibili") and Progetto MAP ("Moduli Abitativi Provvisori"). This analysis shows how the micromammal community has changed, qualitatively and quantitatively, because of the improvised and inadequately planned earthquake urbanization. For example, more sensitive species, such as wood mouse (*Apodemus sylvaticus*) and Savi's pine vole (*Microtus savii*), both abundant before the earthquake, were replaced by the more anthropophilous house mouse (*Mus domesticus*) after the construction of the new settlements.

Keywords: *Micromammal community, post-disaster management, land use, barn owl pellets, biodiversity loss*

Introduction

Land-use changes and urbanization are the main responsible processes of biotic homogenization and loss of biodiversity, worldwide (Sala et al. 2000; McKinney 2006). In central Italy, the rural territories are highly suitable areas for urban development; therefore, the lack of correct urban planning leads to a metastatic organization of the urbanized areas, causing reduction of ecological efficiency, destruction of agricultural landscape and, thus, a strong threat to biodiversity (Romano & Zullo 2014).

Earthquakes are natural events that can deeply change the urban planning of an area in the short, medium and long period, and a severe rearrangement of built spaces often occurs as a consequence. Usually more damage can be found in low-technology areas, but further aggravating factors are represented by unskilled technicians, bad public administrators and a lack of urban plans, as well as corruption, ignorance and indifference (UN/ISDR 2002).

An earthquake of $M_L = 5.8$ and $M_W = 6.3$ occurred in L'Aquila (Abruzzi Region, Italy) on 6 April 2009, leading to the destruction of its historical city center and causing great damage to all neighboring municipalities in a 50-km radius, with detrimental social consequences: 309 deaths, 1600 injured in the short time and mental disorders during the following years (Stratta et al. 2012; Gigantesco et al. 2013).

To address the immediate needs of the L'Aquila population, about 23% of the 66,000 displaced people (Civil Protection Dpt 2014) were housed in purpose-built residential complexes in small towns around the city of L'Aquila, comprising the "Progetto CASE" (acronym of "Complessi Antisismici Sostenibili ed Ecocompatibili", meaning Environmentally friendly, Sustainable and Anti-seismic Residential Complex) and "Progetto MAP" (acronym of "Moduli Abitativi Provvisori", meaning Temporary Housing Units). Eighteen out of 19 "Progetto CASE" were built in rural areas, far from the city, where small villages were strongly linked to agricultural practices and pasture; these settlements were claimed to be "new towns".

As consequence of these new edifications, many roads were enlarged and vehicular traffic increased,

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and agricultural and pasture areas were paved over, along with cut-off of hedges and deviations of water bodies, causing an acceleration in the homogenization of the environment, with possible consequent loss in biodiversity, increase in allochthonous species, edge-habitat modifications and microclimate changes (cf. Yahner 1988; Mahan & O'Connell 2005; Riley et al. 2005; Kühn & Klotz 2006; McKinney 2006; Rebelo et al. 2011).

Our study highlights, through a barn owl (*Tyto alba* Scopoli) pellet analysis, how significant changes in a local community of micromammals were possibly caused by an earthquake-induced sudden urbanization.

Materials and methods

Study area

The study area (Figure 1) consists of a 3-km circular buffer from the barn owl roost site under study (42° 22′32" N, 13°17′15"E), which is located at an altitude about of 748 m above sea level (a.s.l.). The area is in the northwestern side of L'Aquila city (Abruzzi Region, Italy), composed mainly of pastures and arable lands, with several ditches and creeks, and small and patchy rural villages; a small airport for local flights is also present.

La Torretta (1086 m a.s.l.), a mountain of the Monte Calvo massif, is in the northwestern area and it is protected as a Site of Community Importance (Natura 2000 Network, EU: IT7110085 "Monte Calvo"). The vegetation cover consists mainly in a deciduous forest composed by downy oak (*Quercus pubescens*) on the northern slope. Shrubs, mainly junipers (*Juniperus* spp.) and brooms (*Spartium junceum*), cover the southern slope; a garrigue with dominance of *Sideritis italica* and *Melica ciliata* is also present.

In accordance with Lovari et al. (1976), the 3-km buffer was defined as the average distance of the barn owl hunting territory.

After the 2009 earthquake, some new settlements were built in the study area: three "Progetto CASE" and four "Progetto MAP". Each "Progetto CASE" settlement is a more or less large district made up by a variable number of multi-storey buildings. All residences have reinforced concrete columns and seismic isolators; every district has paved roads, car parks and urban green spaces. The "Progetto MAP" is similar to the "Progetto CASE" but the buildings are single or double storeyed with thin concrete foundations and wooden structures; these were thought to be more removable than the "Progetto CASE" buildings.

The three "Progetto CASE" settlements occurring in the study area are:

- "Cese di Preturo" (42°22′19"N, 13°17′33"E, 673 m a.s.l.) with 20 buildings;
- "Sassa zona NSI" (42°21′57"N, 13°18′58"E, 655 m a.s.l.) with 18 buildings;

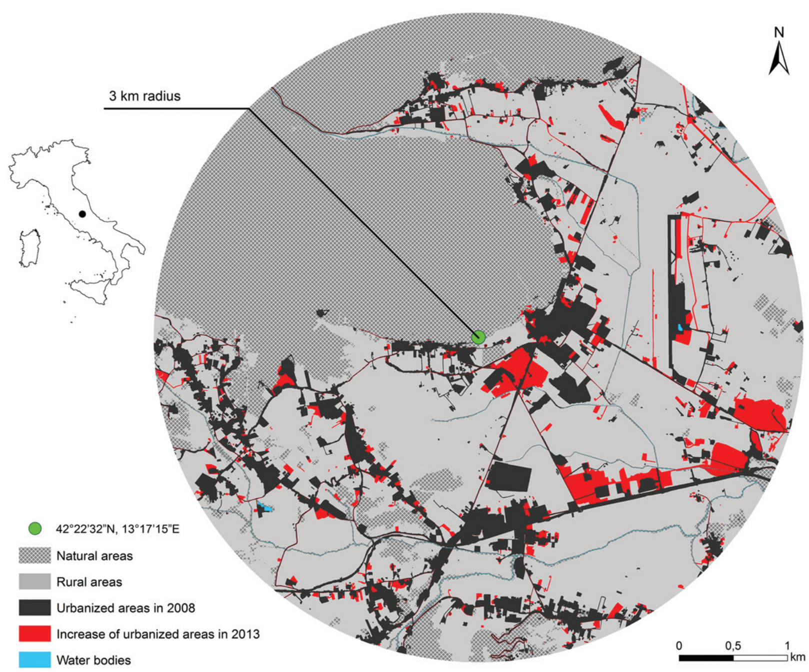

Figure 1. Study area in L'Aquila city (Abruzzi Region, Italy).

- "Coppito 3" (42°22′11"N, 13°19′12"E, 693 m a.s.l.) with 18 buildings.

The four "Progetto MAP" settlements in the study area are:

- "Preturo" (42°22′56"N, 13°17′51"E, 680 m a.s.l.) with eight buildings;
- "Sassa" (42°21′07"N, 13°18′06"E, 679 m a.s.l.) with four buildings;
- "Scoppito – Civitatomassa" (42°21′18"N, 13° 16′38"E, 719 m a.s.l.) with one building;
- "Scoppito – Capoluogo" (42°21′51"N, 13° 16′00"E, 714 m a.s.l.) with eight buildings.

Cartography

Digitization and spatial analysis, based on the aerial photographs made by the "Ufficio Infrastrutture Geografiche – Regione Abruzzo" in 2001–2002, 2007 and 2010, were performed by ESRI ArcMap 10.0; the Web Map Services (WMS) layers can be found at the URL http://geoportale.regione.abruzzo.it/geoportale/. Digitization of 2011 ortho-photographs was performed in QGis 2.2 "Valmiera" through the "OpenLayers" plugin, using the "Google satellite layer" 2011 scan. The digitization was performed at a scale of 1:1000, and the reference coordinate system used was WGS84, with UTM33N map projection. The cartography used consists of maps with land-use categories.

Photointerpretation of aerial photographs was based on the Corine Land Cover project (Level III) (Bossard et al. 2000; European Environmental Agency 2007), but using a more fine-scale digitization due to the limited extension of our study area.

We considered the following macro-categories and categories for our analysis:

1. Macro-category "urbanized areas", including three categories:
   - "Built areas": all cemented areas or areas where soil has been heavily modified. "Progetto CASE", "Progetto MAP", quarries and the small airport were classed in this category.
   - "Urban green": flowerbeds, gardens and small green areas "trapped" inside the urban fabrics.
   - "Roads": railways and roads, but not mountain paths and very small white roads.
2. Macro-category "rural areas", including two categories:
   - "Agricultural areas": pastures, cultivated areas, small orchards and vineyards.
   - "Hedges": including long rows of shrubs dividing cultivated areas and pastures.
3. Macro-category "natural areas", including seven categories:
   - "Transitional vegetation": areas with scattered and low-density patches of shrubs and trees, often re-colonizing abandoned pastures.
   - "Deciduous forest": natural wide areas covered by broad-leaved trees.
   - "Riparian forest": natural narrow forest running along streams, creeks and rivers.
   - "Shrubs": densely vegetated areas predominantly composed by shrubs, with medium or large extension.
   - "Natural grassland": non-pasture areas with herbaceous natural vegetation.
   - "Reforestation": man-driven forests composed by conifers and shrubs.
   - "Bare rocks": areas with rocks and cliffs inside natural grasslands.

Pellet analysis

Barn owl pellets were collected every 15 days, from early April to late September, in the years 2002, 2008, 2010 and 2013, and were studied according to the standard procedures proposed by Chaline et al. (1974). Barn owl pellets were used because of its euryphagous diet (Chaline et al. 1974; Bunn et al. 1982) and its stable presence in the study area. In addition the micromammals, usual preys of the barn owl, are generally considered good indicators for ecosystem health (Sorace 2001; Avenant & Cavallini 2007), particularly for their response to environmental "natural to urban" gradients (Cavia et al. 2009; Teta et al. 2012). The species identification of the micromammals was based on the examination of their skulls, according to the taxonomic keys proposed by Chaline et al. (1974), Amori et al. (2002) and Amori et al. (2008). Statistical analyses and graphics were performed using the package NCSS version 9.0.7 for Windows (www.ncss.com) and Primer version 6.1 (www.primer-e.com). One-way analysis of variance (ANOVA) was performed to test eventual significant differences among the sampled total number of pellets examined per year; Pearson correlation coefficient (r) was used to correlate the frequency of the species in the pellets per year and the changes in the extension of the land-use patches in the study area; Bray-Curtis analysis (Bray & Curtis 1957) with group average was performed to test differences in the micromammal community through the 4 years considered.

Results

Following the digitization of the aerial photos made in the years from 2002 to 2011, we can observe a strong increase of urban areas, and a concomitant decline of natural and rural patches in the study area (Figures 1 and 2). The most significant variations (Table I) involve the "built areas", "roads" and "urban green" categories, particularly in 2010, as result of the post-earthquake urbanization. "Built areas" increased by 76.8% (from 4.71 to 8.33% of total area), followed by "urban green", which increased by 56.8% (from 2.85 to 4.47% of total area) and "roads", which increased by 24.6% (from 1.52 to 1.89% of total area). The "hedges", "agricultural areas" and "natural grassland" were the most transformed land-use categories, with a decrease of −16.7% (from 2.23 to 1.85% of total area), −10.5% (from 53.89 to 48.22% of total area) and −2.2% (from 8.17 to 7.99% of total area), respectively.

The micromammal community response to these fast modifications is shown in Figure 3, where the number of species declined soon after 2009: nine and 13 species in 2002 and 2008 but only six in 2010. In 2013, the number of species came back to 13 again but the community composition was significantly changed.

In the years 2002 and 2008, the number of specimens of micromammals found in the barn owl pellets was 294 and 318, respectively; after the post-earthquake urbanization this number decreased to 73 in 2010 and 75 in 2013 (Figure 3), but it was balanced by a significant increase in insects (Figure 4b). Orthoptera, mainly Acrididae and Gryllidae, and Coleoptera, mainly Scarabaeidae (subfamilies Melolonthinae and Cetoniinae), in fact, increased from a total of 50–70 individuals per year before 2009 to about 600–700 in 2010 and 2013 (Figure 4b), suggesting a temporary "adjustment" in the diet of the barn owl. For the insect portion included in the pellets, we preferred to consider the number of individuals (or their percentage) rather their biomass because of the

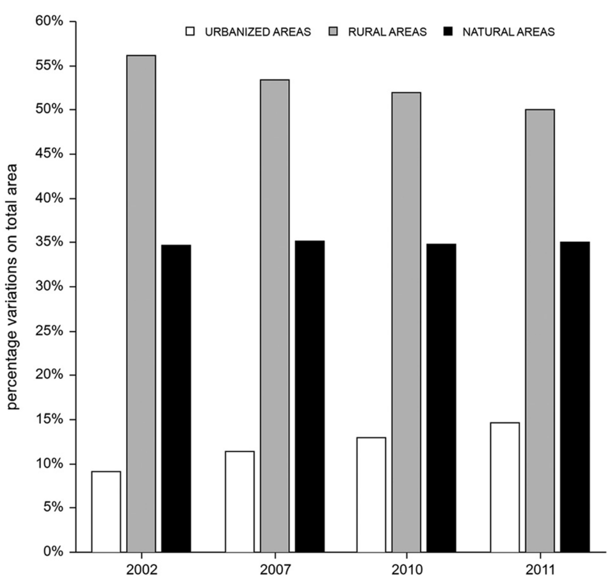

Figure 2. Histogram of the percentage variations in the land-use macro-categories considered.

Table I. Percentage variations of the land-use categories compared to the total area in 2002, 2007, 2010 and 2011.

	2002 (%)	2007 (%)	2010 (%)	2011 (%)
Urbanized areas				
Built areas	4.71	6.26	7.15	8.33
Urban green	2.85	3.60	4.25	4.47
Roads	1.52	1.49	1.62	1.89
Rural areas				
Agricultural areas	53.89	51.28	49.96	48.22
Hedges	2.23	2.11	2.02	1.85
Natural areas				
Transitional vegetation	7.03	7.18	7.05	7.25
Deciduous forest	15.68	15.84	15.78	15.94
Riparian forest	1.26	1.29	1.23	1.24
Shrubs	1.83	2.07	2.05	1.99
Natural grassland	8.17	8.06	8.06	7.99
Reforestation	0.66	0.66	0.66	0.66
Bare rock	0.02	0.02	0.02	0.02

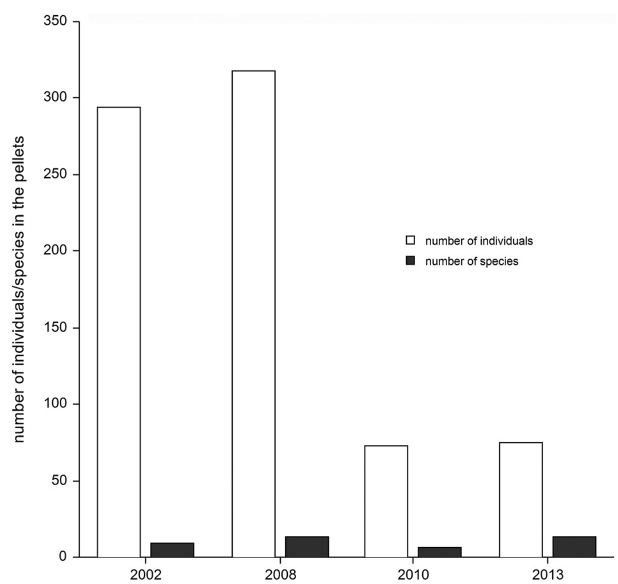

Figure 3. Total number of the micromammal species and individuals found in the barn owl pellets for year.

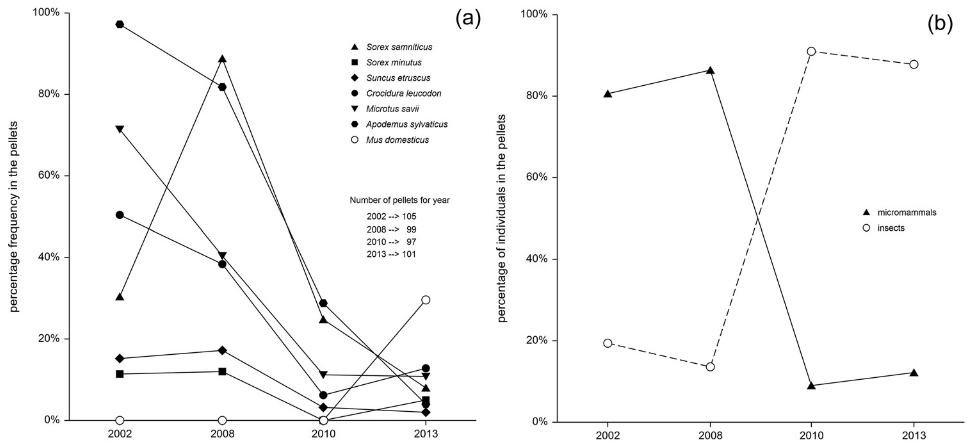

Figure 4. Trends in the barn owl pellets per year: (a) most numerically representative micromammal species; (b) comparison between micromammals and insects.

high variability in weight in Coleoptera Scarabaeidae, and the continuous variation in the life cycle of hemimetabolous insects such as the Orthoptera.

The number of pellets collected was 105, 99, 97 and 101, respectively, in 2002, 2008, 2010 and 2013, and the relative frequencies of the micromammal individuals found inside are reported in Table II. The one-way ANOVA performed among the sampled total number of pellets examined per year showed no significant differences ($F = 2.1$).

In Table III, the Pearson correlation coefficient (r) between the relative frequency of micromammal species and the variations, in decrease or increase, of the land-cover categories considered are reported. The trends of the species numerically more representative (with at least 25 individuals in total) show significant variations (Figure 4a):

Table II. Frequency of the micromammal species in the pellets per year.

	2002	2008	2010	2013
Sorex samniticus	0.30	0.89	0.25	0.08
Sorex minutus	0.11	0.12	0.00	0.05
Sorex araneus	0.00	0.18	0.00	0.01
Suncus etruscus	0.15	0.17	0.03	0.02
Neomys fodiens	0.01	0.01	0.00	0.04
Crocidura suaveolens	0.00	0.04	0.00	0.08
Crocidura leucodon	0.50	0.38	0.06	0.13
Microtus multiplex	0.00	0.10	0.01	0.02
Microtus savii	0.71	0.40	0.11	0.11
Clethrionomys glareolus	0.02	0.00	0.00	0.03
Apodemus sylvaticus	0.97	0.82	0.29	0.04
Apodemus flavicollis	0.00	0.07	0.00	0.02
Rattus rattus	0.00	0.01	0.00	0.00
Arvicola terrestris	0.00	0.01	0.00	0.01
Mus domesticus	0.00	0.00	0.00	0.30
Eliomys quercinus	0.00	0.00	0.00	0.01
Moscardinus avellenarius	0.01	0.00	0.00	0.00
Total number of pellets	105	99	97	101

– Apennine shrew (*Sorex samniticus* Altobello) has a very high positive correlation ($r = 0.93$) with a wider extension of the riparian forest, confirming the low affinity of this species for anthropogenic and rural habitats (Contoli 2002a; Nappi & Contoli 2008). Mortelliti et al. (2007) observed the absence of Apennine shrew in dense deciduous forest. In our analysis, the riparian areas occurring in the study area are indeed composed by sparse woods and therefore represent a suitable habitat for this species. The maximum frequency of the Apennine shrew until 2008 coincides in fact with the increase of the riparian forest patches (Table III), while after 2009, consequent to post-earthquake land-use modifications, the cause of the sharp decline in the Apennine shrew can probably be found in the reduction of the riparian forest in the study area due to the correction of various riverbanks.
– Eurasian pigmy shrew (*Sorex minutus* Linnaeus) also shows a high positive correlation with a wider extension of the riparian forest ($r = 0.84$), confirming data from Aloise (2008), who found the highest relative abundance for this species in riparian environments. This species is also positively correlated with the increase in the agricultural areas ($r = 0.73$), where it finds more easily its preferred preys, mainly represented by Insecta: Coleoptera, Hemiptera and Lepidoptera larvae. In addition, the significant negative correlations

Table III. Pearson correlation coefficients (r) between the frequency of the most representative micromammal species in the barn owl pellets (more than 25 individuals in total) and the landscape changes in the study area. In bold normal: positive values of r > 0.70; in bold italics: negative values of $r > -0.70$.

	Sorex samniticus	*Sorex minutus*	*Suncus etruscus*	*Crocidura leucodon*	*Microtus savii*	*Apodemus sylvaticus*	*Mus domesticus*
Urbanized areas							
Built areas	−0.41	***−0.73***	***−0.85***	***−0.89***	***−0.95***	***−0.96***	**0.75**
Urban green	−0.41	***−0.83***	***−0.88***	***−0.96***	***−0.99***	***−0.97***	0.62
Roads	***−0.72***	−0.59	***−0.82***	−0.65	−0.67	***−0.88***	**0.96**
Rural areas							
Agricultural areas	0.38	**0.73**	**0.83**	**0.89**	**0.95**	**0.96**	***−0.73***
Hedges	0.49	0.69	**0.85**	**0.84**	**0.89**	**0.96**	***−0.84***
Natural areas							
Transitional vegetation	0.06	0.00	−0.24	−0.27	−0.47	−0.49	**0.77**
Deciduous forest	−0.12	−0.37	−0.55	−0.61	***−0.76***	***−0.76***	**0.80**
Riparian forest	**0.93**	**0.84**	**0.84**	0.65	0.47	0.66	−0.35
Shrubs	0.36	−0.42	−0.31	−0.63	***−0.75***	−0.47	0.01
Natural grassland	0.19	0.56	0.68	**0.78**	**0.89**	**0.87**	***−0.73***

with increase in the built areas ($r = -0.73$) and urban green ($r = -0.83$) explain why this species declined soon after the 2009–2010 post-earthquake urbanization.

– The relative frequency of white-toothed pygmy shrew (*Suncus etruscus* Savi) in the pellets seems negatively correlated with the general increase in the urbanized areas ($r = -0.85$/-0.88/-0.82), while it is positively correlated with the increase in the rural patches (0.83/0.85) and riparian forest (0.84). The decline of this species observed in 2010 and 2013 can be also explained by the altered and shrunk agricultural landscape due to the improvised post-earthquake urbanization.
– The significant decline of the bicolored white-toothed shrew (*Crocidura leucodon* Hermann) could be due to a response to the rapid changes of rural environments around small urban areas ($r = 0.89$/0.84) where this species probably lives (Contoli 2002b). However, the bicolored white-toothed shrew registered a small increase in the new urban and rural arrangements in 2013.
– Savi's pine vole (*Microtus savii* de Sélys-Longchamps) frequency is highly negatively correlated with wider extensions of built areas, urban green and roads, with $r = -0.95$, -0.99 and -0.67, respectively, but positively correlated with increase in rural and natural environments, especially with agricultural areas ($r = 0.95$), hedges ($r = 0.89$) and natural grasslands ($r = 0.89$). Also, in this case, we can observe a population decline, as consequence of the increase of urbanized areas, for a species preferring natural or semi-natural open habitats (Contoli 1980; Capizzi & Santini 2002).
– However, the most significant responses to the landscape changes in the study area are represented by the wood mouse (*Apodemus sylvaticus* Linnaeus) and house mouse (*Mus domesticus* Schwarz et Schwarz). The strong decline of wood mouse (−96%) inhabiting natural and rural areas (Lovari et al. 1976; Luiselli & Capizzi 1996; Marsh & Harris 2000; Contoli et al. 2008) is opposed to the parallel increase of the common house mouse, as observed by our barn owl pellet analysis.
– Wood mouse is indeed negatively correlated with the increase of built areas ($r = -0.96$), urban green (−0.97) and roads (−0.88), but positively correlated with the extension of agricultural areas (0.96), hedges (0.96) and natural grassland (0.87). House mouse is instead positively correlated with the increase of roads ($r = 0.96$), built areas (0.75) and, to a lesser extent, urban green (0.62). Regarding wood mouse, it was also observed that it is significantly influenced by the great increase of roads, which cause high levels of physiological stress in this species (Navarro-Castilla et al. 2014).

Finally, Bray-Curtis analysis (Bray & Curtis 1957) with group average, performed on the micromammal species and the relative number of individuals occurring in the barn owl pellets in the 4 years considered, clearly shows a significant separation between the situation pre- (years 2002/2008) and post-earthquake (years 2010/2013) of the community examined (Figure 5).

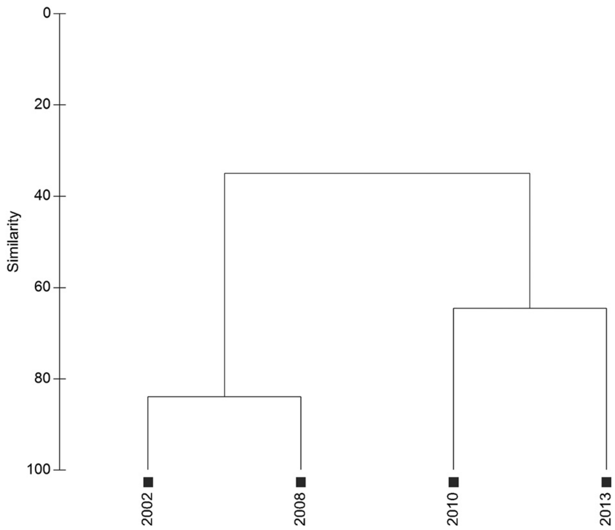

Figure 5. Bray-Curtis cluster analysis with group average performed considering the different frequencies of the micromammal species in the barn owl pellets for the four years considered.

Discussion

Micromammal community structure seems to be changed significantly after the rapid and vast reconstruction that involved L'Aquila after the earthquake of 2009. In our study area, the number of species and individuals of micromammals as found in barn owl pellets declined soon with a significant simplification and a substantial change in the species composition. By our analysis, the barn owl under study preyed on only six species, for a total of 73 individuals, in 2010, compared to the 13 species in 2008, for a total of 318 individuals, just before the earthquake. As observed also in other studies (Bosè & Guidali 2001; Sahores & Trejo 2004), the barn owl has temporarily integrated insects (mainly Orthoptera and Coleoptera) into its diet in response to the lower number of micromammals.

Notwithstanding that the number of species in the pellets came back up to 13 in 2013, the micromammal community has changed significantly in its composition. In fact, before the rapid urbanization, the main rodent preys of the barn owl were wood mouse and Savi's pine vole, as found for central Italy also by Lovari et al. (1976), but after the construction of the three "new towns" in the study area, house mouse replaced these two species in the diet of the barn owl, probably because of the increased abundance due to its high adaptability to the human-made environments (Castiglia & Corti 2008).

The loss of hedges and agricultural lands, mainly caused by post seismic re-construction and the extension of the industrial core, induces high levels of fragmentation in many rural and natural habitats in the study area. Perforation and dissection (Forman 1995) of the rural territories, induced by new edifications, car parks and urban green, are the main consequence of urbanization, as also is the conversion from white or small roads to intensely trafficked roads. Noteworthy is how the appearance and sharp increase of house mouse in the barn owl pellets examined mirror this sudden and intense environmental fragmentation.

Conclusion

Our study shows how the rapid, vast and inadequately planned reconstruction of buildings and sudden changes in land use as responses to catastrophic events may strongly influence the composition of the autochthonous fauna, including for species that were thought to be quite adaptive such as wood mouse (Santini 1983).

Unfortunately, emergency and post-disaster management often lacks planning, but we need to remember that any loss in terms of biodiversity may be irreversible. So it will be important to reflect in the future on the consequences that improvised actions in the post-disaster situation may cause more damage than the disaster itself.

In conclusion, we hope that in the future it will be possible to draw up a better preventive urban plan to rule emergencies at a local scale, considering biodiversity and its role in the environmental equilibrium as an integral parts of the planning.

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