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Does postfire management affect the recovery of Mediterranean communities? The case study of terrestrial gastropods

Vicenç Bros [a], Gregorio Moreno-Rueda [b], Xavier Santos [c,*]

[a] Parc Natural de Sant Llorenç del Munt i l'Obac, Oficina Tècnica de Parcs Naturals, Diputació de Barcelona, c/Urgell 187, Edif. Rellotge 3º, E-08036 Barcelona, Spain
[b] Estación Experimental de Zonas Áridas (CSIC), La Cañada de San Urbano, Ctra. Sacramento s/n, E-04120 Almería, Spain
[c] Departament de Biologia Animal, Universitat de Barcelona, Av. Diagonal 645, E-08028 Barcelona, Spain

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ABSTRACT

In fire-prone regions, understanding the response of species to fire is a major goal in order to predict the effects on biodiversity. Furthermore, postfire management can also model this response through the manipulation of environmental characteristics of the burnt habitat. We have examined the taxonomic and functional response to fire and postfire management of a Mediterranean snail community affected by a summer fire in 2003. After the fire, the area was logged, leaving wood debris on the ground, and three alternative practices were implemented in several plots within the burnt area: subsoiling, removal of trunks having branches, total removal of trunks and branches, as well as one area not logged. Our results indicated that fire exerted a major impact on the snail community, strongly reducing diversity and species richness, particularly for forest species living in the humus and having European distribution ranges. By contrast, we found slight differences within the postfire practices, presumably because of the strong initial impact of fire and subsequent xerophilous postfire conditions. However, the area with only trunk removal showed a positive response of generalist snail species, probably due to moist microhabitats provided by the accumulation of wood debris on the ground. The effects of postfire management should be further explored due to the expected increase of fire risk associated with climate change and land-use histories.

1. Introduction

In the Mediterranean region, wildfire has been a common natural disturbance that has modelled landscapes and hence has acted as a fundamental element on ecosystem functioning (Trabaud and Prodon, 1993; Moreno and Oechel, 1994; Piñol et al., 1998; Keeley and Fotheringham, 2003; Gillson, 2009). Fire expands open areas during the early ecological succession, favouring a shift in dominant species, which lead to different species assemblages in burnt areas compared with unburnt ones (Herrando et al., 2003; Moretti et al., 2004; Brotons et al., 2005; Apigian et al., 2006; Rugiero and Luiselli, 2006; Santos et al., 2009). This, in turn, increases gamma diversity (at the landscape level), and thus fire may contribute to maintain habitat heterogeneity and biological diversity in the Mediterranean region (Moreira et al., 2001; Blondel et al., 2010). However, species responses to alterations in habitats caused by fire vary greatly, depending on life histories and functional traits of taxonomic groups (Whelan, 1995; Caturla et al., 2000; Pausas and Verdú, 2005; Moretti et al., 2009), and there are often specific responses among species of a single taxon (e.g. amphibians [Pilliod et al., 2003], reptiles [Driscoll and Henderson, 2008; Santos and Poquet, 2010], molluscs [Santos et al., 2009], and arthropods [Moretti et al., 2004]).

In addition to this variation, recent studies have demonstrated that the response of organisms to fire can be modelled by postfire management (e.g. Izhaki and Adar, 1997; Haim and Izhaki, 2000; Eun-Jae et al., 2008; Puerta-Piñero et al., 2010). Logging (i.e. removal of the burnt tree trunks) has been practiced routinely by forest managers worldwide (Beschta et al., 2004; Lindenmayer et al., 2004), but there is controversy concerning its impact on ecosystems (Donato et al., 2006; Lindenmayer and Noss, 2006). For example, logging reduces bird-species abundance and has selective impact on certain species (e.g. seed dispersers, cavity-nesting birds), finally hampering the natural regeneration of the forest through its impact on some bird assemblages (Hutto and Gallo, 2006; Herrando et al., 2009; Castro et al., 2010a,b). The responses of organisms to postfire practices are expected to vary widely according to species-specific differences in habitat requirements (Herrando et al., 2009). Unfortunately, the effects of postfire management have been scarcely addressed in animals other than birds. For this reason, there is an urgent need to test how postfire man-

* Corresponding author. Tel.: +34 93 4021456; fax: +34 93 4034426.
E-mail addresses: broscv@diba.cat (V. Bros), gmr@ugr.es (G. Moreno-Rueda), xsantos1@ub.edu (X. Santos).

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agement affects wildlife responses in terms of abundance, diversity, and dominance of species.

In this light, the present study evaluates how postfire management affects the response of a Mediterranean terrestrial gastropod community. Due to the strict dependence of gastropods on soil structure, we have analysed the response to post-fire management by examining some functional traits of gastropod species, in order to understand the mechanisms that drive community responses to environmental changes, such as those prompted by fire and postfire management (functional approach; Moretti and Legg, 2009; Moretti et al., 2009). Terrestrial gastropods are important elements in ecosystems, with a fundamental role in the decomposition of the leaf litter and soil formation (Mason, 1970; Shachak et al., 1987; Dallinger et al., 2001), and are a source of essential nutrients for other animals (Graveland et al., 1994). Because of their small home ranges and low mobility, terrestrial gastropods are adequate organisms to evaluate fire survival and postfire recolonization of burnt areas (Nekola, 2002; Kiss and Magnin, 2003). Snails are also sensible to forest type and coarse wood debris in the ground (Kappes et al., 2006), two variables that can greatly change after fire. Previous studies have demonstrated that fire inflicts severe initial impact on the snail community, which becomes dominated by xerophilous species (Kiss et al., 2004; Kiss and Magnin, 2006; Santos et al., 2009). However, in some Mediterranean landscapes, quick recovery of the preburnt community has been reported, depending on the number of existing shelters (Kiss and Magnin, 2003, 2006). Nevertheless, little information is available on how the snail community and its recovery capacity are affected by postfire management. An impact of postfire management on terrestrial gastropods is predicted, given that other management practices such as intense grazing and the amount of wood debris alter gastropod diversity (Kappes et al., 2006; Baur et al., 2007; Boschi and Baur, 2007). Moreover, as terrestrial gastropods depend strongly on soil moisture (Cook, 2001; Martin and Sommer, 2004), different levels of wood removal are expected to be correlated with the availability of moist microhabitats, thus influencing snail abundance and/or diversity.

2. Material and methods

2.1. Study area and fire history

The field work was conducted in a 4500 ha burnt area in Sant Llorenç del Munt i l'Obac Natural Park (Barcelona province, NE Spain, Fig. 1A). This reserve is located in the Catalan Pre-coastal Mountain Range and it has a total area of 13,694 ha. The landscape of the park is rugged, with sheer crags and unusual monoliths. The geological substrate is polymictic conglomerates. The climate of the study area is subhumid Mediterranean with annual rainfall of around 600 mm, the highest peaks being more windy, rainy, and cool than lowland areas (Panareda and Pintó, 1997). Rainfall is higher in spring and autumn than in summer. Thus, the area is prone to fast-spreading fires during hot, dry summers. The original forest tree in the Park is Holm oak *Quercus ilex*. Peripheral lowland areas were covered by vineyards during early XX century, and after the Phylloxera plague replaced by pines *Pinus halepensis* and plantations of *Pinus nigra*. The pine forest has Holm oak underbrush. The study area burned in August 2003 during a summer fire that affected 4443 ha on the eastern border of the park, with 1778 ha of this lying inside the park. Impelled by wind, the blaze spread quite quickly and the entire area burned in just one day (10th August 2003). The burnt landscape was previously dominated by a pine forest with Holm oak underbrush. After the fire, charred areas were occupied by dense scrub dominated by Mediterranean shrub species such as *Cistus albidus*, *Rosmarinus officinalis*, *Dorycnium pentaphyllum*, *Rubus ulmifolius* and *Coriaria myrtifolia*.

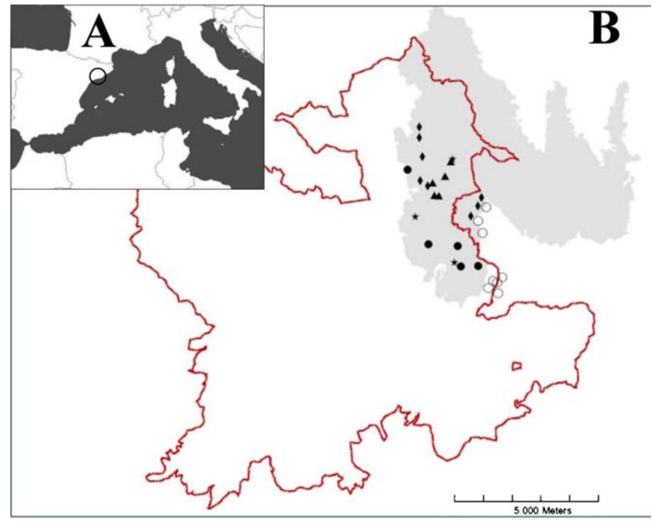

Fig. 1. Geographic location of the study area (A) and the sampling sites (B). The solid line indicates limits of the Sant Llorenç del Munt Natural Park and the grey area the surface of the 2003 fire. Symbols indicate the treatments: unburnt control (empty circles), no management (stars), trunk removal (diamonds), complete removal (solid circles), and trunk removal plus subsoiling (triangles).

2.2. Postfire management and site selection

Timber removal begun soon after the fire in August 2003, and two years later most of the area was almost completely logged, leaving very few or no standing snags. Logging in the study area did not include the elimination of branches and snags, and woody debris remained on the ground. After the logging, a sub-area was also subsoiled in order to plant mainly coniferous stands. However, the Park managers experimentally designed two alternative postfire practices: some areas of approximately 2 ha were maintained without any wood removal, whereas several 1-ha squares were managed with a complete wood removal.

According to the postfire management, we defined four different areas and selected several replicated sites per area (Fig. 1B): (1) No management (NM, 3 replicates); burnt in August of 2003 with no postfire treatment and removal. (2) Trunk removal (TR, 8 replicates); burnt in August 2003, with subsequent complete trunk removal and all the branches spread over the ground. (3) Complete removal (CR, 5 replicates); burnt in August 2003 with the removal of trunk and branches. (4) Trunk removal and subsoiling (SU, 5 replicates); burnt in August 2003 where besides trunk removal, the area had been subsoiled and later replanted with pines. Additionally, we established 8 unburnt control replicates (UN) in the pine forest near the fire edge with the same tree species that had been dominant in the burnt area before the fire.

The study area was relatively small (see geographic scale in Fig. 1) and had low altitudinal variation among sites (range 490–730) this fact precluding differences in precipitation and temperature between burnt and unburnt sites. We have only sampled areas with pine forest that cover peripheral areas of the park to avoid the effect of forest type on snail assemblages (Kappes et al., 2006).

2.3. Snail community and sampling

The gastropod community in Sant Llorenç del Munt i l'Obac Natural Park includes more than 90 terrestrial and freshwater species, with dominance of forest and rupiculous specialist species. The Natural Park stands out for the presence of Iberian endemisms with highly restricted distributions such as *Abida secale bofilli*, *Chondrina soleri*, *Montserratina bofilliana* and *Xerocrassa montserratensis*. The biogeography origin of the community includes approximately 55 Mediterranean and 36 European or Palaearctic species (Bros, 2000).

In May-June 2007, we searched for snails at 29 sites inside the burnt area using two complementary methods: (1) all snails over 5 mm of shell-size were actively searched for in adequate microhabitats for a period of 30 min in a 10 × 10 m area; (2) snails smaller than 5 mm were collected from four 25 cm × 25 cm square subsamples of litter and the top 5 cm of soil. The four subsamples were randomly located within the large 10 × 10 square. The subsamples were examined in the laboratory with a microscope to count and identify small snails (more details in Santos et al., 2009). Specimens were identified to species level following Kerney and Cameron (1999). Furthermore, *Oxychilus courquini* and other endemic species were determined by means of specialized papers such as Bech (1990), Martínez–Ortí (1999), and Riedel (1972). To determine *Deroceras altimirai* and other slug species, we used Borredà (1996) and Castillejo (1998). Only fresh shells and living individuals were recorded as representative of current communities. We considered shells to be fresh (recently dead) when the periostracum was present and coloured as in the living animal. Other shells were also considered recently dead, depending on their state of preservation in relation to their size and the microhabitat in which they were found, as shell size and direct radiation affect shell degradation in the Mediterranean climate (Ménez, 2002).

We also recorded species for which only dead specimens were collected. These species can be considered to be locally extinct at a particular site. The addition of living and dead species is an adequate way to determine the preburnt gastropod community even without previous sampling (Santos et al., 2009).

Spatial autocorrelation has been checked with a Mantel test with 999 permutations by comparing the distance matrix between pairs of sites and snail-composition similarity matrix calculated by means of Euclidean distances as suggested by Fortin and Gurevitch (2001). Distance and similarity matrices, as well the Mantel test were performed with the software Passage 1.1 (Rosenberg, 2004). When all sites were considered, spatial autocorrelation was significant (Z = 44567081.54, P = 0.048); that is, nearby sites had more similar snail communities than did distant ones. However, when we repeated this analysis only with burnt sites (excluding unburnt control sites), we found no significant spatial autocorrelation (Z = 22466147.93, P = 0.2). This result may be related to limitations in the unburnt-site selection to find control sites with vegetation structure similar to those of burnt sites prior to the fire.

2.4. Sampling of the structure of the habitat

The cover structure of the sampling sites was characterized by recording several vegetation and ground variables. At the centre of each sampling site, vegetation and ground-cover variables were recorded at points 50 cm apart along five parallel 10 m transects; thus, we recorded 100 points that characterized the abundance of vegetation and ground-cover types at each site. Vegetation variables included the extent of grass and scrub as well as abundance of three dominant tree species, namely Holm oak (*Q. ilex*), downy oak (*Quercus pubescens*) and pine (*Pinus* sp.). Ground variables included abundance of materials such as refuges (dead trunks and stones), bare ground, litter, and fallen branches on the ground.

2.5. Statistical analysis

The effect of fire and postfire management was analysed with regard to vegetation structure and snail assemblage following two consecutive steps: first, we included all the samples in order to detect potential differences between burnt and unburnt (control) sites; secondly, we removed the unburnt sites from the analysis in order to find differences among the burnt sites. This method enabled a more detailed search for differences among postfire treatments, because differences between burnt and unburnt sites were expected to be much higher than differences among postfire treatments.

The relationship between the habitat variables (covariates) and the treatments defined was analysed using the program CANOCO for Windows (version 4.55; ter Braak and Šmilauer, 2002). Before, statistical analyses, data were log-transformed, and rare species were down-weighed. The linear or unimodal relation between variables and treatments was formerly tested by a Detrended Correspondence Analysis (DCA). We found that the DCA largest gradient was 1.059. According to ter Braak and Šmilauer (2002) and Lepš and Šmilauer (2003), a Canonical Correspondence Analysis (CCA) which assumes unimodal distribution of the data is not adequate when the length of gradient (estimated with a DCA) is smaller than 4. Such was the case in our data, this indicating that the distribution was linear (Lepš and Šmilauer, 2003). Therefore, we analysed the relation between covariates and treatments by a Redundancy Analysis (RDA), statistically testing the relationship between the axes and variables by a permutation Monte Carlo test (ter Braak and Šmilauer, 2002). Once finding significant differences between unburnt and burnt sites, we repeated the RDA only among burnt areas submitted to different management practices. A similar analysis was performed in order to evaluate the differences in snail community structure between burnt and unburnt areas, as well as among postfire treatments. In this case, the DCA indicated a linear relation between specific snail abundances per site and areas (gradient length = 2.135), implying the use of a RDA (Lepš and Šmilauer, 2003).

To analyse the functional response of gastropods to fire and postfire management, we selected three traits based on characteristics that are recognized as important in gastropod autoecology (Barker, 2001): (1) the preferred habitat, with three categories (according to the classification of Bros (2000), made in the same area): forests (F), open areas (OA), and generalists species occurring in both (G); (2) the preferred microhabitat, with three categories that follow Bros (2004, 2006) and also new field observations: walls and stones (S), shrub and herbaceous vegetation (V) and humus, fallen leaves and dead trunks (H); and (3) the distribution pattern following Altonaga et al. (1994) and Kerney and Cameron (1999), which includes species with wide distributions (W), central and western European species (E), and Mediterranean species (M) (Annex 1). Within each trait and category, we performed the same statistical analysis as for the taxonomic approach, i.e. first a RDA analysis with all the samples, and second a new RDA excluding control sites.

Kruskall–Wallis ANOVA tests were used to examine the differences in number of snails, living species, dead species, total species and the Shannon diversity index among treatments.

3. Results

3.1. Differences in the vegetation and soil structure among treatments

The redundancy analysis (RDA) showed significant differences in the vegetation and soil structure among areas (trace = 0.675, F-ratio = 12.44, P = 0.001). The biggest differences were between unburnt and burnt sites, with a clear and significant discrimination in axis 1 (eigenvalue = 0.602, F-ratio = 36.31, P = 0.001). The unburnt samples in axis 1 are characterized by a major extent of pines and Holm oak trees, and litter (Fig. 2A). On repeating the RDA analysis, excluding unburnt sites, we found significant differences among burnt sites (F-ratio = 3.30; P = 0.001), this suggesting that postfire management in the study area resulted in habitat differences in

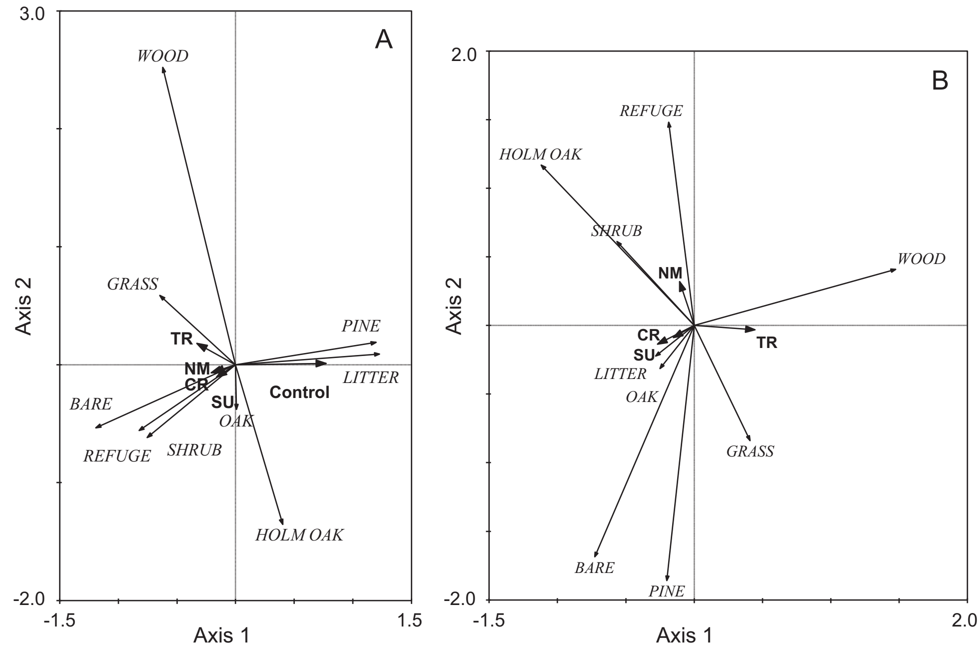

Fig. 2. Redundancy analysis plots of the association between vegetal plus soil variables and treatments, including (A) and excluding (B) control unburnt sites.

some of the vegetation and soil variables measured. Graphically, trunk removal (TR) and Non-management (NM) sites were clearly differentiated from the CR and SU treatments, which showed similar habitat structure (Fig. 2B).

3.2. The snail community and differences among treatments

A total of 666 snails were collected, representing 30 species plus two species for which we only found shells of dead specimens (Table 1). Univariate analyses showed that there were more living species and diversity per site in the unburnt treatment, and complementarily, the number of dead species per site was higher in all the burnt treatments than at the unburnt sites (Table 2), reflecting the snail mortality provoked by the fire. Adding living and dead species, we still found more species in unburnt than in burnt treatments (Table 2), probably because of the difficulty of finding shells of micromollusc species in burnt habitats, due to shell destruction (personal observation). Finally, the total number of snails encountered per site showed no differences among treatments (Table 2), suggesting that, although the fire drastically reduced diversity, some species took advantage of new habitats and expanded their populations, resulting in similar total numbers of snail individuals in burnt and unburnt treatments. When we removed the unburnt sites from the analyses, the diversity per site showed no differences among treatments, although the number of living species showed marginally significant differences among treatments (Kruskall–Wallis $H_{3,21} = 6.38$, $P = 0.09$), due to higher values in number of species at trunk-removal sites.

The multivariate analyses gave similar results. The RDA showed significant differences between snail communities in unburnt vs. all burnt areas, with the canonical axis being significant (eigenvalue = 0.255, F-ratio = 8.20, $P = 0.002$). All but five snail species were associated mainly with unburnt habitats (Fig. 3), the exceptions being three common (*Cernuella virgata*, *Xerocrassa montserratensis* and *Xerocrassa penchinati*) and two scarce species (*Granopupa granum* and *M. bofilliana*). When unburnt sites were removed from the analysis, all tests proved non-significant (trace = 0.143, F-ratio = 0.94, $P = 0.61$) in spite of habitat differences in vegetation and soil structure linked to habitat management. In fact, differences in snail community between burnt and unburnt sites were related to differences in habitat structure, given that when we controlled for habitat-structure variables in the RDA, differences in snail community between burnt and unburnt zones disappeared (F-ratio = 1.32, $P = 0.12$).

3.3. The functional response of gastropods to fire and postfire management

We replicated the RDA for Forest (F), Generalist (G), and Open-area (OA) species separately, first including and later excluding unburnt sites. For the three macrohabitat categories, species were associated with the control sites, although association was stronger

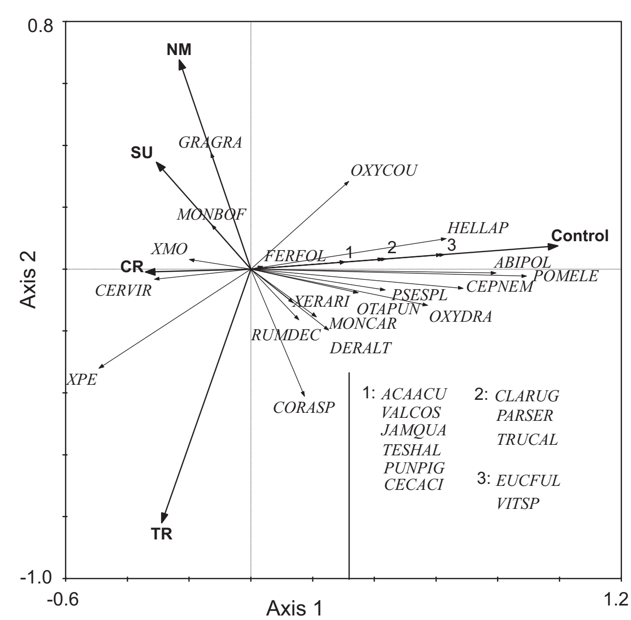

Fig. 3. Redundancy analysis plot of the association between the snail species and treatments. Meanings of acronyms of snail species are in Table 1.

Table 1
Mean number of snails found per species and sample in the five treatments: burnt but not managed (NM), burnt with trunk removal (TR), burnt with trunk removal and subsoiling (SU), burnt with complete removal (CR), and unburnt (UN). EX indicates species in a particular management type in which only empty shells were found (in brackets the number of samples with dead animals found).

		Burnt and management practices				Unburnt
		NM ($n=3$)	TR ($n=8$)	SU ($n=5$)	CR ($n=5$)	UN ($n=8$)
Abida polyodon	ABIPOL	EX(4)	0.25	EX(4)	EX(3)	3.5
Acanthinula aculeata	ACAACU	0	0	0	0	0.125
Cepaea nemoralis	CEPNEM	EX(3)	0.25	EX(5)	EX(4)	1.25
Ceciliodes acicula	CECACI	0	0	0	0	0.125
Cernuella virgata	CERVIR	1.75	4.25	0.4	22.8	0
Clausilia rugosa	CLARUG	0	0	0	0	0.75
Cornu aspersum	CORASP	2	1.875	EX(2)	EX(1)	1.125
Deroceras altimirai	DERALT	0	0.5	0	0.4	0.75
Euconulus fulvus	EUCFUL	0	0	0	0	1.5
Euomphalia strigella	EUOSTR	0	0	0	0	EX(1)
Ferussacia folliculus	FERFOL	0	0	0	1	0.25
Granaria braunii	GRABRA	0	EX(1)	0	0	0
Granopupa granum	GRAGRA	0.5	EX(1)	0	EX(1)	0
Helicigona lapicida	HELLAP	EX(2)	EX(2)	0.2	EX(3)	1
Jaminia quadridens	JAMQUA	EX(3)	EX(4)	0	EX(3)	0.375
Monacha cartusiana	MONCAR	EX(1)	0.25	0	0	0.625
Montserratina bofilliana	MONBOF	0	0	0.2	0	0
Otala punctata	OTAPUN	0	0.125	0	0	0.5
Oxychilus courquini	OXYCOU	0.25	EX(1)	0.2	EX(3)	0.375
Oxychilus draparnaudi	OXYDRA	EX(1)	0.25	0	EX(1)	1
Paralaoma servilis	PARSER	0	0	0	0	0.375
Pomatias elegans	POMELE	EX(3)	0.375	EX(5)	EX(5)	6.75
Pseudotachea splendida	PSESPL	EX(2)	0.25	EX(3)	EX(3)	1.375
Punctum pygmaeum	PUNPYG	0	0	0	0	0.125
Rumina decollata	RUMDEC	0	0.125	EX(1)	EX(4)	0.125
Testacella haliotidea	TESHAL	0.25	0	0	0	0.25
Truncatellina callicratis	TRUCAL	0	0	0	0	0.25
Vallonia costata	VALCOS	0	EX(1)	0	EX(1)	0.125
Vitrea sp.	VITSP	0	0	EX(1)	0	0.625
Xerocrassa penchinati	XPE	6	11.125	8.4	8	1.25
X. montserratensis	XMO	2	1.875	0.8	2.8	0.25
Xerosecta arigonis	XERARI	0	0.5	0	0.6	1.5
Living + extinct sp.	30 + 2	7 + 8	14 + 6	6 + 7	6 + 12	27 + 1

for F species ($F = 28.71$, $P = 0.002$, Fig. 4A), medium for G species ($F = 9.79$, $P = 0.002$, Fig. 4B), and smaller for OA species ($F = 4.22$, $P = 0.04$, Fig. 4C) as many open-area species showed no significant association with control sites. Excluding unburnt sites, only generalist species showed a significant ordination ($F = 5.56$, $P = 0.04$, Fig. 4D), with most of them being associated with areas subjected to trunk removal.

The RDA with the microhabitat preference showed similar results with a strong significant association for species of humus ($F = 22.76$, $P = 0.002$), medium for rocky species ($F = 6.85$, $P = 0.002$), and smaller for vegetation species ($F = 4.94$, $P = 0.04$). This suggests that species inhabiting humus were more affected by fire than were species living in rocks or small vegetation. However, when the analyses were performed without unburnt sites, none of the RDA analyses proved significant. A similar pattern emerged for the distribution trait, with stronger association on axis 1 for species with European and wide distributions ($F = 10.58$ and $F = 14.11$, respectively, $P < 0.005$ for both cases) and the smallest for Mediterranean species ($F = 6.43$). This suggests that Mediterranean species were less affected by fire than species typical of other biogeographic regions. The analyses without control sites gave non-significant results.

4. Discussion

This study shows that the fire resulted in significant differences in the snail community in accordance with variation in habitat structure. By contrast, habitat differences brought about by the postfire treatments did not cause variation in the mollusc communities.

4.1. Differences between burnt and unburnt sites

Our results indicate that after the fire, vegetal structure and soil cover changed significantly and, accordingly, this process strongly affected gastropod composition. The RDA analyses suggest different responses of gastropods according to functional traits of species, as forest species, living in the humus and dead leaves, and having European and wide distributions showed a strong preference for unburnt control sites, and major impact from fire. This finding reflects the decrease or apparent absence of species typical of woodland and shady habitats at burnt sites, and hence the increase of species characteristic of xerophilous and ruderal environments (e.g. *C. virgata* and *X. penchinati*) (Santos et al., 2009). Gastropod species need special edaphic conditions (Outeiro et al., 1993; Hermida et al., 1996; Ports, 1996), and thus one of the causes of the low densities of snails is the absence or reduction of humus and dead leaves in the ground (Cameron, 1982) in agreement to the strong correlation between snails and leaf litter weight (Kappes et al., 2006). Therefore, the negative effects of forest fires are due not only to the direct action of the fire, but also to alterations of chemical and micro-environmental conditions of the ground (Andreu et al., 1996; Alcañiz et al., 1996; DeBano et al., 1998; Neary et al., 1999).

According to our results, the species clearly favoured by the forest fire, at least 4 years after the fire, were *C. virgata*, *X. penchinati* and *X. montserratensis*. Wildfires imply a loss of resistance from some bushes, leading to a simplification of the vegetation structure and encouraging Gramineae vegetation (Vilà-Cabrera et al., 2008). This fact favours snail species characteristic of habitats with grassy vegetation, such as *C. virgata*, which significantly increased its abundance at burnt sites. This is a generalist and widely distributed

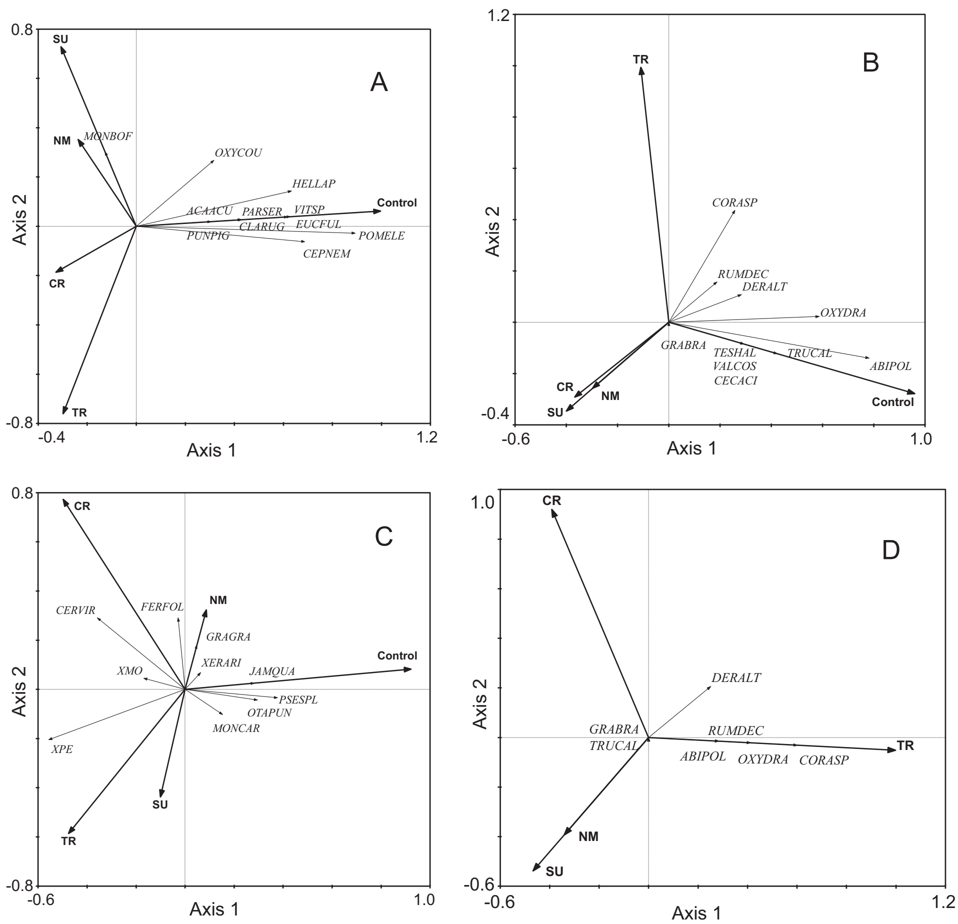

Fig. 4. Redundancy analysis plots of the association between snail species and treatments, for forest (A), generalist (B) and open-area (C) species including control sites, and generalist species (D) excluding control sites.

species in Europe that lives preferably in ruderal environments with herbaceous vegetation (Kerney and Cameron, 1999). After the fire, it appears to expand and colonize suitable habitats with herbaceous vegetation resulting from fire.

Kiss and Magnin (2003, 2006) suggested that the rapid recovery of Mediterranean snail communities after the fire is related to the existence of cryptic refuges at burnt sites. The low recolonization rates of snails from the edges of burnt areas support their conclusions (Santos et al., 2009). Similarly, the absence at unburnt sites of some species common to burnt sites (e.g. *C. virgata* and *Xerocrassa* species) suggests the existence of refuges within the forest for xerophilous and ruderal species. After the fire, the general increase of open areas enhanced their population recovery and extension, as occurred for other open-area organisms (e.g. Herrando et al., 2003; Brotons et al., 2005, 2008; Menz et al., 2009)

4.2. Differences among postfire managed sites

In southern France, Mediterranean gastropod communities recover one year after fire thanks to the presence of cryptic refuges (Kiss and Magnin, 2003, 2006). The occurrence of cryptic refuges has also been proposed in our study area (Santos et al., 2009). Therefore, postfire management, by affecting the extent of refuges, can be an extrinsic factor that can potentially modify burnt habitats and indirectly influence snail recovery. In fact, we have shown that different postfire management has produced variation in habitat structure within burnt areas. This variation concerns the extent of wood and refuges, reflecting different levels of wood removal. In spite of this habitat heterogeneity caused by the management, we found only slight differences in the mollusc communities among burnt managed areas. It is possible that the fire severely damaged the snail community, precluding significant differences among burnt treatments. The xerophilous environmental conditions in burnt areas would also interfere with the recovery of forest snail species from surrounding zones in these sites. In this context, management could not promote snail variability among burnt areas on a short-term basis. Therefore, fire and postfire habitat conditions would have great impact on the snail community, considerably reducing the number of snail species, and then diminishing the potential effects of postfire management. On the other hand, we found that trunk removal, leaving wood debris on the floor, favoured generalist snails, and this treatment tended to harbour more living species. This conclusion agrees with Kappes et al.'s (2006) results in Central Slovakia where coarse wood debris enhanced snail abundance, species richness and biodiversity. Woody debris probably promote suitable microhabitats for snails by lowering temperature and radiation, thereby contributing to moist microenvironments as has also been demonstrated to aid tree-seedling establishment (Castro et al., 2010a). In the CR and SU treatments, the absence of wood debris would not favour the community of generalist gastropods.

In recent decades, rural abandonment and the generalized loss of agricultural fields have provoked the increase of the forest cover, promoted by programs of massive reforestation (Moreira and Russo, 2007; Poyatos et al., 2003) mainly with pines and other economically profitable species (e.g. Piñol et al., 1998; Lloret, 2004). This management has contributed to an escalation of fires (Mouillot et al., 2005). Global climate warming and land-use history are

Table 2
Mean ± standard error and range of the total number of snails, living species, diversity (Shannon index), dead species and total species (alive and death) observed in the five treatments: burnt not managed (NM), burnt with trunk removal (TR), burnt with complete removal (CR), burnt with trunk removal and subsoiling (SU) and unburnt (UN). For each variable, the comparison is performed with a Kruskall–Wallis test and *post hoc* pairwise comparisons indicating the significant ($P \leq 0.05$) differences in the last column.

	NM ($n = 3$)	TR ($n = 8$)	CR ($n = 5$)	SU ($n = 5$)	UN ($n = 8$)	$H_{4,29}$	P	Pairwise comp.
# snails	11.67 ± 2.67 (9.00–17.00)	22.00 ± 4.44 (2.00–36.00)	35.60 ± 17.48 (3.00–103.00)	10.20 ± 4.34 (2.00–26.00)	26.25 ± 3.67 (14.00–42.00)	7.22	0.13	–
Living sp.	1.67 ± 0.33 (1.00–2.00)	3.88 ± 0.74 (2.00–8.00)	2.40 ± 0.51 (1.00–4.00)	2.40 ± 0.24 (2.00–3.00)	9.25 ± 0.59 (7.00–12.00)	20.06	<0.001	UN > TR, SU
Diversity	0.29 ± 0.16 (0.00–0.53)	0.84 ± 0.16 (0.41–1.54)	0.54 ± 0.20 (0.00–0.98)	0.61 ± 0.15 (0.29–1.10)	1.91 ± 0.08 (1.67–2.41)	19.13	<0.001	UN > NM, CR, SU
Dead sp.	6.00 ± 0.58 (5.00–7.00)	3.88 ± 0.61 (1.00–6.00)	7.00 ± 0.89 (5.00–10.00)	4.60 ± 0.24 (4.00–5.00)	2.50 ± 0.42 (1.00–5.00)	16.98	0.002	UN < NM, CR
Total sp.	7.67 ± 0.88 (6.00–9.00)	7.75 ± 1.28 (3.00–14.00)	9.40 ± 1.33 (6.00–14.00)	7.00 ± 0.45 (6.00–8.00)	11.75 ± 0.75 (8.00–14.00)	10.58	0.03	UN > all

thus complementary causes of greater fire risk, both situations promoting an expected increase in fire frequency and extension (Westerling et al., 2006). Logging is the most widespread postfire practice in the Mediterranean basin. However, its negative effects have been reported in bird communities (Castro et al., 2010b) and other groups such as ants (authors, unpublished data). However, our data here suggest that logging has no detrimental effect on snail communities, at least in the time span considered here. In fact, it may favour forest and generalist snails when wood debris is left in the field (Kappes et al., 2006). Although terrestrial snails are highly effective passive dispersers, during active movements their dispersion capacity is extremely low, and we cannot rule out the possibility of logging effects on a broader time scale. Thus, given the expected increase in fire frequency, there is urgent need to continue working on this topic in the future.

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Annex 1

Predominant macrohabitat and microhabitat, and geographic distribution patterns of terrestrial gastropods recorded in the study area at Sant Llorenç del Munt i l'Obac Natural Park. The macrohabitat categories follow the classification of Bros (2000) made in the same area: forests (F), open areas (OA), areas characterized by species occurring in both, i.e. generalists (G). Predominant microhabitat categories follow Bros (2004, 2006) and also new field observations: walls and stones (S), shrub and herbaceous vegetation (V) and humus, fallen leaves and dead trunks (H). The distribution patterns follow Altonaga et al. (1994) and Kerney and Cameron (1999): species with wide distribution (W), central and western European species (E) and Mediterranean species (M).

	Macrohabitat	Microhabitat	Distribution
Abida polyodon	G	S	M
Acanthinula aculeata	F	H	W
Cepaea nemoralis	F	H	E
Ceciliodes acicula	G	S	W
Cernuella virgata	OA	V	E
Clausilia rugosa	F	H	E
Cornu aspersum	G	V	E
Deroceras altimirai	G	H	M
Euconulus fulvus	F	H	W
Euomphalia strigella	G	V	E
Ferussacia folliculus	OA	V	M
Granaria braunii	G	S	M
Granopupa granum	OA	S	M
Helicigona lapicida	F	S	E
Jaminia quadridens	OA	S	E
Monacha cartusiana	OA	V	E
Montserratina bofilliana	F	S	M
Otala punctata	OA	V	M
Oxychilus courquini	F	S	M
Oxychilus draparnaudi	G	H	E
Paralaoma servilis	F	H	W
Pomatias elegans	F	H	E
Pseudotachea splendida	OA	V	M
Punctum pygmaeum	F	H	W
Rumina decollata	G	H	M
Testacella haliotidea	G	H	E
Truncatellina callicratis	G	H	M
Vallonia costata	G	S	W
Vitrea sp.	F	H	W
Xerocrassa penchinati	OA	S	M
Xerocrassa montserratensis	OA	S	M
Xerosecta arigonis	OA	V	M

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