Silva Lusitana ***14****(1): 85 - 100, 2006*
© EFN, Lisboa. Portugal

Carabid (Coleoptera) Community Changes Following Prescribed Burning and the Potential Use of Carabids as Indicators Species to Evaluate the Effects of Fire Management in Mediterranean Regions

Luisa Nunes*, Israel Silva, Marina Pité**, Francisco Rego***, Simon Leather**** and Artur Serrano*******

*Professora Adjunta
Escola Superior Agrária de Castelo Branco. Departamento Florestal, Quinta. Senhora de Mércules, 6000 CASTELO BRANCO
** Bolseiros de Investigação
***Professor Associado c/Agregação
Centro de Ecologia Aplicada Prof. Baeta Neves. Instituto Superior de Agronomia. Tapada da Ajuda, 1349-017 LISBOA
****Senior Professor
Department of Biological Sciences. Imperial College at Silwood Park, Ascot, Berkshire SL5 7PY. UK
*****Professor Associado
Faculdade de Ciências. Centro de Biologia Ambiental. Universidade de Lisboa, Rua Ernesto Vasconcelos, Ed. C2-3º, Campo Grande, 1749-016 LISBOA

Abstract. This study investigates the effects of prescribed burning on ground beetle (Coleoptera: Carabidae) communities in two different habitats, a pine forest stand in Northern Portugal and a shrubland in a central region that were fire treated in spring of 1998. These two ecosystems were considerably different floristically as well as structurally. Pitfall trapping was performed for two years in the pine stand and three years in the shrubland. Species of dryer open habitats dominated after fire in the shrubland site while the pine stand habitat showed a more or less constant carabid community structure for all treatments. Some Carabid taxa such as species/subspecies like *Chrysocarabus lateralis, Petrophilus brevipennis sousai, Macrothorax rugosus celtiberus* and *Steropus globosus ebenus* may be considered as indicators for fire managed areas in Mediterranean ecosystems.
Key words: Carabids; prescribed burning; Mediterranean ecosystems; Portugal

Alterações nas Comunidades de Coleópteros Carabídeos após Fogo Controlado e o Uso destes Insectos como Potenciais Bio-Indicadores na Avaliação dos Efeitos do Fogo em Regiões Mediterrânicas

Sumário. Este estudo investiga os efeitos do fogo controlado em comunidades de coleópteros carabideos em dois habitats distintos, um povoamento de pinheiro bravo no norte de Portugal e

---

Corresponding Author E-mail: lfnunes@mail.esa.ipcb.pt

uma zona de matos na região central. Ambos os locais foram sujeitos a queima em 1998. Estes dois ecossistemas eram muito distintos em termos de composição e estrutura vegetal. As espécies de zonas mais áridas dominaram após o fogo na região de matos enquanto que no povoamento de pinheiro bravo a composição da comunidade de carabídeos foi menos consistente.

Algumas espécies e subespécies como *Chrysocarabus lateralis, Petrophilus brevipennis sousai, Macrothorax rugosus celtiberus* and *Steropus globosus ebenus* poderão eventualmente ser consideradas como indicadores das condições pós-fogo em ecossitemas mediterrânicos
Palavras-chave: Carabídios; fogo controlado; ecossistemas mediterrânicos; Portugal

Modifications dans les Communautés de Coléoptères Carabes après l'Utilisation du Feu Contrôlé et son Utilisation comme Indicateurs pour l'Évaluation des Effets du Feu

Résumé. Cette étude est une recherche sur les effets du feu contrôlé dans les communautés de coléoptères carabes dans deux habitats distincts, un peuplement de sapin dans le nord du Portugal et une zone de brousse dans la région centrale. Les deux lieux ont été soumis au brûlage, en 1998. Ces deux écosystèmes étaient très distincts en termes de composition et de structure végétale. Les espèces des zones plus arides ont dominé après le feu dans la région de brousse tandis que dans le peuplement de sapin la composition de la communauté de carabes a été moins consistante.

Quelques espèces et sous-espèces comme *Chrysocarabus lateralis*, *Petrophilus brevipennis sousai*, *Macrothorax rugosus celtiberus* et *Steropus globosus ebenus* pourront éventuellement être considérées comme des indicateurs des conditions post-feu dans des écosystèmes méditerranéens.
Mots clés: Carabes; feu contrôlé; écosystèmes méditerranéens; Portugal

Introduction

Prescribed fire is a forest management tool used to manage vegetation in Mediterranean ecosystems, particularly to reduce fuel levels and thus the severity of wildfires. There is however, concern over the extent of the effects of this practice on plant and animal communities.

Insects may act as useful bio-indicators of ecosystem health because of their large populations, short generations, and relative sensitivity to habitat changes (REFSETH, 1980). Also, the scales that insect populations respond to are much smaller than those of indicator species such as birds or mammals. Approximately 40% of all insects are beetles (Coleoptera) (WERNER and RAFFA, 2000) and these comprise several families such as Carabidae. The distributions of ground-dwelling beetles are often correlated with microhabitat features (NIEMELA and SPENCE, 1992; MICHAELS and McQUILLAN, 1995) and with habitat heterogeneity (NIEMELA *et al.,* 1993). Coleoptera are an insect group with great taxonomic diversity. Ecologically they occupy a large number of niches and they exploit a wide range of trophic resources (GARCIA-VILLANUEVA *et al*., 1998). Some occur in stable ecosystems while others are specialists in recently disturbed areas (SPENCE *et al*., 1996; BEAUDRY *et al*., 1997).

The dynamics of species selected as indicators after fire could assess the changes in ecosystem communities. Several studies have reported an increase in abundance of some species common to open habitats as well as a decline in generalists and disappearance of specialists following fire (NIEMELA and SPENCE, 1992; NIEMELA *et al*., 1993, 1994; WERNER and RAFFIA, 2000). To obtain a better understanding of how prescribed burning may modify and act on organisms, studies on the effects of burning are required for different habitats including woodlands and shrublands. There is little information on the effects of prescribed burning on invertebrate abundance and diversity in Southern Europe forest habitats. The objective of this paper is to characterise the carabid community in two different Mediterranean ecosystems subjected to prescribed fire treatment. The responses of the dominant insect species were analysed for each of the disturbed habitats.

Material and methods

Study area

Two different sites were subjected to prescribed burning in February/March 1998. The first site was located within a *Pinus pinaster* stand (41º53'N and 8º5'E), approximately 550 m above the sea level in Northern Portugal, Minho. The trees were approximately 7.5 m high and planted at a density of 1600 trees/ha. The understory (with a total cover of about 70%) mainly comprised *Ulex minor, Pteridium aquilinum*, *Chamaespartium tridentatum* and *Calluna vulgaris*. The mean annual temperature is about 15ºC, and the climate is humid with an annual mean precipitation of approximately 2000 mm.

The second site, in central Portugal, Mafra, is located in a degraded hilly area (38º56'N and 9º15'W) with elevations over 240 m above sea level and a slope of approximately 30%. The shrubland vegetation included species such as *Erica scoparia*, *Erica lusitanica* (reaching up to 2m high) and *Pteridium aquilium.* Total vegetation cover was approximately 90%. The mean annual temperature is about 17ºC with a mean annual precipitation of approximately 750 mm.

Experimental design

The effect of prescribed burning on carabid communities was measured for two years (1998, 1999) at the Minho site, and for three years (1998 to 2000) at the Mafra site. In 1998, two adjacent 1-hectare plots were established at each site. The plots and years since burning for the Minho and Mafra sites are shown in Table 1. One plot was left unburned (Plot 1) and the other was burned in 1998. The Minho plot was burned in February and the Mafra plot was burned in March (Plot 2). In order to prevent the effects of micro site differences between the two plots being erroneously attributed to fire treatment, the unburned plot from 1998 (Plot 1) was burned in March 1999 allowing for a comparison of the same plot during consecutive years.

The same approach was used for Plot 2. In this case it was then possible to compare the situation one year after fire with the situation, in the same plot, in the second and third post burn year. In order to detect some possible differences due to weather conditions between years, a new unburned plot was established in 1999 (Plot 3). Both sites had never previously been burned. The burnings were made against the wind with a slow progress of the flame front.

Table 1 - Schematic of the plots at the Minho and Mafra site

Years	Plot 1	Plot 2	Plot 3
1998	Unburned	1 st year after fire (Burned in February in Minho site) (Burned in March in Mafra site)	
1999	1st year after fire (Burned in March 1999)	2nd year after fire	Unburned
2000	2nd year after fire	3rd year after fire	Unburned

Sampling

Ground beetles were sampled using pitfall traps. Samples were collected twice a month from April/May to September/October. The trapping period in the last year for the Mafra shrubland site was slightly shorter due to inclement weather conditions. Pit fall traps consisting of plastic containers (15.5 cm in height, 8 cm diameter), were half filled with 4 % formaldehyde solution. To prevent overflow of the traps during rainy periods, a drainage hole was drilled about 10 cm from the bottom. All traps were covered with a raised plastic cover in order to minimise the entry of rainwater and small vertebrates. In the first year, in both burned and unburned plots, 50 traps were equidistantly positioned 5 m apart along lines in a square grid design and in the central area of the plot to avoid edge effects. In the following years, due to reduced manpower available for identification and collection, the number of traps was reduced to 25 equidistantly positioned 5 m apart and with the same grid design.

Data analysis

Following insect identification at the species level, changes in the Carabid community after prescribed burning were assessed using Shannon species diversity index and species richness. The average abundance per trap was calculated to allow values to be comparable, given the different number of traps from the first to second and third year. Abiotic parameters, including temperature, humidity and precipitation, were recorded for each trapping period during the three years of the study. Correlations for the relationship between biotic and abiotic data were employed using Spearman rank correlations. A cluster analysis using average linkage was performed to profile the structure of the data in each site/habitat.

Results

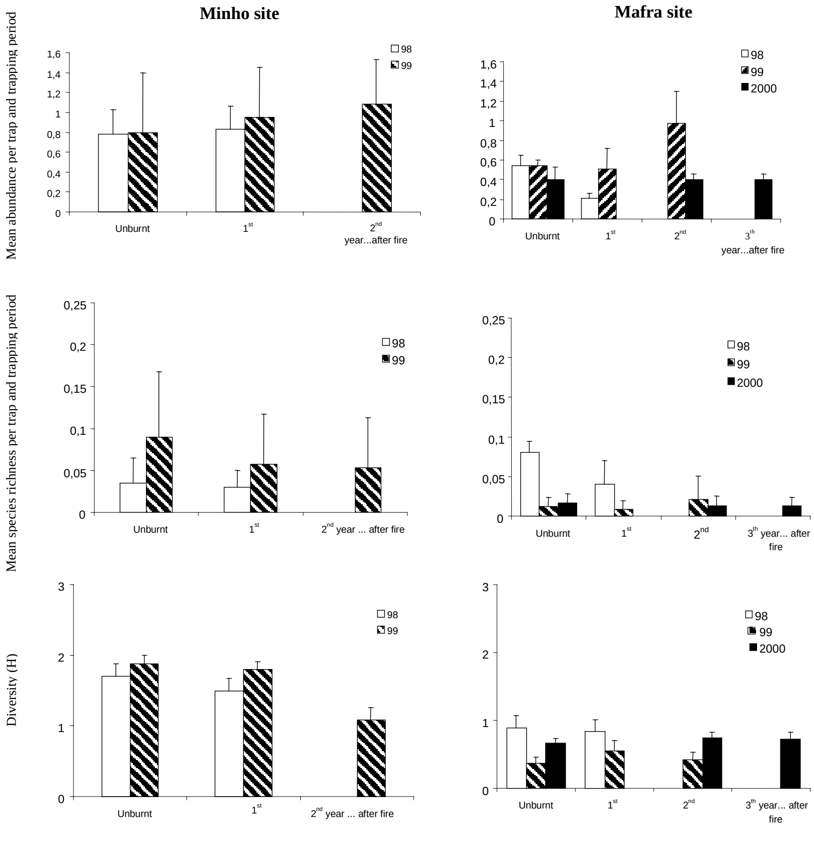
Overall, approximately 1800 carabid individuals and 32 species were collected from pitfall traps in Minho. Total abundance in Mafra was approximately 1267 individuals and 28 species (Tables 1 and 2).

Abundance, richness and diversity

Mean carabid abundance, species richness and species diversity were plotted for the two sites as shown in Figure 1. Graphed values were calculated per trap and trapping period (each 15 days). The trends were analysed by year in each habitat, and some comparison tendencies were also made between years.

Pine stand habitat

The number of individuals and the number of species were higher in the second year of study in 1999 than in 1998. For this habitat, of the 32 species captured, 78% were present in both treatments, burned and unburned, 6% were only present for burned and 16% were only present for unburned (percentages based on values presented in Appendix1). The increase in abundance for the burned plots and especially for the second year following fire is mainly due to the large increase in number of abundant species including, *P. brevipennis* and *P. gallaecus*, by contrast to *C. lateralis* and *O. amplipennis*, which though also abundant, increased less (Appendix 1).



Treatments

Figure 1 - Abundance, richness and diversity of carabid beetles at Mafra and Minho sites in all plots and treatments. Error bars indicate one S.E.

Shrubland habitat

At the Mafra site, trends are more inconsistent and patterns are therefore difficult to establish. During 1998, the abundance, richness and diversity trends all decreased for the burned plots while in 1999 these trends vary for all plots. As occurred at Minho, higher abundance was recorded in the second year after fire plot but this resulted from the increase of an already abundant species, P. brevipennis (see Appendix 2).

In the shrubland habitat, of the 28 species captured, 25% were present in all treatments, 50% were present only in the unburned (mainly in the unburned plot of 1998, and represented the initial carabid community of the shrubland) and 25% only appeared in burned plots (see Appendix 2). Richness and diversity were higher at the beginning of the study and for the unburned plot. The reduction in number of species from 1998 to 1999 was from 82% (unburned 1998) to 14% (unburned 1999). This decrease in species richness and diversity occurred after the fire in 1998, but also occurred from 1998 to 1999; a generalised reduction in both treated and untreated plots (see Appendix 2).

It is interesting to note the high degree of homogeneity of abundance richness and diversity (Figure 1) for all of the shrubland plots in the third year of the study (2000). During the last year only four carabid species were trapped in all plots. The third year of study was characterized by intense precipitation that limited the trapping season to a shorter period. Flooded traps combined with their destruction by wild boars may have reduced the number of individuals caught.

Community structure and composition

Species were classified into three groups based on relative abundance; dominant (equal to or more than 20% of individuals per trap), abundant (between 1 and 20%) and rare (less than or equal to 1% of individuals per trap). A comparison of the species relative abundance data (Figure 2) indicates that the composition of the carabid community was substantially different between the two habitats. Overall, the distribution of species among abundance groups and for the Minho site was: dominants, 3 species, *L. oopterus* in the unburned and *C. lateralis* and *P. gallaecus* in burned (Figure 2, Appendix 1); abundants, ranging from 8 to 14 species, according to each treatment, and rare, ranging from 8 to 13 species. The relative abundance of species within each treatment at the Minho Pine site is very similar. Moreover, although the relative abundance of each species may change for each treatment, the differences are very slight, which means that the structure and composition are also very similar between plots (see Appendix 1). By contrast, the structure of the carabid community at the Mafra site (1999, 2000) was weighted towards the dominant species, *P. brevipennis*, *S. globosus* and *M. rugosus*. As observed at the Minho site, the dominant species are present in all plots but were especially numerous in the burned plots. The number of abundant species varied from 1 to 4 depending on the plot. Because of the very low number of species following the first year of study, in some treatments a single species may represent up to 30% of the total carabids captured on that plot. Rare species represented 74% of the total species relative abundance in the unburned plot of 1998. As this plot may be considered to reflect the original community before disturbance, these data suggested that changes in this habitat had resulted in a reduction of rare species in the community after 1998. Three rare species did appear in the second year after fire plot in 1999, representing 50% of the total of species in that treatment.

Cluster analysis was used to group sampling entities according to their similarity, and contributes to clarifying the ordination of species by depicting their relationship among the variables considered (abundance per trap for each year and plot/treatment) (Figures 3 and 4).

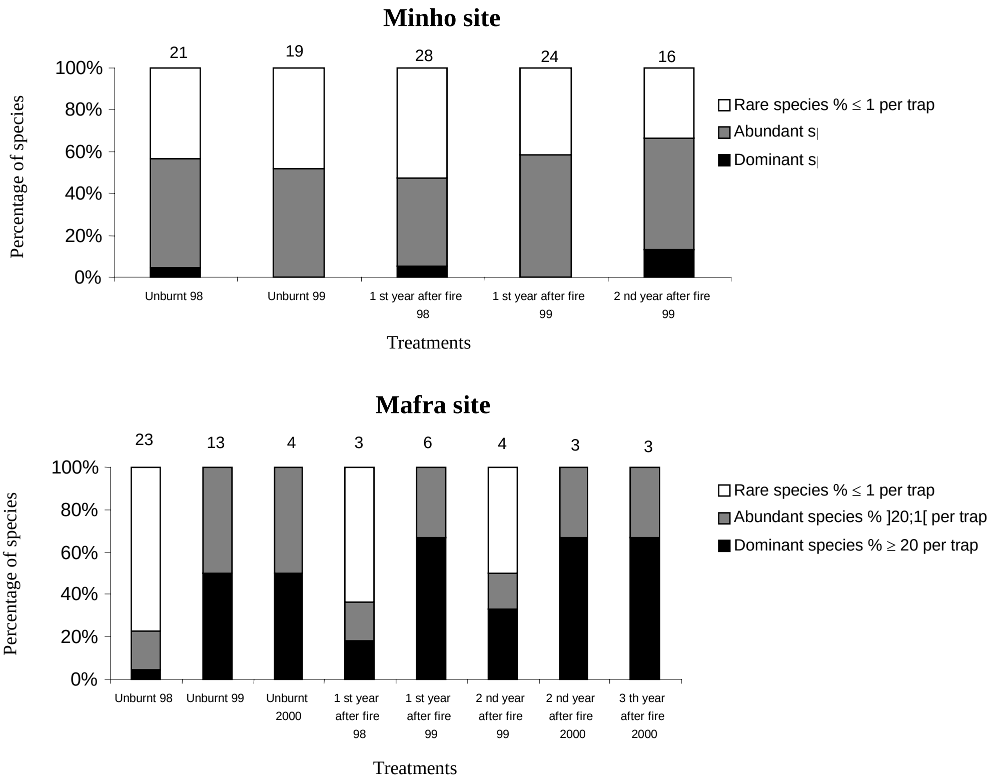


Figure 2 - The structure of carabid communities on burned and unburned plots as an indicator of the relative abundance of species. Data represents the % of species with relative abundance of dominant, abundant and rare species at the Minho and Mafra sites. Values on the top of each column represent the number of species for that plot

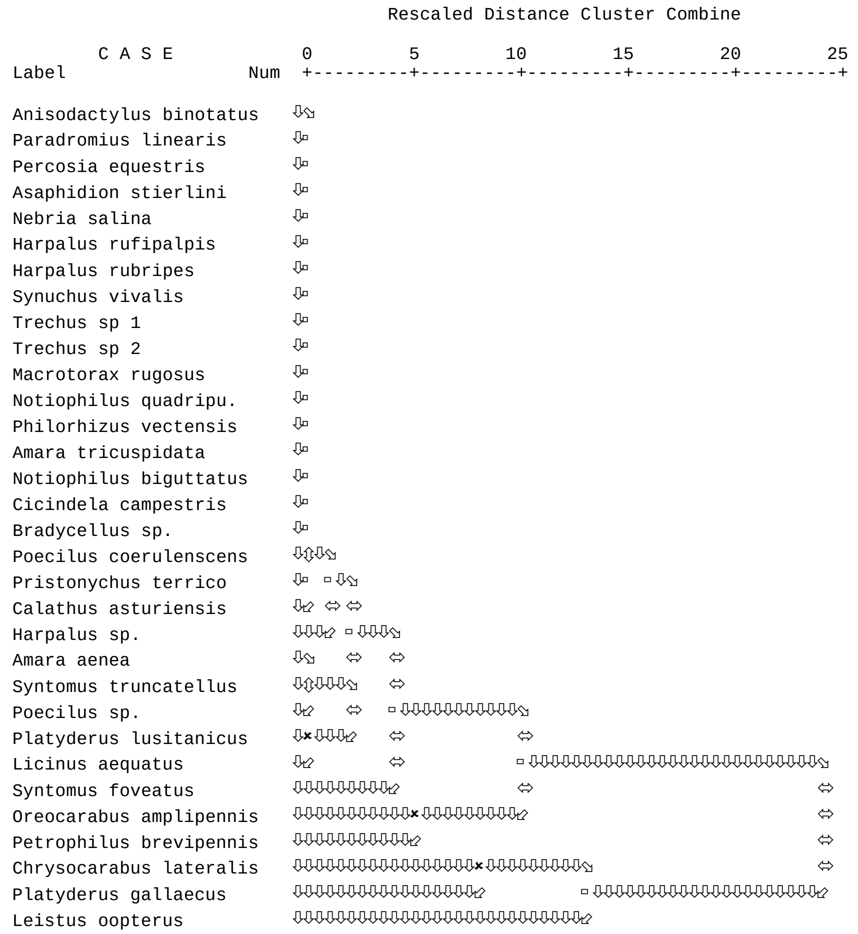


Figure 3 – Dendogram for the agglomeration sequence of species at the Minho site, based on average linkage between groups

Figure 3 depicts several clusters from which it is possible to draw some explanations. A major cluster groups the species with lower abundance, mostly a few individuals per trap. The least abundant were *Nebria salina* a nocturnal carabid (Halsall and Wrattan, 1988), *Trechus* sp 2 and *Percosia equestris* (1 individual, total abundance, see Table 1). Species like *Amara aenea*, *Syntomus truncatellus* and *Poecilus* sp., grouped together, were especially abundant in the unburned plots of 1999 (Table 1) and the former two species show a clear preference for the unburned plots. Both *L. aequatus* and *P. lusitanicus*, each part of a common branch were abundant in certain burned or unburned plots (Figure 3). The species *O. amplipennis* and *P. brevipennis* were particularly abundant two years after fire. Both *C. lateralis* and *P. gallaecus*, grouped as the most abundant species show a preference for burned plots. The species *L. oopterus,* which is also part of this branch is an outlier and varies considerably in both unburned and burned plots. The more complex branch structure in the lower part of the dendogram suggest that all of the plots in the Minho site support a similar carabid assemblage, sharing species across all treatments.

The dendogram for the Mafra site (Figure 4) indicates that there is a group of species of low abundance that was generally present only in the first year study. A second cluster aggregates those species of moderate abundance. The remaining three species form a branch of those species that are more abundant during the second year and exceed the total species abundance of the previous year (Table 2). The species *P. brevipennis* is the most abundant carabid for this habitat, and therefore is an outlier in the cluster analysis. Four species were found in both pine and shrubland habitats but they vary in their response to treatment and time. The exception is *P. brevipennis* that reached higher abundance two years after fire in both Minho and Mafra.

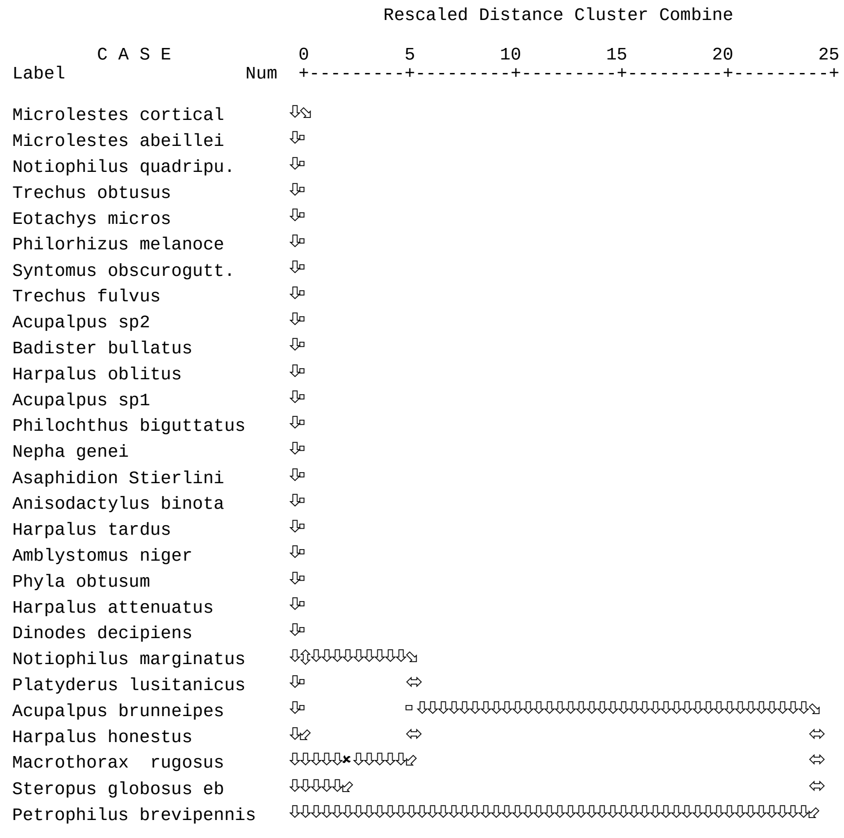


Figure 4 - Dendogram for the agglomeration sequence of species at the Mafra site, based on average linkage between groups

Correlating biotic and abiotic parameters

To measure the strength of association between biotic and abiotic variables a Spearman correlation was performed. Abundance, richness and diversity were correlated with temperature, precipitation and humidity. Results were obtained from the parameters correlation considering each trapping period, plots and years. For the pine stand habitat, it seems that temperature has the greatest influence on carabid abundance (r= -0.312; *P*=0.01) For a lower temperature and a higher humidity (temperature-humidity correlation; *r*= - 0.405; *P*=0.02) the environmental conditions were more favourable to Minho ground beetles' activity. No significant correlations were found between biotic and abiotic parameters at the Mafra site.

Dominant species responses

The abundance for the more frequent species caught is graphed in Figure 5. During the second year study there was an increase in abundance after fire for all species except to *L. oopterus*. *C. lateralis*, as well as *M. rugosus*, were those with the major dimensions and also more capable of exploiting the recent burned areas. *P. gallaecus* showed an increase in abundance in the second year after fire. Concerning *L. oopterus*, it showed an ambiguous preference for either unburned or burned areas being more abundant in the unburned of 1998.

The three carabid species in Mafra presented in Figure 5 dominated throughout the study, and were almost the only species captured in 1999 and 2000 in this site. *P. brevipennis* was the most abundant species. This species began to be more frequently caught in the unburned in 1998. *S. globosus* increased in abundance in burned plots in 1998. Nevertheless, their number was almost constant in 2000, especially in burned plots. *M. rugosus* species was also similar in number for all plots in 2000.

Discussion

The effects of each prescribed fire may vary according to the plants and animals present and their life stages (GILL *et al.*, 1996), the fire intensity, the context of the burned area and the post-fire weather conditions. Relative abundance and diversity patterns following prescribed fire at Minho and Mafra are difficult to generalise as trends appeared to be inconsistent and sometimes opposite. Moreover there is an observable decreasing tendency in species richness and diversity in burned plots in the pine stand habitat. Other authors also mentioned temporary loss of species after disturbance due to the simplification of habitat features. In the shrubland habitat all variables were negatively affected by fire during the first year of study but in the following years as abundance increased during 1999, species richness and diversity remained almost constant. This increase in abundance related to the high numbers of the dominant species shows the community changes that were general to entire all study area.

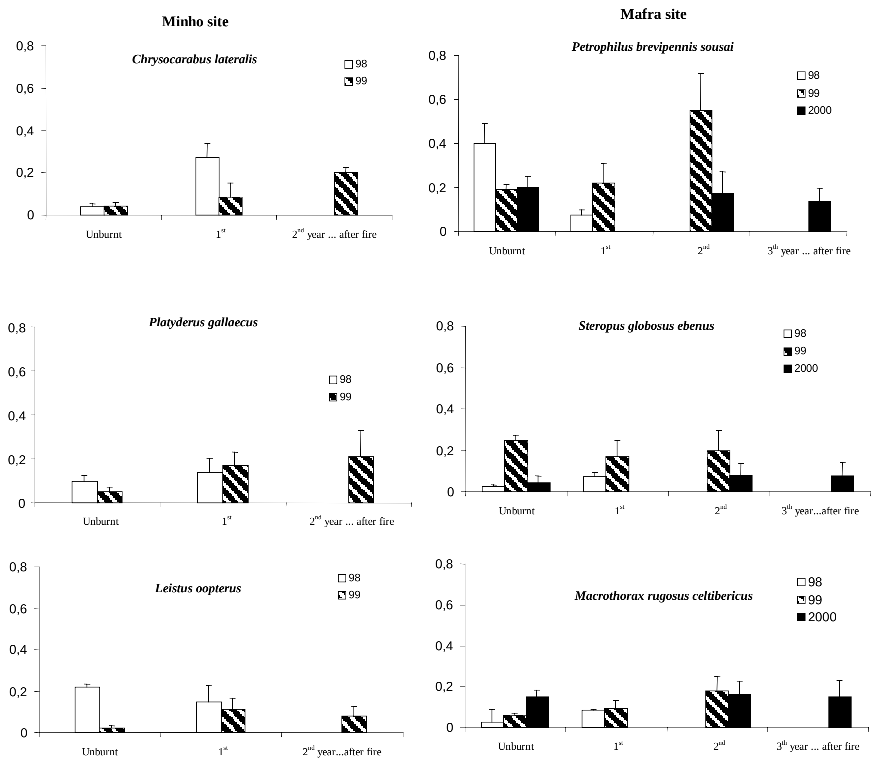


Figure 5 - Abundance of the most frequent caught carabid species at Minho and Mafra. Error bars indicate one *S.E.*

A small number of abundant species and a large number of «rare» species were present in both habitats during the first year. At the Minho site, changes in the species structure and composition were less evident than at the Mafra site. At Minho the dominant species reduced their number after 1998, increasing again for the second year after fire, although the «rare species» were always present for most plots. In Mafra, on the other hand, the dominant species became more abundant after 1998 and «rare» species disappeared during following years and for all plots. An explanation for these findings may be that the microclimatic changes induced by fire, in particular soil humidity loss and the lack of refuges could affect larval stages and the exposure to predators. Other authors observed that changes in species assemblage and abundance were reflected in microclimatic conditions caused by disturbances like fire. Previous studies (EPSTEIN and KUHLMAN, 1990) have correlated coleopteran distribution to soil moisture and other micro site differences after disturbance, although research is needed to determine more precisely what combination of variables influence carabid communities after fire and what is the extent of their effects.

In the pine stand habitat, the presence of canopy may have favoured the post fire conditions. That is, the variability of temperature and moisture affecting the uppermost level of the soil did not occur so markedly as in the shrubland. In addition, the herbaceous layer that covered the soil soon after fire may have contributed to the maintenance of those non-frequent species as well as the fast recovery of a thick litter level that resulted from the accumulation of the pine needles.

The species *C. lateralis* and *P. gallaecus* increased in abundance after fire during second year study. This was most likely due to their being present on a continuing basis and the probability of being caught is also higher. Certain species appeared to exploit recent burned areas. It is suggested that the absence of the field layer after burning permits these species to have increased movement (LUFF, 1975), resulting in higher trapping frequencies. This applies in particular to the larger carabids (REFSETH, 1980), which were those more frequently caught in this study.

One useful generalisation seems to have emerged: the most common species, especially in the shrubland habitat were positively responsive to fire. The dominant species exclusively during 1999 and 2000 in Mafra seem to be characterised by attributes that make them adaptable to the post-disturbance conditions whether they were related to fire or not. Classification of communities may include either the most numerous species, or those, which are specific to the habitat in question. Although when the community consists of a single, or only few species, this is probably the result of a high population density and consequently represents an expression of a preference for a particular habitat (REFSETH, 1980), in this case a disturbed habitat.

Species like *P. brevipennis* in Mafra site, despite being the most abundant carabid beetle in the area, showed an opportunistic and temporarily higher abundance associated with burning during 1999 as well as *M rugosus*. In 2000, the values for abundance of these species were close to those at the beginning of the experiment and constant for all plots. This result may show what could be a stabilisation of the dominant carabid population three years after prescribed burning. Nevertheless no recovery of diversity was observed as abundance continued to depend on four species.

In the literature reviewed on the effects of fire on Mediterranean carabid species, Garcia-Villanueva *et al.* (1998), provided the only reference to *S. globosus* being in high abundance after burning. In the present study, this species showed a preference for burned areas in the first year and an increased general abundance for all plots in the second year. As the species is also particular to open areas (CARDENAS *et al*., 1998) their increase in the second year study, when the fire treated area was enlarged may have been a result of a habitat more favourable to this stony inhabitant species (ZABALLOS, 1986).

The differences between the community structures in the two habitats also could be attributable to the effects of a prescribed fire carried out in early spring of 1999 in Mafra when the unburned plot of 1998 was burned. As noticed, and perhaps due to dry weather conditions and the amount of dry and dense vegetation, the shrub layer was almost completely reduced in a fast and intense combustion. The level of management practices and habitat structure and composition affect beetles diversity (WERNER *et al.*, 2000). The highest values of Shannon's H were obtained at moderate level of management (LEVIN and PAIN; CONNEL, 1978)

It could be hypothesised that the rare species disappeared as a result of an intense sampling during the first year study as their number were already very low at the beginning of the trial. Conversely, what explains their absence from the unburned plot of 1999, which was never submitted to trapping before? As the results on community changes were generalised to all treatments and plots, they could be further broken down in order to try to reveal how many other variables could contribute to a better understanding. Perhaps, rare species were not only affected by an intense previous trapping but maybe environmental conditions, fire related or not, did not permit their recovery in the area. The last two years (1999 and 2000) were characterised by intense periods of rain during the trapping season and especially about one-month after the prescribed fire when soil was still exposed.

However, the rate at which recovery occurs, as well as the long-term structure and composition of the community is determined by the resource conditions that existed previously to disturbance (HUSTON, 1994) The degraded habitat of the Mafra site, dry soil conditions, slope erosion, the crescent spread of *P. aquilium* may have contributed to a longer recovery time after the disturbance. Factors like fire intensity, time since fire and ecosystem health before the disturbance may be considered in attempting a better understanding of the effects of prescribed burning in poor diversity areas as Mafra.

In conclusion, this fuel management tool appeared not to have a pronounced impact in the pine stand habitat, as the conditions prior to post burning were favourable to a faster recovery. Also, the dominance of certain species after fire suggests that prescribed burning may be a viable option in promoting species common to open space areas. The results combined with previous investigations (NUNES *et al.*, 2000, in review) allow us to associate certain carabids species that respond to forest management with the habitat in which they are most commonly captured.

References

BEAUDRY, S., DUCHESNE, L., COTE, B., 1997. Short-term effects of three practices on carabid assemblages in the jack pine forest. *Canadian Journal of the Forest Research* **27** : 2065-2071.

CARDENAS, A., HIDALGO, J., 1998. Data on the biological cycle of *Steropus globosus* (Coleoptera: Carabidae) in the south west of Iberian Peninsula. *Vie Milieu* **48** : 35-39.

CONNEL, J., 1978. Diversity in tropical rain forests and coral reefs. *Science* **199** : 1302-1310.

EPSTEIN, M., KUHLMAN, H., 1990. Habitat distribution and seasonal occurrence of carabid beetles in east central Minnesota. *American Midland Naturalist* **123** : 209-225.

GARCIA-VILLANUEVA, J., ENA, V., TÁRREGA, R., MEDIAVILLA, G., 1998. Recolonization of two burned *Quercus pyrenaica* ecosystems by Coleoptera. *International Journal of Wildland Fire* **8** : 21-27.

GILL, A., WILLIAMS, J., 1996. Fire regimes and biodiversity: the effects of fragmentation of the south eastern Australian eucalypt forests by urbanisation, agriculture and pine plantations. *Forest and Ecology Management* **85** : 261-278.

HALSALL, N., WRATTEN, S., 1988. The efficiency of pitfall trapping for polyphagous predatory Carabidae. *Ecological Entomology* **13** : 298-299.

HOLMES, P., BOYCE, D., REED, D., 1993. The ground beetle (Coleoptera: Carabidae) fauna of welsh peatland biotopes: Factors influencing the disturbance of ground beetles and conservation implications. *Biological Conservation* **63** : 153-161.

HUSTON, M., 1994. Biological Diversity. The coexistence of species on changing landscapes. 3th edt., Cambridge University Press pp. 227-231. Cambridge, U.K.

LEVIN, S., PAIN, R., 1974. Disturbance, patch formation and community structure. *Proceedings of the National Academy of Science* **71** : 2744-2747.

LUFF, L.,1975. Some features influencing the efficiency of pitfall traps. *Oecologia* **19** : 345-357.

MICHAELS, K., McQUILLAN, P., 1995. Impact of commercial forest management on geophilous carabid beetles (Coleoptera: Carabidae) in tall, wet *Eucalyptus obliqua* forests in southern Tasmania. *Australian Journal of Ecology* **20** : 316-323.

NIEMELA, J., LANGOR, D., SPENCE, D., 1993. Effects of clear-cut harvesting on boreal ground-beetle assemblages (Coleoptera: Carabidae) in Western Canada. *Conservation Biology* **7** : 551-561.

NIEMELA, J., SPENCE, J., 1992. Habitat associations and seasonal activity of ground-beetles (Coleoptera: Carabidae) in Central Alberta. *Canadian Entomology* **124** : 521-540.

NIEMELA, J., SPENCE, J., LANGOR, D., HAILA, Y., TUKIA, H., 1994. Logging and boreal ground-beetle assemblages on two continents: implications for conservation. *In*: Gaston K, Samways M, New T (eds.) *Perspectives in Insect Conservation* pp. 29-50. Andover.

REFSETH, D., 1980. Ecological analyses of carabid communities: potential use in biological classification for nature conservation. *Biological Conservation* **17** : 131-141.

SPENCE, J., LANGOR, D., NIEMELA, J., CARCAMO, H., CURRIE, C., 1996. Northern forestry and carabids: The case for concern about old-growth species. *Annales Zoologici Fennici* **33** : 173-184.

WERNER, S., RAFFA, K., 2000. Effects of forest management practices on the diversity of ground-occurring beetles in mixed northern hardwood forests of the Great Lakes Region. *Forest Ecology and Managemen* **139** : 135-155.

ZABALLOS, J., 1986. Notas fenológicas sobre los Carabidae (Coleoptera) de la Península Ibérica. Anuarios de Biología 7 (Biología Animal 2) Secretaria de Publicaciones de la Universidad de Murcia.

Entregue para publicação em Outubro de 2003
Aceite para publicação em Janeiro de 2006

Appendix 1

Abundance of carabid species (expressed as the mean number of individuals per trap and per year) at the Minho site

Species	**Treatment**				
	1998		**1999**		
	Unburned	**1st year after fire**	**Unburned**	**1st year after fire**	**2nd year after fire**
Cicindela campestris	0	0	0.12	0.24	0
Chrysocarabus lateralis	0.42	3.26	0.44	1	2.40
Macrotorax rugosus	0	0.04	0.04	0.12	0
Oreocarabus amplipennis	0.12	0.40	1.12	1.36	1.52
Leistus oopterus	2.66	1.78	0.32	1.40	1.04
Nebria salina	0	0	0.04	0	0
Notiophilus biguttatus	0.14	0.02	0.04	0.08	0.20
Notiophilus quadripuntactus	0.12	0.02	0.08	0.08	0
Trechus sp 1	0	0.06	0	0	0
Trechus sp 2	0.02	0	0	0.04	0.08
Asaphidion stierlini	0.02	0	0	0	0
Poecilus coerulenscens	0.04	0.04	0.12	0.40	0.08
Poecilus sp.	0.16	0.12	1.08	0.12	0.24
Petrophilus brevipennis	0.28	0.62	0.52	0.20	2.56
Synuchus vivalis	0	0	0.08	0.04	0.04
Platyderus lusitanicus	0.84	0.5	0.64	0.8	0.60
Platyderus gallaecus	1.2	1.68	0.68	2.12	2.60
Calathus asturiensis	0.02	0	0.60	0	0
Pristonychus terricola	0.04	0.36	0.08	0.04	0.04
Amara tricuspidata	0.02	0	0.24	0.08	0
Amara aenea	0.80	0.06	1.16	0.2	0.36
Percosia equestris	0	0	0	0.04	0
Anisodactylus binotatus	0	0	0.04	0.04	0
Harpalus rubripes	0	0	0.08	0	0
Harpalus rufipalpis	0.02	0	0.04	0	0
Harpalus sp.	0	0	0.04	0	1
Bradycellus sp.	0.04	0	0.08	0.24	0
Licinus aequatus	0.72	0.04	0.32	0.92	0.16
Paradromius linearis	0	0.02	0.04	0.04	0
Philorhizus vectensis	0.14	0.06	0.08	0.08	0
Syntomus truncatellus	0.78	0.10	0.92	0.20	0.08
Syntomus foveatus	0	0.02	0.64	1.60	0
Total mean abundance	8.6	9.2	9.68	11.48	13
Mean number of species per trap	0.42	0.36	1.08	0.96	0.64

Traps were collected 12 times in each year.

Appendix 2

Abundance of carabid species (expressed as the mean number of individuals per trap and per year) at the Mafra site

Species	Treatment							
	1998		1999			2000		
	Unburned	1st year after fire	Unburned	1st year after fire	2nd year after fire	Unburned	2nd year after fire	3rd year after fire
Macrothorax rugosus celtibericus	0.30	0.10	0.90	1.20	2.36	1.40	1.44	1.80
Notiophilus marginatus	0.02	0	0	0	0	0.10	0	0
Notiophilus quadripunctatus	0.06	0	0	0	0	0	0	0
Trechus fulvus	0.02	0	0	0	0	0	0	0
Trechus obtusus	0.06	0	0	0	0	0	0	0
Eotachys micros	0.10	0	0	0	0	0	0	0
Asaphidion Stierlini	0.02	0	0	0	0	0	0	0
Philochthus biguttatus	0.02	0	0	0	0	0	0	0
Nepha genei	0.02	0	0	0	0	0	0	0
Phyla obtusum	0	0.02	0	0	0	0	0	0
Steropus globosus ebenus	0.30	0.88	3.30	2.36	2.64	0.40	0.72	0.68
Petrophilus brevippenis	4.86	0.88	2.50	3.16	7.40	1.80	1.56	1.24
Platyderus lusitanicus	0.20	0.02	0	0	0	0	0	0
Anisodactylus binotatus	0.02	0.02	0	0	0	0	0	0
Harpalus oblitus	0.02	0	0	0	0	0	0	0
Harpalus attenuatus	0	0.04	0	0	0	0	0	0
Harpalus honestus	0.04	0.24	0.40	0	0.08	0	0	0
Harpalus tardus	0	0.02	0	0	0	0	0	0
Acupalpus sp1	0.02	0	0	0	0	0	0	0
Acupalpus sp2	0.02	0	0	0	0	0	0	0
Acupalpus brunneipes	0.22	0.04	0	0	0.12	0	0	0
Amblystomus niger	0	0.02	0	0	0	0	0	0
Badister bullatus	0.02	0	0	0	0	0	0	0
Dinodes decipiens	0	0	0	0	0.04	0	0	0
Philorhizus melanocephalus	0.02	0	0	0	0	0	0	0
Syntomus obscuroguttatus	0.02	0	0	0	0	0	0	0
Microlestes corticalis	0.06	0.02	0	0	0	0	0	0
Microlestes abeillei	0.06	0.02	0	0	0	0	0	0
Total mean abundance	6.50	2.32	7.10	6.72	12.64	3.70	3.72	3.72
Mean number of species per trap	0.46	0.26	0.16	0.04	0.24	0.16	0.12	0.12

Traps were collected 11 times in 1998, 13 times in 1999 and 9 times in 2000.