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Original article

Recolonization of a burnt pine forest (*Pinus pinaster*) by Carabidae (Coleoptera)

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Abstract

This paper describe changes in Carabid fauna after a wild fire in June 1996 in a *Pinus pinaster* forest in Spain, and also, provides information about trap selectivity and the influence of a firebreak on carabid abundance. Sampling was carried out from April to October 1997 in the burnt area and in a nearby unburnt pine forest. Pitfall traps contained three different types of attracting bait and were placed in each area at different distances from the firebreak. The colonizing species in the burnt area are described and compared to those captured in the control pine forest. Data on abundance, species richness, equitability, diversity and size differences are given. Seasonal changes and the composition of the Carabidae community after the fire are also discussed. Greater abundance was observed in the burnt pine forest due to the arrival of opportunistic species after the wild fire. Species adapted to open areas were captured in the burnt pine zone whereas species detected in the control forest are characteristically located in areas covered by a lot of vegetation or in grasslands, needing more humidity and therefore not tolerant to prevailing post-fire drought conditions.

Keywords: Pine forest; Fire; Carabidae; Recolonization; Spain

1. Introduction

Many insects have developed their own survival or recolonization strategies [14,26] in ecosystems that are frequently affected by fire. A relatively high number of insects including predators [2], wood-borers, soil-dwellers [27] or pyrophilous insects respond positively to heat and smoke [10,11]. In Europe, about 40 species of pyrophilous insects are favored by fire [39]; most of them are Coleoptera, and some are carabids. According to García-Villanueva et al. [15], the first insects to colonize a burnt *Quercus* sp. forest were carabids, belonging mainly to the genera *Steropus* and *Calathus*. They are more opportunistic in comparison to the fauna of unaffected forests. These pyrophilous insects take advantage of fire because they are mostly decomposers and there is more food available for them and have many characteristics required for use as an indicator taxon [38] that permit to evaluate the impact of the disturbances on the ecosystems and changes in habitat. Various authors such as Winter [40], Collet and Neuman [5], Sgardelis et al. [32], McCoullough et al. [24], Dajoz [6] have studied changes in carabid populations after a wild fire. This paper reports the effect of burning on species richness, abundance, equitability and diversity of carabid fauna. Differences in the Coleoptera community in a burnt pine forest and in an unburnt one were compared.

2. Materials and methods

2.1. Study area

The study area is located in Ferreras de Abajo (Zamora province, Spain). It is a natural *Pinus pinaster* forest of

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11 500 ha with 2500 trees per ha that had been subjected to wild fire in June 1996. A total of 640 ha were burnt. Both sampling areas, each with an area of 1000 m^2 are situated on a gentle slope with northern exposure at an altitude of 900 m above sea level. The first sampling area is in the burnt zone (Bp) and the second one in the unburnt zone (control pine forest, Cp). The climate is Mediterranean with a dry period from July to September, mean annual temperature of 11.5 °C and mean annual rainfall of 692.6 mm [25].

2.2. Sampling method

Sampling was started 10 months after the fire. Carabids were captured using 18 pitfall traps (glass vials 6 cm in diameter and 12 cm deep, buried just below the ground surface) with different types of attracting baits: three liver baits, three beer baits and three water baits (the last with a few drops of formol) were placed in both burnt and control areas. Beer traps as well as other fermented liquids have been tested as attractant for carabids [29,31]. Water traps are often used for the capture of carabids [20,35]. Finally, liver is the most effective bait used in the capture of necrophagous, but often, a lot of carabids were found inside due to the fact that liver provides a high number of Diptera larvae that will be used as food for carabids [1,12,28]. Cannibalism has been noticed by several authors [4,17,23], but in this study it was not important because of the high presence of Diptera larvae. The traps containing liver were covered with a perforated lid so that the insects could get in but ensured that would not be eaten by small mammals. The beer and water traps were buried in the same way without a lid and filled to 2/3 of their capacity. They were all covered with a flat stone to prevent excess evaporation or rainwater getting in and damaging the attracting baits but with enough space to allow entry of carabids.

The pitfall traps were placed along transects at 50 m intervals. The first one was placed on the outer limit of the sampling area, coinciding with the firebreak. The second one was placed at a distance of 50 m from the first, and the third, 100 m, towards the inner part. All the traps were located perpendicular to the firebreak (Fig. 1). In all, nine traps were placed in the burnt pine forest and nine in the control. They were collected about every 12–15 days for 6 months (April–October 1997).

2.3. Data analysis

Diversity was calculated using the Shannon and Weaver index [33] as $H' = -\Sigma \text{Pi}*\log_2 \text{Pi}$, where Pi is the relative frequency of each species. Equitability is $E = H'/\log_2 N$. Variance was calculated as $\text{Var} = H' = \Sigma\ \text{Pi}(\log_2 \text{Pi})^2 - (\Sigma\ \text{Pi} \log_2 \text{Pi})^2/N - [S - 1/2N^2]$ were Pi, relative frequency for each species; S, number of species – 1; N, total number of specimens. A χ^2-test was used to compare species richness between the two areas for each sampled month. An χ^2-test was used to compare the species that had fallen into the beer, liver and water traps in Cp and Bp.

A principal component analysis [37] was also applied to relate species data obtained using the attracting traps in both study areas and type of forest. The type of forest, the bait used as well as the distance to the firebreak were all tested by ANOVA [36]. Finally, all the captured specimens were measured. Total length was taken from the margin of clypeus to apex of elytra. A Student's t-test was applied in order to compare significant differences between the mean body length of carabids captured in both pine forests for each sampled month.

3. Results and discussion

3.1. Abundance and trap selectivity

A total of 393 Carabidae specimens were captured. Greater abundance was recorded for the beer baits, followed by the water and liver baits, respectively, in both study areas. Using a χ^2-test and taking into account the species appearing in the different baits, significant differences were observed only amongst those species caught in the beer baits in Bp and Cp ($\chi^2 = 23.6$; $P < 0.05$).

Data on abundance, species richness, equitability, diversity and variance for each studied area is shown in Table 1. Greater abundance was observed in the burnt zone. Diversity was similar in both pine zones and no significant differences were noticed ($t = 1.94$, $n = 208$, $P < 0.10$).

3.2. Composition of the carabid community

The carabid community in the burnt area was different from that in the control zone (Table 1). Species adapted to

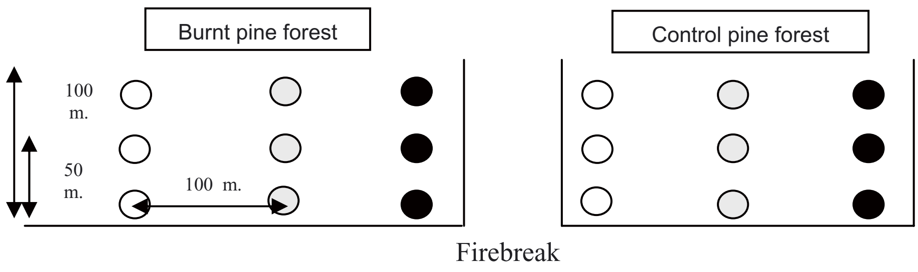

Fig. 1. Plot design for each experimental pine forest. White circles represent water traps, grey circles indicate beer traps and black ones, the liver traps.

Table 1
Number of captured specimens for each species in both burnt and control pine forest with each type of bait (B, beer; W, water; L, liver). Data on species richness, equitability, diversity and variance

	Burnt pine forest			Control pi deforest		
	B	W	L	B	W	L
A. aenea	7	2	0	0	0	0
C. dejeanni	33	0	2	4	2	3
C. mollis	1	1	0	2	0	0
C. piceus	14	0	0	8	0	0
C. uniseriatus	8	5	0	0	0	0
H. neglectus	15	8	0	0	0	0
N. salina	46	2	2	11	9	2
O. rufipes	3	0	0	0	0	0
O. gestchmanni	1	0	0	0	0	0
Platyderus sp.	0	0	0	0	1	0
P. coerulescens	0	0	0	2	1	0
P. kugelanni	0	0	0	29	6	0
S. globosus ebenus	65	69	14	0	0	0
T. obtusus	0	0	0	1	0	0
T. quadristriatus	0	0	0	12	1	1
Total (%)	193 (64.7)	87 (29.1)	18 (6.2)	69 (72.6)	20 (21)	6 (6.4)
Total	298			95		
Species richness	10			9		
Equitability	0.68			0.77		
Diversity	3.32			3.16		
Variance	0.007			0.014		

open areas, such as *Amara aenea, Calathus uniseriatus, Harpalus neglectus, Ophonus rufipes, Oreocarabus gestchmanni* and *Steropus globosus ebenus* were captured in the burnt zone. These are all lapidicolous requiring very little humidity. The presence of *A. aenea* and *H. neglectus*, which are typically pyrophilous according to Wikars [39], should also be noted. Species detected in the control pine zone, including *Platyderus* sp., *Poecilus coerulescens, Poecilus kugelanni, Trechus obtusus, Trechus quadristriatus*, are characteristically found in forest areas or in grasslands, needing more humidity and therefore not tolerant to post-fire drought conditions. They are all lapidicolous. Beaudry et al. [3] stated that the drastic effect of fire could bring about the disappearance of some species and the appearance of others such as *Amara* sp. and *Harpalus* sp., which are attracted by fire [18]; both of them were are also recorded in this study.

Principal component analysis (Fig. 2) showed that the cumulative percentage of variance for the first two axes was 60%. The first axis included six species situated in the most positive part of axis I. They were all captured in the burnt area exclusively (*A. aenea, C. uniseriatus, Calathus dejeanni, H. neglectus, O. rufipes* and *S. globosus ebenus*). The second axis shows the distribution of the species depending on the bait used (beer). Five species: *T. obtusus, T. quadristriatus, P. coerulescens, Calathus mollis* and *Calathus piceus* can be seen at the top of axis II. Some species, such as *P. kugelanni* caught mostly in the beer bait and only in the control pine stand did not appear on either axis.

In the group of carabids that exclusively appeared in the burnt area, an ANOVA test (Table 2) showed that five species were related to fire and type of bait,whereas the distance to the firebreak only affected the abundance of *A. aenea, H. neglectus* and *S. globosus ebenus*. Among species that exclusively appear in the Cp, three were related to type of forest and distance to the firebreak, whereas *P. coerulescens* was not related with the type of bait. Finally, common species to both areas: *C. dejeanni* and *Nebria salina* were related to all three factors whereas *C. piceus* was not related with the type of forest.

3.3. Size distribution

Small and medium-sized species were predominant in the control pine stand. The two largest species: *O. gestchmanni* and *S. globosus ebenus* were captured in the burnt area only (the latter one constantly). *S. globosus ebenus* has a clear preference for deforested and dry areas and was present during the whole sampled period. Of the remaining four species found exclusively in Bp; two are small (*A. aenea* and *H. neglectus*), and two are medium-sized (*C. uniseriatus* and *O. rufipes*). If we compare species found exclusively in Cp, three of them (*Platyderus* sp., *T. obtusus* and *T. quadristriatus*) are small and the other two are medium-sized (*P. coerulescens* and *P. kugelanni*). While the body size remained relatively constant for beetles in the control area, it clearly increased in the burnt pine (Table 3). However, only significant statistical differences were noticed between the areas for the month of April ($t = 0.56$; $P < 0.05$, $n = 102$). These data

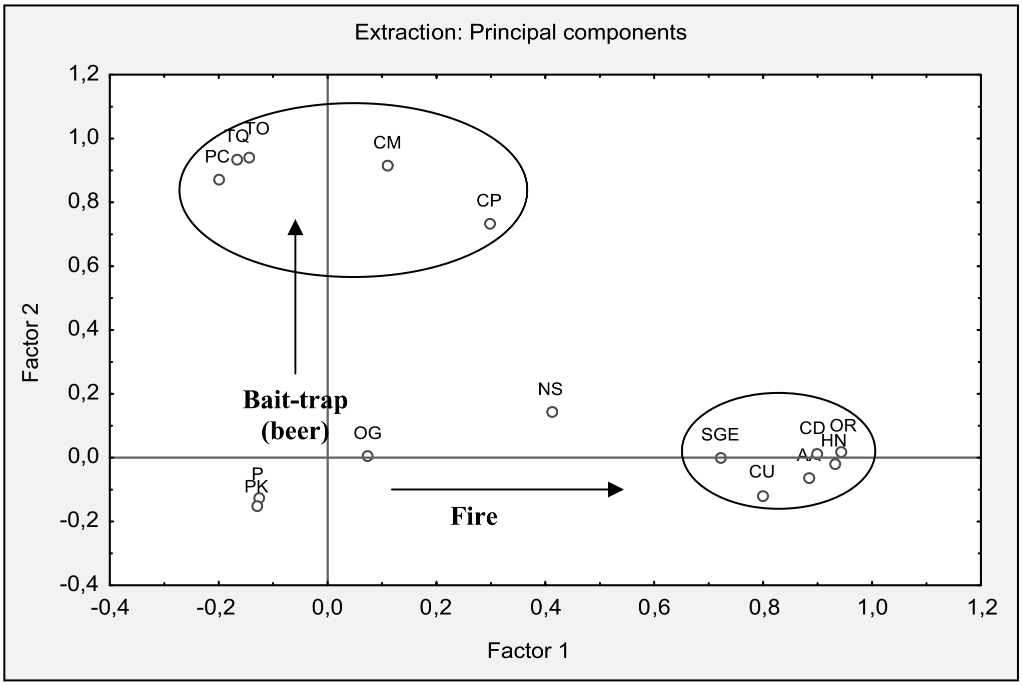

Fig. 2. PCA analysis (AA: *A. aenea*, CD: *C. dejeanni*, CM: *C. mollis*, CP: *C. piceus*, CU: *C. uniseriatus*, HN: *H. neglectus*, NS: *N. salina*, OR: *O. rufipes*, OG: *O. gestchmanni*, P: *Platyderus* sp., PC: *P. coerulescens*, PK: *P. kugelanni*, SGE: *S. globosus ebenus*, TO: *T. obtusus*, TQ: *T. quadristriatus*).

supports the observation by Holliday [19] who showed that the size of ground beetles increased with time after the fire. Moreover, the present study had the two largest carabid beetles (*O. gestchmanni* and *S. globosus ebenus*) occurring exclusively in the burnt area. Southwood [34] and Greenslade [16], have pointed out that the first colonizers after fire are normally large number of "r" strategists with small body sizes, mainly because these small species are macropterous with higher flight ability. Rowe [30] stated that small, apterous carabids survived fire better than winged ones. Interestingly, we noticed that at the beginning of our study (April), most of the captured species in Bp (66.6%) were apterous and 33.3% winged. Dispersion abilities of carabid beetles is directly related to wing length [8]. Therefore, we would expect that winged species would emigrate into the area after a fire. During the present study, less winged species (33.3%—none of them were brachypterous) and more apterous species (66.6%) were found soon after the fire (April). In May, the percentage of winged carabids is higher due to the arrival of two new winged species. In August, also two more winged species appears and by the end of the sampling season, the same number of winged species (50%) and apterous (50%) were collected. This data appears to support Den Boer's [8] claim.

Table 2
Results obtained from an ANOVA test (generalized linear model with a Poisson distribution) for the three parameters: type of forest, type of bait and distance to the firebreak. (Values statistical significant are marked with *)

	ANOVA value/*P* level		
	Type forest	Type bait	Distance
A. aenea	12.4/0.0004 *	10.2/0.005 *	10.2/0.005 *
C. dejeanni	16.4/<0.001 *	49.7/<0.001 *	14.2/0.0008 *
C. piceus	1.65/0.19	48.3/3/<0.001 *	18/0.0001 *
C. uniseriatus	18/2/<0.001 *	11.2/0.003 *	2.2/0.32
H. neglectus	31.8/1/<0.001 *	20.8/<0.001 *	10.2/0.006 *
N. salina	11.1/0.0008 *	67.1/<0.001 *	19.5/<0.001 *
O. rufipes	4.1/0.04 *	6.5/0.03 *	2.7/0.24
P. coerulescens	4.1/0.04 *	2.7/0.2	6.5/0.03 *
P. kugelanni	48.5/3/<0.001 *	44.8/<0.001 *	61.5/<0.001 *
S. globosus ebenus	205.1/0 *	46.8/<0.001 *	16/0.0003*
T. quadristriatus	19.4/<0.001 *	16.5/0.0002 *	23.5/<0.001 *

Table 3
Mean and standard deviation of body length (mm) of carabid beetles from a burnt (Bp) and an unburnt (Cp) *P. pinaster* forest in Spain (*N*, number of specimens measured. Body length was taken from edge of clypeus to apex of elytra)

	April		May		June		July		August		September	
	Bp	Cp	Bp	Cp	Bp	Cp	Bp	Cp	Bp	Cp	Bp	Cp
N	70	34	31	15	29	14	34	8	48	8	86	16
Body length (*mm*)												
Mean	12.5	11.1	10.8	11.1	12.6	10.5	12.7	10.2	14.8	10.8	15.1	9.81
St. dev.	3.6	2.86	4.77	3.23	4.81	4.62	4.34	4.72	3.43	3.18	2.84	3.55

In Cp, at the beginning of the sampling period (April), 20% of apterous, 40% of brachypterous and 40% of winged species were collected. The highest percentage of brachypterous was noticed in the month of June (67%) and, in total, of all species captured from April to October, seven were winged (three of them brachypterous) and two apterous. This coincides with observations of Darlington [7], who states that brachypterous occur more frequently in relatively permanent habitats.

3.4. Seasonal changes

Species diversity remained more or less constant during the study period in both areas (Table 1, Fig. 3) and no significant differences were found between monthly values of Bp in comparison to Cp (χ^2 = 4.7; $P < 0.05$). Monthly number of specimens was quite similar in the control pine whilst in the burnt area, the number of individuals tended to increase progressively (Fig. 3). This was also observed by Winter [40], French and Keirle [13], Beaudry et al. [3] and Holliday [19]. Burning has an important effect on carabids because it increases diversity (*Harpalus* sp. and *Amara* sp.) and the population levels of some species while other species are eliminated for at least 2 years [3]. In Bp there were two peaks in abundance: one in April and one in October due to the high number of individuals of *N. salina*, with spring habits and due to the autumn habits of *S. globous ebenus* [41]. This observation coincides with observations by Lecordier and Benest [21] that found in their study about the carabid community, two maxima in abundance: one at the end of the spring—beginning of summer, and the other at the beginning of autumn. Whereas in the control stand a peak in abundance was observed in April (Fig. 3) due to the high number of individuals of *N. salina* and *P. kugelanni*, both predominantly spring breeders [41]. Table 4 shows the species for both areas, classified into those found in spring, summer and autumn. In the burnt area the majority of them were found in summer, followed by spring, then autumn. On observing the species found in the control area, we find that the number is constant but the composition varies.

In Bp, some species such as *S. globosus ebenus, C. piceus, C. uniseriatus* or *C. dejeanni* appear all year round. Some disappear in autumn, as is the case of *A. aenea, H. neglectus* and *N. salina*. On the other hand, *C. mollis* and *O. rufipes* appear later (in summer and autumn). *O. gestchmanni* was captured in summer only. If we look at species distribution in Cp, *T. quadristriatus* and *C. piceus* appeared all year round whilst *Platyderus* sp. and *N. salina*, both of which are typical spring breeders [31] were captured in April and May. *H. neglectus* was only observed in summer and *T. obtusus* and *C. dejeanni*, in autumn, only supporting studies by Kurka (1972) and Salgado et al. [31]. *P. kugelanni* appeared in spring–summer in and *C. mollis* in summer–autumn.

Liebherr and Mahar [22] observed that the higher the vegetal cover, the lower the sunshine and species requiring more humidity appear. Therefore, the previously mentioned species captured in Cp are included in this group of species, which are intolerant to drought. On the other hand we have the species favored by fire which are considered to be pyrophilous and highly attracted to xerics areas, which is the case of the species captured in Bp. Dessender and Bosmans [9]

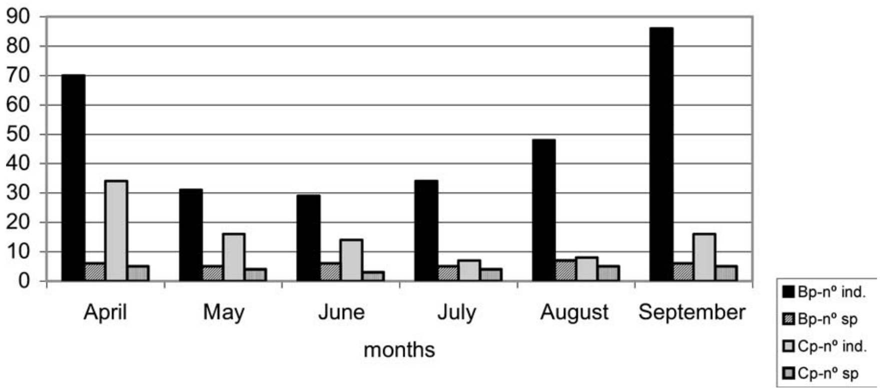

Fig. 3. Monthly numbers of specimens and species for each study area.

Table 4
Classification of carabids in spring, summer and autumn species in the burnt and control pine forests

Burnt pine forest			Control pine forest		
Spring	Summer	Autumn	Spring	Summer	Autumn
	O. rufipes				
	O. gestchmanni				
	S. globosus ebenus				
S. globosus ebenus	*N. salina*				
N. salina	*C. uniseriatus*	*O. rufipes*			
C. uniseriatus	*H. neglectus*	*S. globosus ebenus*	*T. quadristriatus*	*T. quadristriatus*	*T. obtusus*
H. neglectus	*C. mollis*	*C. uniseriatus*	*P. kugelanni*	*H. neglectus*	*T. quadristriatus*
C. piceus	*C. piceus*	*C. mollis*	*Platyderus* sp.	*P. kugelanni*	*C. mollis*
C. dejeanni	*C. dejeanni*	*C. piceus*	*N. salina*	*C. mollis*	*C. piceus*
A. aenea	*A. aenea*	*C. dejeanni*	*C. piceus*	*C. piceus*	*C. dejeanni*

found a high number of species belonging to *Harpalus* and *Amara* in dry areas because they are known to be highly xerophilous seed-eaters to which the species: *S. globosus ebenus*, captured in very significant numbers in the burnt area, should be added.

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