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ANT COMMUNITIES AS INDICATORS OF ENVIRONMENTAL HEALTH: SUCCESSIONAL ANALYSIS IN A REHABILITATION CONTEXT

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Ant (Hymenoptera: Formicidae) communities were sampled with pitfall traps in four different habitats inside and near a rehabilitated lignite mining district in Tuscany (Italy). The four habitats were: (i) open fields, (ii) a middle-age mixed plantation (10 years), (iii) an old-age mixed plantation (20 years) and (iv) an oak woodland not directly affected by mining activities. The aims of the study were a) to assess the suitability of Mediterranean ant assemblages as indicators in biomonitoring of rehabilitation operations, b) to identify different stages of colonization by ant species and their relation to vegetational succession, c) to assess the degree of restoration success. Species richness and diversity indexes were not significantly different among the four environments. However, multivariate analyses showed that the communities in the different habitats were clearly segregated: similarity relationships reflected a successional gradient among rehabilitated sites and showed a clear gap between them and the woodland sites. The analyses of ant assemblages provided information on the effects of rehabilitation practices and some insights into community dynamics along an ideal successional gradient.

KEY WORDS: Ants, rehabilitation, community, succession, biomonitoring.

INTRODUCTION

The rehabilitation of areas degraded by human activities is a major issue in conservation biology (ORMEROD, 2003). The use of selected species or taxa as indicators of the success of rehabilitation practices has been extensive during the last few decades (HILTY & MERENLENDER, 2000). Arthropods can play a fundamental role in the assessment of the success of rehabilitation, and among arthropods, ants have been successfully used in several different contexts. Numerous features make this group a potentially ideal tool in biomonitoring, among which: world-wide distribution, abundance, key role in ecosystem functioning, generally well known ecology and taxonomy, and ease of sampling (HOLLDOBLER & WILSON, 1990; AGOSTI *et al.*, 2000).

In the last twenty years, ants have been used to monitor various kinds of managed and disturbed environments (e.g. ANDERSEN, 1995; MAJER & NICHOLS, 1998; PERFECTO & VANDERMEER, 2002). However, little has been done to assess the utility of including ants in routine monitoring in Europe, particularly in the Mediterranean basin (but see GÓMEZ *et al.*, 2003). The aim of this study was to use a standardised protocol of sampling and analysis to assess the changes in ant communities following the rehabilitation of an abandoned mining area in central Italy. The analysis used a chronosequence approach based on the comparison of rehabilitated areas of different ages and 'control' areas located outside the mining site.

METHODS

STUDY AREA

The study was carried out in the Santa Barbara mining district (Arezzo, Tuscany), consisting of an open-cast lignite mine (now closed), a thermoelectric power plant and seven dumps of inert (clay) materials. The lignite ore body was open-pit mined from the late nineteenth century to the last few decades of the twentieth century. During this period, more than three hundred million tons of clay material were moved and stocked in a system of dumps extending over a 1100 ha area. Pristine environments were entirely destroyed and replaced by bare soil, which, after the end of the mining activities, were destined to agriculture and rehabilitation (about 250 ha).

The area surrounding the mining site, not affected by excavation and dumping, is a mosaic of small cultivated areas, permanent crops (olive groves and vineyards), pastures and abandoned land, interspersed in a matrix of woods consisting mainly of *Quercus pubescens*. Rehabilitation of the mine/dump system consisted in revegetation of the area according to the criteria described in BURESTI & MORI (2003).

SELECTION OF SITES

A nested sampling design was employed following UNDERWOOD (1997). Four habitat types were chosen:

i) Open fields, not subjected to tree planting and left untouched for the last 3-4 years. These fields were characterised by spontaneous regrowth of herbs and grasses.
ii) Recently planted woods, about 10 years old;
iii) Older plantations (about 20 years old), representing the last available stage of evolution of the rehabilitated environment.
iv) Oak woodland (age about 40 years), located immediately outside the mining area and not affected by the mining activities and subsequent rehabilitation.

For each habitat type (hereafter referred to as 'open field', 'middle-age plantation', 'old-age plantation', and 'woodland', respectively) two independent replicate plots were randomly established.

ANT SAMPLING

In each plot, three square grids of 9 pitfall traps, spaced at 5-m intervals, were established at random, during late May 2003. The traps consisted of plastic cups (diameter 7 cm), filled with

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100 ml of alcohol/glycerol (70/30 v/v), buried at the soil level. Each trap was left in place closed for a week before the beginning of sampling and then left open for 5 consecutive days. The keys of EMERY (1916), SEIFERT (1988) and AGOSTI & COLLINGWOOD (1987) were used to count all individuals and identify them at the species level, with the exception of *T.* gp. *tuberum*. Each species was assigned to a functional group according to the list compiled by BROWN (2000).

DATA ANALYSIS

Captures in pitfall traps of the same grid were pooled and the number of species and their relative abundance were calculated for each grid. Diversity was computed as the reciprocal of the Simpson diversity index (1/D). The analysis considered two factors: A) habitat type, a fixed factor with four levels, and B) a random factor 'plot', nested in A.

Compositional differences among habitat types were investigated using multivariate techniques after fourth root transformation. The multivariate distances among the different samples were computed with the Bray-Curtis dissimilarity index and the resulting distance matrix was analysed by non-metric Multidimensional scaling (nMDS) according to CLARKE & WARWICK (2001). Species composition differences among samples were tested with a permutation-based non-parametric multivariate analysis of variance (npMANOVA), as described in ANDERSON (2001).

The value of each species as 'indicator' of specific habitat types was calculated by means of the IndVal index, developed by DUFRÊNE & LEGENDRE (1997). The significance of IndVal measures for each species was tested at P=0.05 using a random reallocation procedure. IndVal measures were computed for each habitat type separately and for combinations of different habitat.

RESULTS

There was no difference in species richness (S) among the habitat types ($F_{3,4}$=1.70, P>0.05), although a significant effect of the nested factor 'plot' ($F_{4,16}$=3.45, P<0.05) revealed some heterogeneity of plots from the same habitat type. No difference in Simpson diversity index was observed among habitat types or among replicate plots ($F_{3,4}$=1.79, P>0.05 and $F_{4,16}$=1.98, P>0.05, respectively).

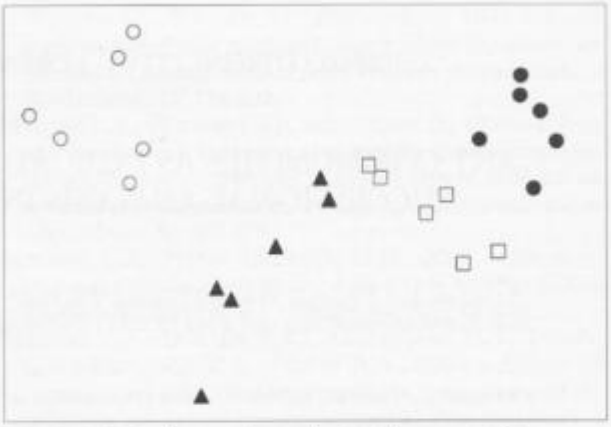

Fig. 1 – nMDS ordination plots. Closed circles, open fields; squares, middle-age plantation; triangles, old-age plantation; open circles, oak woodland.

Figure 1 shows the nMDS ordination plots. The different groups of observations, representing different habitat types, are fairly well separated. Samples from the mining area are arranged along a gradient, with the open field and old-age plots at the two extremes and the middle-age plots in an intermediate position. Data points representing woodland are separated from all the other plots, with the old-age samples being closest to them and the open fields farthest away. npMANOVA showed no significant effect of the nested factor ($F_{4,16}$=2.49, P>0.05), whereas significant differences among habitat types were detected ($F_{3,4}$=8.35, P<0.01).

Table 1 shows the IndVal values obtained for the different species over a range of habitat types. There is an evident group of species with high IndVal values for open habitats (open field and middle-age plantations). At the opposite extreme is a pool of species highly characteristic of woodland habitats. Between these two extremes is a small group of species characteristic of intermediate habitats. With regard to the functional groups to which the listed species belong, the first group consists of species scored as Opportunists plus two Dominant Dolichoderines. In contrast, the woodland group is mainly composed of Cold Climate Specialists.

Table 1 – IndVal values for different habitat types. Only significant IndVal values are reported. of, open fields; ma, middle-age plantations; oa, old-age plantations; wo, oak woodland. Fg indicates the functional group: OP, Opportunist; DD, Dominant Dolichoderine; CCS, Cold Climate Specialist; CR, Cryptic Species; GM, Generalist Myrmicine.

		Habitat types						
Species	Fg	of	of+ma	ma	ma+oa	oa	oa+wo	wo
T. caespitum	OP	98.88	61.27					
F. cinerea	OP	60.36	76.92					
T. simrothi	DD	56.25	58.96					
T. ambiguum	DD	89.62	91.46					
M. specioides	OP	79.03	82.27					
L. niger	CCS			66.67				
L. paralienus	CCS				92.9	75.35		
L. unifasciatus	CCS						67.05	
A. subterranea	CR						71.71	89.26
T. gp. *tuberum*	CCS							96.19
F. gagates	OP							83.33
C. scutellaris	GM							88.24
L. emarginatus	CCS						53.54	80.77
T. parvulus	CCS							81.90
S. striatula	CCS							66.67

DISCUSSION

The results of the present investigation demonstrate a change in ant communities along the studied chronosequence. Ant assemblages of different habitat types are fairly well separated and the observed changes in species composition and their relative abundances reflect the successional gradient from open fields to woodland, through plantations of varying age. Moreover, the analysis showed a gap between the communities inhabiting woodland (outside the mining area) and old-age plantations (the last stage of the mining area habitats), suggesting a discontinuity between them. These differences are even more evident when the species most indicative of each habitat type are considered. Open fields represent a young and poorly structured environment, with conditions favourable to the establishment of a community adapted to sunny habitats. The ants characterising this habitat and the transition with middle-age plantations are three Opportunist species (*Tetramorium caespitum*, *Myrmica specioides* and *Formica cinerea*) and two Dominant Dolichoderines (*Tapinoma ambiguum* and *T. simrothi*). At the opposite extreme is the community characterising oak woodland, mainly composed of Cold Climate Specialists such as *Lasius emarginatus*, *Temnothorax sp.*, *Stenamma striatula* and *Myrmica graminicola*. Other species are *Aphaenogaster subterranea* (a Cryptic species), *Formica gagates* (an Opportunist typical of oak woods) and *Crematogaster scutellaris* (a Generalised Myrmicine).

The two types of plantations (middle-age and old-age) present less distinct species and are intermediate between the two extremes represented by open fields and woodland. For example, the abundances of thermophilic species are already drastically reduced in the younger woods and near zero in the old-growth plantations. On the other hand, some shade-tolerant species, such as *Lasius sp.*, are also present. In particular, *L. paralienus* strongly characterises the middle-age/old-age transition and the old-age plantations, representing about 66% of the sampled specimens. In contrast, ants of the genus *Temnothorax* are relatively rare or absent.

A full understanding of the differences between the old-age plantation and oak woodland ant communities is important in order to draw some conclusions about the success of restoration activities. Of particular significance is the rarity of *Temnothorax* species and the absence of *Formica gagates* in the old-age plantations compared to the woodland and the numerical dominance of the ruderal and invasive *Lasius paralienus* in the former habitat type but not in the latter. The scarcity of *Temnothorax* ants in the plantation is probably due to the lower availability of suitable nest sites (see below). The reasons for the lack of *Formica gagates* from the plantations are less clear. This species is typical of oak woodlands and forms specific associations with oak trees (BERNARD, 1968). However, various oak species were common in both the plantation and woodland habitats and there is no clear explanation of the absence of *F. gagates* from the former.

These two habitat types differed in a number of elements, only partly related to their age such as the composition and structure of the undergrowth, the thikness of the leaf litter and the number of standing dead trunks and logs (greater in the woodland). Moreover, the plantation trees were arranged in a regular pattern and all had the same age. All these differences can, at least in principle, affect small-scale habitat complexity, producing different microclimatic conditions which in turn can affect the presence or absence of a given set of species (e.g. GREENSLADE & GREENSLADE, 1977; MAJER, 1983).

In summary, it seems that several factors have played a role in determining the observed differences in the ant communities of the various habitat types. Although the age of the different habitats may have affected the composition of the communities, it seems likely that part of the observed differences between plantations and woodland resulted from the specific sylviculture criteria adopted, including the choice of tree species, the arrangement of the trees and the management of the plantations. The result is a community with an uneven distribution of species, dominated by relatively unspecialised species.

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RIASSUNTO

LE COMUNITÀ DELLE FORMICHE COME INDICATORI DI QUALITÀ AMBIENTALE: ANALISI DELLE SUCCESSIONI IN UN CONTESTO DI RIPRISTINO FORESTALE

In questo studio sono state analizzate le comunità di formiche (Hymenoptera, Formicidae) all'interno di una ex miniera a cielo aperto di lignite, soggetta ad opere di ripristino ambientale. Lo scopo del lavoro è stato quello di a) valutare la possibilità di utilizzo delle formiche come bioindicatori per la valutazione dell'efficacia di opere di rinaturalizzazione b) fornire informazioni sui fenomeni di colonizzazione e sui cambiamenti di composizione delle comunità di formiche durante diverse fasi di un processo di successione, c) fornire una indicazione sul successo delle opere di ripristino. All'interno dell'area di studio sono stati selezionati quattro diversi tipi di ambiente, rappresentativi di diversi stadi del processo di successione ecologica: i) terreno incolto, ii) rimboschimenti 'giovani' (età 10 anni), ii) rimboschimenti 'vecchi' (età 20 anni) e iv) bosco maturo (bosco in posto). Per ciascun tipo di ambiente sono state individuate due repliche indipendenti, all'interno delle quali sono state posizionate a caso tre unità di campionamento. Ciascuna unità di campionamento era rappresentata da una batteria di nove trappole a caduta, rimaste aperte per un totale di cinque giorni in due differenti stagioni (primavera/autunno). I risultati hanno messo in evidenza una sostanziale identità dei diversi tipi di ambiente per quanto riguarda ricchezza di specie e diversità. Al contrario, l'utilizzo di analisi multivariate (nMDS, MANOVA) ha consentito l'individuazione di un gradiente netto nella composizione delle specie, nettamente orientato lungo l'asse incolto-bosco maturo. In sintesi, i risultati ottenuti, oltre a confermare le notevoli potenzialità offerte dall'uso delle comunità di formiche nella valutazione ambientale hanno fornito indicazioni sulla struttura e composizione delle comunità durante il processo di successione ecologica.

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