Forest Ecology and Management 263 (2012) 262–267

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

The spatial and temporal effects of fire on insect abundance in Mediterranean forest ecosystems

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ARTICLE INFO

Article history:
Received 26 July 2011
Received in revised form 22 September 2011
Accepted 23 September 2011
Available online 26 October 2011

Keywords:
Forest fires
Insect abundance
Post-fire turnover
Oak Mediterranean ecosystems
Protected areas
Southern Italy

ABSTRACT

Among ecological communities, insects are important bioindicators of fire disturbance due to their sensitivity to environmental change and habitat requirements. In this study, we explored the relationship between insect abundance and distance from the ignition point of fires over a two-year period in an oak-dominated forest located in Southern Italy. Using 18 pitfall traps along three transects (running from the interior to the exterior of the burnt area), 2556 insect specimens belonging to eight orders and 26 families were collected. We used analysis of variance and developed a number of regression models to determine the spatial and temporal responses of insect abundance to fire. In addition, a comparison was made between terrestrial Coleoptera and Lepidoptera and the results were used to explain the effects of forest fire on different taxa. In terms of spatial variation, we observed a significant difference between abundance of Coleoptera in burnt (0–300 m) and unburnt (300–600 m) locations with the highest level of abundance in the forest at the edge of the burnt area. For Lepidoptera, differences were not as significant. In terms of temporal variation, we observed significant differences between the abundance of Coleoptera in the two study years, both in burnt and unburnt locations, with the highest level of abundance in the second year after fire. For Lepidoptera the temporal differences were also significant. The two insect orders showed a contrasting pattern in terms of mean abundance values: the abundance of Coleoptera increased during the survey period, while the abundance of Lepidoptera decreased. Fire disturbance influences the short-term response of insect abundance with positive or negative effects depending on the ecological traits and habits of taxa. Understanding these effects is crucial in highly-modified ecosystems, such as the Mediterranean forests.

1. Introduction

Mediterranean forests harbour a wide range of species which make this biogeographical region one of the world's biodiversity hotspots (Myers et al., 2000; Lafortezza et al., 2005; Santos et al., 2009). A number of threats affect the integrity and resilience of forest ecosystems in the Mediterranean, such as habitat fragmentation, human exploitation, pest outbreaks, invasion from exotic species, overgrazing and forest fires, etc. (Lafortezza et al., 2008; Penman et al., 2011). In particular, forest fires can have severe impacts on ecological communities through direct mortality of individuals (plants and animals) caused by the heat and smoke during the fire (Gerson and Kelsey, 1997) and indirect effects on vegetation structure and species turnover in the post-fire period (Whelan, 1995; Pickering, 1997).

In ecological communities, insects are regarded as bioindicators of fire disturbance due to their sensitivity to environmental change and habitat requirements (Holliday, 1991; Villa-Castillo and Wagner, 2002). Recent studies reported on the cause-effect relationship between fire and insects in different types of forest ecosystems (Rainio and Nimelä, 2004). For example, Huntzinger (2003) explored the effects of fire on Lepidoptera and concluded that maintaining heterogeneity in fire-adapted forests facilitate recolonisation. Other authors have focused on ground-dwelling insects and found contrasting patterns in terms of response, e.g., in Mediterranean Pine forests where Nunes et al. (2006), found a decreasing tendency in ground beetle abundance in the post-fire period. While these studies provide evidence that fire disturbance can alter ecological community composition, they do not provide enough information on the spatial and temporal responses of insects in the post-fire period (Paquin and Coderre, 1997).

The short-term response of insect communities to fire remains to be fully explored in Mediterranean forest ecosystems, especially when considering the spatial and temporal relationships between the abundance of insects and distance from fire ignition (Larsen and Williams, 1999; Ne'eman et al., 2000; Brandmayr et al., 2005).

The consequences of forest fires on ecological communities are not uniformly distributed across space and time: depending on fire intensity and propagation, the effects can be circumscribed to a

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doi:10.1016/j.foreco.2011.09.034

limited portion of the burnt forest area (i.e., the ecosystem level) or be more widely distributed (i.e., the landscape level). In both cases, if the ignition point is considered the starting point of forest fire propagation, the effects of fire on ecological communities, such as insects, are expected to follow a gradient from the interior to the exterior of the burnt forest area, with the exterior (unburnt forest area) having the highest level of abundance. At the same time, depending on the resilience of the ecological community (e.g., species turnover), the effects of fire is expected to change over time, with the highest effects in the short-time period (Reinhardt et al., 2006; Campbell et al., 2007).

To shed light on these assumptions, a research study was developed addressing the following question: *does distance from ignition point explain patterns of spatial and temporal variation in insect abundance*? In answering this question, it should become possible to incorporate the ecological response of insects to fire disturbance in management practices and hence guide decisions on how to regenerate forest stands and support ecological processes across space and time (Potts et al., 2003; Michaels, 2007).

In this paper, we explored the relationship between insect abundance and distance from the ignition point over a two-year period time in a typical Mediterranean forest ecosystem (oak-dominated forest). We collected 2556 specimens, using pitfall traps along transects running from the interior to the exterior of the burnt area. We used analysis of variance and developed a number of regression models to determine the spatial and temporal responses of insect abundance to fire. In addition, comparisons were made between terrestrial Coleoptera and Lepidoptera and results have been used to explain the effects of forest fire on these two taxa (McGeoch, 2007). The implications of the study in terms of post-fire management at ecosystem and landscape level are discussed and research needs in this emerging field are addressed.

2. Materials and methods

The effects of forest fire on insects were modelled by analysing changes in insect abundance in a forest area of about 600 hectares located in Puglia region of Southern Italy, within the ‘‘Alta Murgia’’ National Park (40°55′43.63″ N; 16°36′52.05″ E).

The landscape in this area stretches from an altitude of 250–410 m with a mean altitude of 320 m. The soil is mixed fine-loamy soil and the forest vegetation is dominated by broad-leaved species, such as *Quercus pubescens* (Willd.) and *Quercus coccifera* (L.). The understory vegetation includes *Pistacia lentiscus* (L.), *Pistacia terebinthus* (L.), *Rosa canina* (L.), *Crataegus monogyna* (Jacq.), *Phillyrea* spp, *Rhamnus alaternus* (L.), *Erica arborea* (L.), *Rubus ulmifolius* (Schott.), *Smilax aspera* (L.) and *Arbutus unedo* (L.).

Variation in the structure and composition of this forest is mainly determined by human-induced impacts. These variations include coppicing and firewood collection especially during the past 20 years, overgrazing and fires (Lafortezza et al., 2008). In terms of management, in the recent past the forest area was intensively coppiced and overgrazed. In the study area canopy cover was around 60–70%; the mean number of stumps per plant was around 4–5 shoots of small diameter and height (Elia et al., 2011).

During the summer of 2008, the forest was affected by a major fire event, along the northern border, which affected an area of approximately 260 hectares (40% of the total forest). Field data from local authorities described this fire event as a crown fire of great intensity and high energy release (Elia et al., 2011). As a result, the fire caused a severe reduction of the canopy tree cover; tree mortality was around 95%.

One year after the fire event, the appearance of the burnt forest area was one of standing dead (oak) trees with large open spaces covered by herbs and seedlings, such as *Ruscus aculeatus* (L.), *Myrtus communis* (L.), *Calicotome villosa* (Poir.), *Cistus incanus* (L.), *Cistus monpeliensis* (L.), *Cistus salvifolius* (L.), *Spartium junceum* (L.), *Euphorbia dendroides* (L.).

Field plots were placed across the borders between the burnt and unburnt forest area. Field sampling was performed in three replicate transects during the autumn season of 2009 and 2010. Each transects included six sample sites, with each site 100 m further apart from the others. The first three sites of each transect were in the burnt area (starting from the point where ignition began), while the other three sites were in the forest at the edge of the burnt area (Fig. 1).

Sampling sites consisted of wet pitfall traps (9 cm diameter) buried in the ground with the rim at surface level and baited with vinegar to attract, kill and preserve the insects that fell into them. To reduce the amount of rain and debris entering the trap as well as to keep out predators, the opening was covered by a sloped stone. Pitfall traps are commonly used to address a question of difference in population size or community structure in time or space (Melbourne, 1999).

During the survey period, each trap was visited weekly and all specimens collected were placed in a plastic container filled with 70% ethyl alcohol. All specimens were examined in a laboratory and identified to family level. Extending the analysis to the species level was outside of the scope of this study, as the aim was to understand the response of insect groups (i.e., taxa) to fire rather than single species behaviour (Rainio and Nimelä, 2004). There has been considerable interest in simplifying insect surveys by restricting analysis to the highest taxonomic level that is sufficient to reveal the response in question, rather than necessarily sorting all specimens to species (Gaston and Williams, 1993; Orgeas and Andersen, 2001).

Using the field data collected in 2009 and 2010, a series of single factor analysis of variance (ANOVA) tests were performed to compare insect abundance across space (between class of distance 0–300 m and 300–600 m) and time (between 2009 and 2010). In addition, a number of regression models were also performed to assess the relationship between variables related to the number of individuals per family and distance from fire ignition (m).

3. Results

A total number of 2556 specimens belonging to eight orders and 26 families were collected during the survey period (Table 1). Two families of Lepidoptera, nine families of Coleoptera, seven families of Diptera, two families of Orthoptera and three families of Hymenoptera were trapped. Only one family of Dermaptera, Hemiptera and Blattodea were trapped.

The most abundant orders were: Diptera (35.5%), Lepidoptera (34.3%) and Coleoptera (23.2%). The remaining specimens belonged to other orders, such as Orthoptera, Dermaptera, Hemiptera, Blattodea and Hymenoptera. Overall, insect abundance increased during the two survey years by 37.3%: 1077 individuals were collected in 2009 and 1479 individuals in 2010 (Table 1).

In order to assess the spatial and temporal variations of insect abundance in response to fire distance, a series of ANOVA single factor analyses were run by grouping sampled data based on distance classes (0–300 m and 300–600 m) and survey years (2009 and 2010). To further analyze the data obtained in the results and ascertain the significance of variance the samples were restricted to the Coleoptera and Lepidoptera orders. Coleoptera and Lepidoptera are by far the most diverse of all insect groups and occupy all consumer trophic levels and, as herbivores, predators and prey, play key roles in nutrient cycling and energy flow. These orders have also proven to be useful bioindicators for environmental monitoring and assessment, due to their high diversity and