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The importance of measuring fire severity—Evidence from microarthropod studies

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ABSTRACT

Fires are considered the most important disturbance regime in many ecosystems, including boreal forest. Fires usually reduce the abundances of soil living animals, but the duration of the fire effect and the recovery rate of soil fauna communities after fire are poorly understood. The species-rich group of microarthropods (collembolans, mites and proturans) constitutes an important part of the soil food-web, contributing to important ecosystem services like decomposition and nutrient mobilization. Recovery rates of microarthropods after fire reported in the literature differ considerable between sites and studies. Here, I examine if variation in fire severity can explain part of the variation in recovery of microarthropods after fire observed among studies. To do so, I have chosen studies done in boreal forests and in which the post-fire situation was described in such a way that fire severity (depth of burn) could be estimated. I also selected studies that used real abundance data and that sampled for animals for at least 2 years after fire.

More severe fires were more determinal to soil fauna. Collembola (springtails) recovered within a few years at sites burnt with low severity, but the time frame in most studies (2–5 years) was too short to detect recovery at moderate or severely burnt sites. For mesostigmata and oribatida the recovery patterns were harder to interpret.

I argue that fire severity is the most important factor explaining differences in microarthropod responses to fire, and that this is probably true also for other soil dwelling organisms. Because fire severity is often not taken into account when the effects of fire are investigated, generalizations about fire effects are hard to make.

1. Introduction

Fire is the most prominent large-scale disturbance regime in many of the world's ecosystems including forests and grasslands (Liacos, 1977; Hobbs and Atkins, 1990; Hartnett, 1991; Jonson, 1992; Swaine, 1992; Pyne et al., 1996; Granström, 2001; Parr and Chown, 2003). In the boreal forests in northern Sweden fires used to occur with intervals of 50–200 years on average (Zackrisson, 1977; Engelmark, 1984), but due to the stochastic character of fire occurrence parts of the forest can escape major disturbances for long periods of time (Kuuluvainen, 2002; Gromtsev, 2002). Today, fire suppression in Sweden is so effective that the amount of burnt substrate in is only about 1% of the amount that was available in the natural state (Granström, 2001). This has lead to a decrease of species that are dependent on fire for their long-term survival either directly or indirectly by being favoured by the disturbance. In order to maintain these species prescribed burning for conservational reasons has become more common (Hörnsten et al., 1995; Granström, 2001). It is therefore important that we understand community responses to natural fires, as well as if these responses are similar to prescribed burns.

Microarthropods (collembolans, mites and proturans) constitute an important part of the soil food-web, contributing to important ecosystem services like decomposition (Seastedt, 1984; Barrios, 2007) and nutrient mobilization (Heneghan and Bolger, 1998). Soil organisms make up a substantional part of the world's biodiversity (Giller, 1996; Adams and Wall, 2000) and by their different feeding habits they can, directly or indirectly, influence the function of the primary decomposers such as fungi and bacteria (Heneghan and Bolger, 1996; Berg et al., 2001). Earlier studies have shown that fire usually reduces the total abundance of soil fauna in most ecosystems (Huhta et al., 1967; Metz and Ferrier, 1973; Metz and Dindal, 1975; Tamm, 1986; Koponen, 1995; Paquin and Coderre, 1997; Broza and Izhaki, 1997; McCullough et al., 1998; Wikars and Schimmel, 2001; Saint-Germain et al., 2005; Barratt et al., 2006; Buddle et al., 2006; Malmström et al., 2008, 2009; Kim and Jung, 2008). Fire destroys the preferred part of the soil habitat for most soil organisms, i.e. the litter and uppermost humus layer,

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or if the fire is very severe, the entire humus layer. More severe fires will destroy more of the habitat for soil- and litter living animals than less severe fires. This habitat destruction is likely to be an important factor affecting survival in the soil and recovery after a fire. Fire severity has indeed been shown to affect the numbers of various soil-living arthropods (Vlug and Borden, 1973; Radea and Arianoutsou, 2000; Wikars and Schimmel, 2001; Hening-Sever et al., 2001; Kim and Jung, 2008).

The recovery rate of soil faunal communities after a fire are, however, poorly understood and recovery rates reported for soil microarthropods in the literature vary from just a couple of years to longer than the time period studied which is up to 5 years (Huhta et al., 1967; Koponen, 1995; Broza and Izhaki, 1997; Malmström et al., 2008, 2009; Kim and Jung, 2008). Often, only total abundances are studied, but total abundances have been shown to be a poor measure of recovery since total abundances often recovers faster than species diversity and species composition (Lindberg and Bengtsson, 2005). Also, different microarthropod groups have been shown to recover at different speed after disturbances (Lindberg and Bengtsson, 2005, 2006; Malmström et al., 2008) with a faster recovery of collembolans and mesostigmatid mites and a slower recovery of oribatid mites. Generally, the mortality of ground-living arthropods seems to be directly related to the combustion of litter and organic soil during the fire (Bellido, 1987) or the heat release during the fire (Malmström, 2008; Malmström et al., 2008). In spite of this, only a few studies have taken fire severity into account (Bellido, 1987; Hening-Sever et al., 2001; Wikars and Schimmel, 2001; Malmström et al., 2008; Kim and Jung, 2008) which makes the results hard to compare and interpret.

If the burns are pre-planned the most straightforward way to measure fire severity is to measure the depth of burn, i.e. the destruction of the vegetation and humus layer. When this is not possible, like at wildfire sites, the fires needs to be classified in some other way. Here, I suggest the use of a classification system described by Ryan (2002) that classifies fires into severity classes based on the post-fire appearance of the site. This system also makes it possible to classify old fire studies if only the post-fire conditions are described.

To measure recovery is usually not uncomplicated. When studying wildfires in forests this is not very difficult since a complete recovery is when the community is similar to the community in the unburnt forest. Many of the burns in the Swedish forests today are prescribed burns on clear-cuts. This is a more complicated situation because a fire applied on a clear-cut is a disturbance applied on an already disturbed site, which means that we are dealing with interacting disturbances. On those clear-cuts other disturbances like planting of trees and soil scarification can complicate the picture even more. Multiple disturbances are known to not always be merely additive but can act synergistically (Hobbs and Huenneke, 1992; Gagnon and Platt, 2008).

In this study I wanted to study recovery of soil microarthropods after fires of different severity to determine if severity could explain the variation in recovery rates found in the literature. I also wanted to see if there was a difference between the recovery of total abundances and the recovery of community composition, and if the recovery differed between different soil faunal groups. My hypotheses were: 1. That recovery would be slower for more severe fires. 2. That Collembola and Mesostigmata would recover faster than Oribatida, due to differences in life-history traits.

2. Materials and methods

2.1. Definitions used

The lack of clear definitions of variables in fire ecology is a problem. For example, the terms fire *intensity* and fire *severity* are commonly mixed up in the literature. I have based on more recent literature used the following definitions: Fire *intensity* refers to the rate at which a fire is producing thermal energy and can be measured in terms of temperature and heat release (DeBano et al., 1998; Keeley, 2009). Fire *severity* is usually measured as depth of burn (DeBano et al., 1998) and can be measured as organic matter loss (Keeley, 2009). I have chosen to use depth of burn and destruction of the organic soil layer as a measure of fire severity. The most straightforward way to measure fire severity of a prescribed burn is to measure the thickness of the organic soil layer before and after fire to see how deep into the soil the fire burns. When wildfires are concerned, this is impossible to do since the fires are not planned in advanced. Instead, some measure of severity must be used that does not take information from before the fire into account. To classify the fires, I have used the classification categories suggested by Ryan (2002). This classification is easy to use even when actual measures of the humus thickness before and after fire are not possible, like at wildfire sites, and uses the post-fire conditions to sort the fires into categories. For a short and simplified description see Table 1.

2.2. Study areas

To investigate microarthropod recovery in response to fire severity I have used data from four previously published studies and seven different areas (Huhta et al., 1967; Malmström, 2006; Malmström et al., 2008, 2009). I wanted to study effects of fire severity on the recovery process of soil microarthropods, and therefore I selected studies with data for a minimum of 2 years after fire. To make the studies comparable only studies that deal with real abundance data, i.e. that was sampled with soil samples and not e.g. pit fall traps were used. In order to reduce variation caused by other environmental factors only studies from boreal coniferous forests were included. I also needed the post-fire situation to be described in such a way that fire severity (depth of burn) could be estimated. Data on Collembola abundances were included in all studies found, at least total abundances. Mesostigmata were not distinguished from Prostigmata and Astigmata in Huhta et al. (1967) and was therefore not included in this study and data on Oribatida was not available from Tyresta LF and Tyresta SF (Malmström, 2006).

2.2.1. Hyytiälä

The site is situated in Central Finland and was originally a pine stand of Vaccinium type mixed with spruce and birch. The stand was clear-cut in the beginning of 1961, and burned over on the 5th of June 1962. The size of the stand is not documented. In the fire, most aboveground parts of the ground vegetation were consumed,

Table 1
A short and simplified version of the classification system for fire severity originally proposed by Ryan (2002). The classification system uses changes in above ground vegetation and soil organic matter to determine fire severity.

	Surface litter	Organic soil	Logs	Twigs/branches
Light	Charred to consumed	Unaltered	Blackened, not deeply charred	Larger branches remain
Moderate	Consumed	Deeply burned, to completely consumed	Deeply charred	Larger branches mostly consumed
Hard	Consumed	Largely consumed	Consumed	Consumed