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Review

Why are forest fires generally neglected in soil fauna research? A mini-review

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ABSTRACT

Climate change, unpredictable dry spells and human population growth are expected to increase the frequency of forest fires. Forest fires induce damage on soil ecosystems and seriously compromise their functionality and provision of ecosystem services. They reduce diversity in many soil organism groups, although they also support flora and fauna dependent on fires. Fires disrupt in the cycling of nutrients, and have been argued to threaten the sustainability of forest biomes. However, despite these potentially large effects on soil ecosystems, a literature survey on the forest fire effects on soil fauna demonstrated that the number of publications on this topic between 1979 and 2013 has been surprisingly low compared with studies of other kinds of disturbances. A poll conducted among soil ecologists who actually studied forest fires revealed that more than 50% of the findings about fire effects on soil ecosystems are unlikely to ever be published.

The aim of this review was to discover and structure the reasons why forest fires are often neglected by soil zoologists and ecologists and to identify the major problems which deter soil zoologists from this area of research and from publishing obtained results. We show that forest fires are harder to study than many other types of disturbances. Fires are largely unpredictable and are often unique, which makes it difficult to apply statistically robust sampling plans and select proper controls. Spatial heterogeneity of fire intensity and soil fauna distribution complicate the resulting picture. Moreover, high variability of soil biota in time and space, and complicating effects of multiple fires make the results of such studies hard to interpret. We propose several approaches, which may help to document biodiversity and functional changes in soil communities affected by fire more effectively. These include prescribed burnings, indoor and outdoor experiments and meta-analyses of large datasets, including unpublished ones. We further justify the need for closer coordination of researchers to solve the "file drawer problem" for the unpublished data on soil biota shifts in response to forest fires.

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1. Introduction

Wildfires are usually unexpected events, which occur in many biomes, irrespectively of whether ecologists are prepared to explore them or not. Fires result in dramatic changes in all kinds of forest ecosystems and have a large impact on biota (Rowe and Scotter, 1973; Zackrisson, 1977; Niklasson and Granström, 2000). The United Nations defined fires as one of the key threats for the sustainability of the World's forest cover during the preparation of the International Year of Forests in 2011 (United Nations Forum on Forests, 2007). Globally every year fires affect about 35–47 million hectare of forested areas (Mouillot and Field, 2005). About 0.5–0.7% of the boreal forest area burn every year (FAO, 2010). This means that not only plants but also soils in large areas of forest are subject to drastic thermal effects, which may result in severe damage to both aboveground and belowground biota.

However, fires are also an integral part of ecosystem dynamics and certain ecosystems are adapted to fires occurring at normal intervals (Pausas and Keeley, 2009). In many parts of the world, the normal fire "schedule" is now disturbed resulting in both lower and higher fire frequencies (Running, 2006). The frequency of forest fires is generally increasing due to global change, population growth and in some cases collapsing forest governance (Millennium Ecosystem Assessment, 2005; Mollicone et al., 2006; Shvidenko and Schepaschenko, 2013). With climate change, fires might become more frequent in places where they today are rare, like Fennoscandia. This will cause different kinds of problems related to forest cover, slow reforestation, increased risks of erosion and soil degradation. On the other hand, in, for example, Sweden fire suppression is so effective that the burnt areas have decreased tremendously irrespectively of climate fluctuations (Granström, 2001). In a long-term perspective this may cause problems for fire-adapted insect species that are now becoming rare and in some cases threatened (Whitehouse, 2000; Milberg et al., 2015). At the same time, in north-eastern Europe and Siberia fires are getting increasingly frequent due to poor forest governance.

Soil fauna communities contribute significantly to overall forest biodiversity (Decaëns, 2010). They consist of numerous functionally important organisms, which provide important ecosystem services like litter decomposition, carbon stabilization and nutrient cycling (Barrios, 2007; Neher et al., 2012; de Vries et al., 2013). Due to their contribution to biological processes (organic matter decomposition and mineralization) soil biota may mitigate consequences of forest fires. For example, soil organisms may have strong impacts on physical charcoal degradation, which was recently recognized as an important part of carbon stock in the forests (Kuzyakov et al., 2009; Hart and Luckai, 2013). Soil animals also significantly contribute to the facilitation of nutrient cycling in soil (see e.g. Carrillo et al., 2011), ecosystem production, the insemination of burnt soils with soil microbes and protozoans, and delivery of different ecosystem services (de Vries et al., 2013). Belowground biota plays a key role in determining the physical and chemical properties as well as the fertility of soils and hence productivity of aboveground ecosystems (Barrios, 2007), and regulate microbial activity and other microscale processes

There are various size classes of soil animals related to different processes of the soil (Wallwork, 1975). In this mini-review we focus on soil mesofauna (0.2–2 mm) and soil macrofauna (2–20 mm) keeping in mind that these formal categories often overlap within the same taxa. The mesofauna is normally more abundant than the macrofauna, up to 10^6 and 10^3 individuals m^{-2}, respectively, whereas the typical biomasses are 0.1–1 and 2–8 g m^{-2} for meso- and macrofauna, respectively (Petersen and Luxton, 1982). The mesofauna regulates microbial activity and other microscale processes, while the macrofauna mainly contributes to physical fragmentation of litter, which enhances the decomposition process. Although physically different in size, these two groups are functionally connected in soil and cannot be analyzed separately when studying post-fire recovery processes in soil communities. However, research covering the entire range of soil meso- and macrofauna taxa with respect to forest fires is rarely performed due to its high complexity.

Yet, not much is known about the real impact of fires on soil animals and detrital food-webs as a whole, both in terms of specific reaction of different soil dwelling taxa and peculiarities with respect to different ecoregions and forest types. Even less information is available about the consequences of soil community shifts for ecosystem functioning. Studies in boreal forests have shown that fire reduced the total abundance of soil meso- and macrofauna on a short-term basis (e.g., Buddle et al., 2006; Malmström et al., 2009; Zaitsev et al., 2014b). Burning presumably has negative functional implications on biodiversity and ecosystem services such as organic matter mobilization and immobilization safeguarded by soil organisms (de Vries et al., 2013). Possible indirect effects of such changes include shifts in carbon and nitrogen cycling, potential reintegration of charcoal into biological turnover, destabilization and lower delivery of ecosystem services and finally disturbance of overall plant-animal interactions in burnt environments (Ameloot et al., 2013; Johnson and Turner, 2014). The major driving forces determining post-fire recovery processes below ground are fire intensity and severity, season when the fire occurred, fire heterogeneity and weather conditions (Bengtsson, 2002; Malmström et al., 2008; Malmström, 2010). Moreover, properties of the plant community and edaphic conditions before the fire may also be important for the post-fire recovery process (Goldammer and Furyaev, 1996). Despite the fact that research on the consequences of forest fires on soil fauna started many decades ago (see e.g. Heyward and Tissot, 1936; Whittaker, 1961), studies of the impact of forest fires on soil organisms remain rather scarce.

Forest fires open a wide range of opportunities for ecologists as a model natural disturbance to study secondary successions, spatial patterns of recovery, resilience of soil communities and ecosystems, processes structuring soil animal communities, and other generally relevant questions. However, exploration of how such hardly predictable, yet rather destructing processes, affect soil biota seems to be a challenging, risky (both physically and scientifically) and complex task. So if forest fires are hot and destructive, why are they not hot enough to attract soil zoologists and ecologists and to form a fascinating area of research? The aim of the present review is to examine and structure the reasons for

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