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Short-term and long-term effects of human trampling on above-ground vegetation, soil density, soil organic matter and soil microbial processes in suburban beech forests

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ABSTRACT

Understanding the effects of disturbance by human trampling on ecosystem processes is essential for the management of recreational areas. Discussions on recreational impacts are based either on data from trampling experiments or on field survey data from sites subjected to long-term recreational use, but rarely on a combination of both. We examined whether results from a short-term trampling experiment reflect the impact of long-term trampling around frequently used fire places. We compared short- and long-term effects of human trampling on above-ground forest vegetation and soil physical, chemical and microbial characteristics. We found both similarities and differences in short- and long-term trampling effects. Both short- and long-term trampling reduced plant cover, plant height and species density, though long-term effects were more pronounced than short-term effects. In both approaches, leaf litter biomass decreased, whereas soil density increased with trampling intensity. Other soil characteristics including soil moisture, total soil organic matter content and total organic nitrogen content were not or only marginally affected by short- and long-term trampling. Furthermore, soil microbial biomass and the activity of dehydrogenase did not change in both approaches. In contrast, the activity of β-glucosidase was only reduced by short-term trampling, whereas activity of phosphomonoesterase was reduced only by long-term trampling. Soil compaction was one factor reducing microbial activities at low and medium trampling intensities in our experiment and in the highly compacted area around the fire rings. We conclude that it could be problematic to use the results of short-term trampling experiments to predict general long-term trampling effects. Our results imply also that the restoration of degraded sites might be hampered by the low nutrient turnover resulting from the reduced litter layer and changes in enzyme activities, mitigating a successful re-establishment and growth of plants.

1. Introduction

The impact of outdoor recreation on natural communities and habitats is of crucial interest to forest managers. In urban areas, forests are often the only freely accessible natural areas to spend some leisure time (Jacsman, 1998; Niemelä, 1999). Large numbers of forest visitors can lead to conflicts between recreation and nature conservation (Liddle, 1997; Baur, 2003). Previous observational and experimental studies have demonstrated effects of recreational activities on soil and vegetation of forest ecosystems (e.g. Cole, 1995; Waltert et al., 2002; Hegetschweiler et al., 2009). In particular, activities such as picnicking, barbecuing and camping can degrade large forest areas, and damages can spread to previously untouched areas (Marion and Cole, 1996; Kutiel and Zhevelev, 2001; Amrein et al., 2005). Furthermore, the deposition of food remains and litter may change soil pH, soil organic matter and nutrient composition (Hart et al., 2005; Arocena et al., 2006; Cole and Spildie, 2007). Field surveys provide information on the extent of degradation, often at sites that have been in use for decades. For example, frequently visited recreational areas show reduced plant cover and decreased height and plant species density of the above-ground vegetation (Liddle, 1997; Kutiel and Zhevelev, 2001; Malmivaara et al., 2002; Roovers et al., 2004; Rusterholz et al., 2009). Short-term trampling experiments revealed that the extent of damage depends on the frequency of visitors and the kind of recreational activity, but also on the type of soil and vegetation and the season (summer or winter) of use (Cole, 1987; Gallet and Roze, 2001).

Human trampling leads to soil compaction, which increases bulk density and decreases porosity, resulting in a shortage of oxygen and a changed water regime in the soil (Kozlowski, 1999). Effects of soil compaction by human trampling on soil organic matter, soil pH and soil nutrient content are not yet clear (Liddle, 1997). Some studies reported either an increase or a decrease in

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organic matter and soil pH and a shift in nutrient composition or even no effect at all (Amrein et al., 2005; Andres-Abellan et al., 2005). Microbes may respond to these environmental stresses by changing their activity, growth or resource allocation (Schimel et al., 2007), potentially altering the production of the soil enzymes responsible for catalyzing carbon, nitrogen and phosphorus cycling (Burns and Dick, 2002).

Understanding the effects of soil compaction caused by trampling on physical, chemical and biological soil characteristics and their interactions with plants is essential to assess the potential effectiveness of management actions aimed at restoring degenerated forest areas (Cole, 2004). In spite of this, effects of recreation on soil microorganisms have rarely been looked at. Notable exceptions are two descriptive field studies by Zabinski and Gannon (1997) and Malmivaara-Lämsä and Fritze (2003) who found shifts in the microbial community structure at intensively used camping sites and in urban forests. In a short-term trampling experiment in a pine forest in Spain, enzyme activities diminished with trampling intensity (Ros et al., 2004).

Short-term experiments are frequently used as a means to understand processes in natural systems. Experiments allow an assessment of the impact of different factors in a controlled way (Freckleton, 2004). However, the time scale of ecological processes is usually longer than the duration of an experiment. While short-term experiments can provide reasonable estimates of long-term effects in some cases, results cannot always be extrapolated to longer temporal scales (Freckleton, 2004; Briggs and Borer, 2005; Olofsson, 2006).

By directly comparing effects at different temporal scales, we studied whether a short-term trampling experiment provides good indications of long-term trampling effects on vegetation and soil enzyme activities in recreational forests. In experimental studies, trampling intensity increases with increasing number of passes, while at fire places frequently used over long periods, trampling intensity increases with decreasing distance to the fire ring. We therefore also determined the spatial dimension of visitor-induced disturbance at fire places. Even though trampling experiments have become a popular means of assessing potential effects of recreational activities on vegetation and soil characteristics, a direct comparison between field survey data and data from experimental trampling has hardly ever been attempted (for an exception see Marion and Cole, 1996).

The objectives of this study were to assess the effects of human trampling on (1) above-ground vegetation, (2) soil chemical and physical characteristics, and (3) microbial biomass and the activities of the enzymes dehydrogenase, β-glucosidase and phosphomonoesterase. Dehydrogenase can be used as an indicator for general metabolic activity, while β-glucosidase and phosphomonoesterase are enzymes of the carbon and phosphorus cycles, respectively. To our knowledge, this is the first study comparing short-term and long-term trampling effects on soil microbial biomass and enzyme activities. The results provide basic knowledge concerning the influence of recreation on selected soil processes and thus contribute to the understanding of impacted forest ecosystem functioning.

2. Materials and methods

2.1. Study sites

The study was carried out in two beech (*Fagus sylvatica*) forests Allschwil (7°32′ E, 47°32′ N) and Sichtern (7°43′ E, 47°29′ N) in the vicinity of Basel, Switzerland, at an elevation of 350–430 m. Common tree species in both forests are *F. sylvatica*, *Carpinus betulus*, *Fraxinus excelsior*, and *Acer pseudoplatanus*. *Quercus* spp. is also abundant in Allschwil forest. Frequent species in the understorey include *Galium odoratum*, *Anemone nemorosa*, *Ranunculus ficaria*, *Hedera helix*, and *Carex sylvatica*. The soil type is a gleyic cambisol in Allschwil and a haplic luvisol in Sichtern (Driessen and Deckers, 2001). Annual temperature averages 10.4 °C in Allschwil and 8.9 °C in Sichtern and annual precipitation 778 mm and 979 mm in the two forests (MeteoSwiss, 2005a,b).

2.2. Short-term effects

We examined short-term effects of different intensities of human trampling experimentally in three undisturbed 25 × 25 m plots in both forests in spring 2005. The plots at each study site were 100 m to 500 m apart. The experimental design was based on the trampling procedures (Cole and Bayfield, 1993), modified and adapted to conditions of beech forests. Two 2.5 × 3.5 m blocks were randomly placed in each experimental plot and two 0.5 × 0.5 m subplots were placed in the middle in each line (Fig. 1). Blocks consisted of four lanes, each 0.5 m wide and 2.5 m long with a buffer zone of 0.5 m between two lanes. Trampling was conducted on a single day by a person weighing 60 kg and wearing hiking boots. Trampling intensities were 100, 300 and 900 passes randomly assigned to lanes. The fourth lane was used as a control. Trampling intensities were based on data on intensity of fire place use at three sites during one vegetation period (from April until the end of September) in the forests investigated.

Immediately before trampling we assessed above-ground vegetation characteristics in two subplots. Total plant cover was estimated using the following classes: 0.5, 1, 5, 10, 20, 30, . . ., 90, and 100% (Cole and Bayfield, 1993). Mean plant height was measured to the nearest cm (five measurements per subplot) and species density (number of plant species per 0.25 m^2) was recorded. Leaf litter was collected from a quarter of each subplot and weighed after oven drying at 80 °C for 48 h. Soil density was measured as soil penetration resistance five times in each of the two subplots using an Eijkelkamp Typ IB handpenetrometer (Eijkelkamp Agrisearch Equipment BV, The Netherlands). Five soil samples approximately 15 cm apart from each other were taken to a depth of 5 cm using a soil corer (diameter 5 cm; volume 100 cm^3), pooled and mixed. The samples were taken next to each subplot to avoid any disturbance other than experimental trampling. The distance between the pooled samples ranged from 1.0 m to 1.5 m. Samples were packed on ice during transport to the laboratory, where they were stored at −20 °C until analysis.

Three days after the trampling, soil samples were taken again next to the subplots and soil penetration resistance was measured once more. Two weeks later plant cover, height and species density

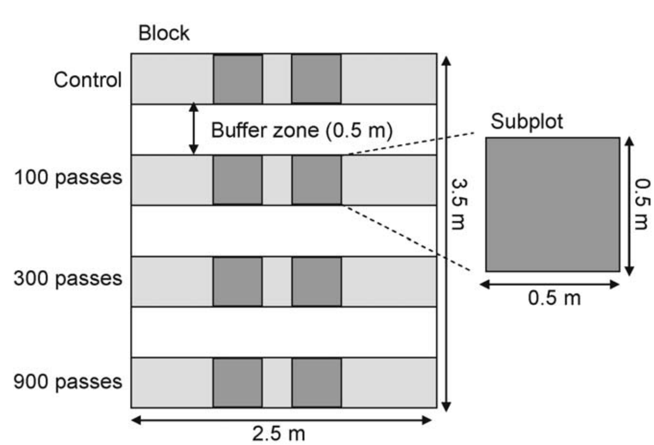

Fig. 1. Layout of sampling design of short-term trampling. One block consists of 4 lanes, each with two subplots.