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Tree influence on soil microbial community structure

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A B S T R A C T

Biological communities differ over time and in space, and in the forest these communities often vary according to trees and tree gaps, mediated by mechanisms that are likely to change over time and as a tree are removed. In this paper we ask the questions: What is the influence of individual trees on soil microbial community structure? Does the soil microbial community change in the short-term when a tree is removed, and does this change depend on the initial influence of the tree? We use phospholipid fatty acid (PLFA) analysis and a geostatistical approach to study effects of trees and tree removal (thinning) on soil microbial community structure in a young boreal Norway spruce (*Picea abies*) forest. An experiment was setup where half (four) of the included trees were cut and soil was collected prior to (t0) and one month after (t1) tree felling. The samples were collected along two perpendicular transects originating from each of the eight study trees. A tree influence index was calculated for each sample point from the distances to neighbouring trees, weighted by tree diameter. We found that individual trees are important in structuring the soil microbial community as microbial community structure responded to the gradient in tree influence. Also strong spatial structure was found corresponding to the patch structure induced by trees. Changes in microbial community structure before and after tree felling (t0 and t1) was found to differ significantly between felled and non-felled trees: samples from felled trees came to resemble samples with a low value of tree influence and samples from below non-felled trees came to resemble samples with a high value for tree influence. We thus found that soil microbial community structure in a boreal forest is spatially structured by the distribution of single trees, and that soil microbial community structure varies seasonally and is affected by tree removal, in an intricate manner that reflects the initial influence of trees.

1. Introduction

The importance of above and belowground interactions is increasingly recognized as essential to the functioning of ecosystems (Bever et al., 1997; Wardle et al., 2004; Bardgett et al., 2005). Spatial patterns in soil microbial communities are often found to be associated with plant species composition, richness and biomass (Pennanen et al., 1999; Saetre, 1999; Saetre and Bååth, 2000; Hooper et al., 2000; Pietikainen et al., 2007). In forest ecosystems, the size and longevity of trees make them important ecosystem engineers that affect both above- and belowground ecosystem components. The effects of trees on belowground properties are associated with aboveground deposition of litter and belowground deposition of matter through root exudation and root death. In this way, the influence of trees on soil properties is in principle not different from that of other plants, but potentially stronger due to the size of the trees. Trees will also through their extended root system take up nutrients over large areas and deposit them under or close to their canopy (Gibson, 1988), and thereby redistribute soil resources (Pärtel and Wilson, 2002). This leads to greater heterogeneity (Grønli et al., 2005) than what we find in ecosystems dominated by smaller-statured plants, or in systems where a single or few species dominate (Felske and Akkermans, 1998). The tree thus has direct effects on soil microbial communities, but can also affect the soil more indirectly through effects on vegetation and abiotic variables.

Ecological field theory (Wu et al., 1985) has proved useful for modelling the influence of single trees in coniferous forest on different response properties, such as variation in environmental factors, soil conditions and seedling growth (Kuuluvainen and Pukkala, 1989; Kuuluvainen et al., 1993; Pukkala et al., 1993; Hokkanen et al., 1995) as well as plant species composition

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(Økland et al., 1999). Saetre and Bååth (2000) investigated the spatial patterns of soil microbial communities in a mixed Norway spruce-birch stand, and related soil microbial community structure to tree influence index calculated by a simplification of the ecological field theory procedure (which models tree influence as an exponential function of tree size and distance from a sample point to the tree). They found that soil microbial communities were influenced by the position of trees (Saetre and Bååth, 2000), and demonstrated a relationship with the quality of the organic matter (Saetre, 1998).

The structuring influence of a tree should eventually disappear after a tree is felled. The time required for the influence to disappear will depend on the method by which a pattern is induced; some effects will be long-lasting, others will be of short duration. The tree as a living entity is, however, immediately removed when the tree is cut, and this will affect the soil microbial community directly as current photosynthesis is an important driver of soil respiration (Högberg et al., 2001). The root system of felled trees and other harvest residues also represent a readily decomposable source of carbon and nitrogen for the soil microorganisms (Newman, 1985; Thibodeau et al., 2000) inducing spatial patterns in the soil community. This carbon source is long-lasting and mycorrhizal root tips are able to live long after the associated tree has been cut (Hagerman et al., 1999).

The main questions we asked in this paper were: What is the influence of individual trees on soil microbial community structure? Does the soil microbial community change in the short-term when a tree is removed, and does this change depend on the initial influence of the tree? We also describe spatial patterns of soil microbial community structure and how such patterns are affected by tree removal. Our study site was a young Norway spruce forest stand that was planted about 35 years ago. Such forest stands are very common in North Europe and they make up a significant part of the present-day forest landscape created by broad-scale industrial forestry. We conducted our study at the time of year when the carbon flow to the roots and the roots' demand for carbon is largest (Högberg et al., 2001) in search for spatial relationships between tree removal and soil microbial community structure.

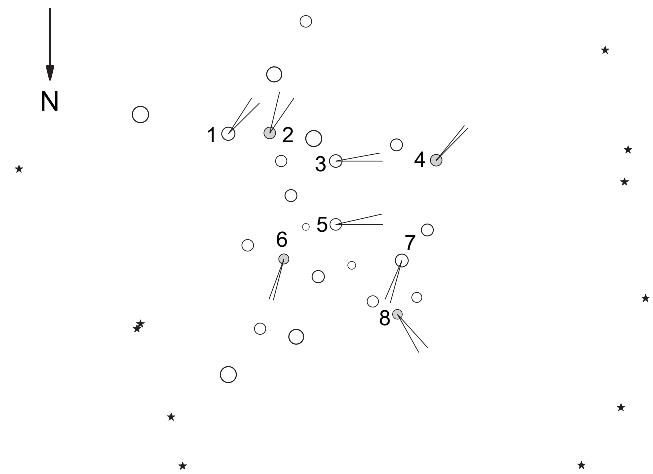

Fig. 1. Map over the study area, a north-facing slope (North is down) with average inclination of 4%; soil sampling was conducted within ca. 15 × 20 m. Each circle is a tree, non-felled trees (NF): tree number 1, 3, 5 and 7 (grey circles) and felled trees (F): tree number 2, 4, 6 and 8 (open circle with transects). The remaining open circles indicate trees that were included in the calculation of TII. Sampling transects (each of the lines are 2.56 m) are indicated by lines and the thinning transects along which the forestry vehicles were operating are indicated by stars. Size of circle indicates diameter at breast height of tree (mean value 16.4 cm (SE = 0.76, $N = 25$), range from 9–24.5 cm). Diameter at breast height for non-felled trees (NF): 1 = 18 cm, 3 = 17 cm, 5 = 11.7 cm and 7 = 19 cm and felled trees (F): 2 = 14 cm, 4 = 16 cm, 6 = 13 cm and 8 = 12.5 cm.

2. Materials and methods

2.1. Study site

The study site is located in the municipality Siljan in Telemark County, South Norway (59°22′N 9°45′E, 460 m a.s.l.), situated on the border between the south and middle boreal vegetation zones in the slightly oceanic vegetation section (Moen, 1999). The annual mean air temperature was 5.4 °C and the annual precipitation was 1120 mm at the Siljan Weather station (1961–1990 means), 20 km south of the study area at an elevation of 100 m a.s.l. (www.yr.no). Average summer (June–August) air temperature and precipitation at the Siljan Weather station were 15.5 °C and 283 mm (1961–1990 means), respectively (source: www.yr.no).

The study site is located on a north-facing slope with 4% average inclination (across the entire study area), and comprised a 10 ha mixed stand consisting of ca. 90% (of approximately 800 stems ha^{-1}) Norway spruce (*Picea abies*) and 10% birch (*Betula pubescens*). Trees were approximately 35 years old. The stand was eligible for thinning in the autumn of 2004. Total standing volume before thinning was 100 m^3 ha^{-1} (according to a forest inventory from August 2004, provided by the forest owner Fritzöe Skoger). Mean height of the trees included in the study was 12.4 m (SE = 0.4, $N = 25$) and mean diameter at breast height (dbh, measured 1.3 m above the soil) was 16.4 cm (SE = 0.76, $N = 25$) (see Fig. 1 for more information). Brown podzolic soils have developed from bedrock consisting of intrusive rocks of Permian age, mostly larvikite, covered with discontinuous to thin gravelly or sandy till (Bergstrøm, 1988). Soil chemistry data (see Nielsen et al., 2007) from the area surrounding the study site was used to calculate soil carbon and nitrogen content of the soil in stands of similar age: total carbon in the organic top layer of the soil was 43.5% (SE = 1.19, $N = 50$) and total nitrogen 1.6% (SE = 0.06, $N = 50$). Data from the studied stand indicate a depth to the mineral soil of around 15 cm, soil pH was around 3.0 (in 0.011 M $CaCl_2$) and water content around 75%. See data for soil organic matter content in section 2.3.

The following species were recorded at individual sampling points: *Empetrum nigrum*, *Vaccinium myrtillus*, *Avenella flexuosa* (=*Deschampsia flexuosa*), *Dicranum* sp., *Plagiothecium undulatum*, *Pleurozium schreberi*, and *Sphagnum* spp.

The study area was selected by visual inspection of the stand. The predefined lines along which the forestry vehicles were expected to operate (these lines were demarcated prior to selection of the experimental trees) were avoided and so was also a buffer zone of 50 m towards a road.

2.2. Experimental setup

Eight trees were chosen for this study (see map in Fig. 1). From each tree, two transects of 2.56 m were established from the stem into the surroundings. The transects were placed along level straight lines and old stumps, storm-felled trees or moose/sheep faecal matter were avoided and so was *Sphagnum* spp. dominated vegetation. We wanted to study the effect of single trees and we therefore placed the two transects, originating from each of the eight trees to minimize the effect of other trees. We placed the transects with similar distance to the main roots and as close together as possible (to minimize the spatial differences between sample points for each tree before (t0) and after felling (t1); maximum distance between transects at 2.56 m distance from trees was 80 cm). We sampled transect one before felling (t0) and transect two after tree felling (t1).