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A bark beetle attack caused elevated nitrate concentrations and acidification of soil water in a Norway spruce stand

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ABSTRACT

A bark beetle attack in a Norway spruce forest in southwestern Sweden killed most trees, which however mostly remained standing, and caused elevated nitrate concentrations and subsequent acidification in the soil water. Long-term monitoring showed very low nitrate concentrations in the soil water before the bark beetle attack. High nitrate concentrations remained throughout five years after the initiation of the bark beetle attack until the monitoring was terminated. The increased nitrate concentrations in the soil water were accompanied by a decrease in both pH and the acid neutralizing capacity, ANC. The significance for future nitrogen and acidity leakage to ground- and surface waters is discussed in relation to the expected future increase in the frequencies of bark beetle attacks in boreal and northern temperate forests.

1. Introduction

The deposition of reactive nitrogen remains as one of the most important air pollution issues for northern European forests as well as for forests worldwide (Sutton et al., 2011). High nitrogen deposition to forests can change the species composition of the understory vegetation (Nordin et al., 2005) and increase the risk of elevated nitrate concentrations in soil water, and thus leaching of nitrate to ground- and surface waters (Aber et al., 1989; Gundersen et al., 2006). Soil water measurements in the the Swedish Throughfall Monitoring Network (SWETHRO, Pihl Karlsson et al., 2011) show that the nitrate concentrations in soil water are elevated in several undisturbed forest sites in southwest Sweden (Akselsson et al., 2010). Disturbances may cause further increased nitrogen concentrations in soil water and a risk of leaching to ground- and surface waters also in other areas. Disturbances that may cause nitrate leaching include clear-cut harvests (Kubin, 1995; Akselsson et al., 2004), site preparations (Nieminen et al., 2012), windthrow (Mellert et al., 1996; Hellsten et al., 2015) and insect attacks (Mellert et al., 1996; Huber, 2005, Kopacek et al., 2017). There are predictions that insect attacks by e.g. bark beetles may increase in Swedish forests in the future (Jönsson and Bärring, 2011).

Air pollutant concentrations, deposition and soil water chemistry have been monitored within the SWETHRO network at forest sites in Sweden since 1985 (Pihl Karlsson et al., 2011). In 2008 it was reported that the Norway spruce trees at one of the sampling sites, in southwestern Sweden, were under attack from bark beetles. The monitoring of throughfall and soil water chemistry at the site continued until 2013, when the plot had to be terminated due to severe damage. During this time period, also the extent of damage to the trees was monitored.

The aim of this study was to describe the change in the soil water chemistry during the five years after the initiation of the bark beetle attack, in particular in regard to nitrogen concentrations and acidification in soil water. The significance for future nitrogen and acidity leaching to ground- and surface waters is discussed in relation to the expected future increase in the frequencies of bark beetle attacks in boreal and northern temperate forests.

2. Materials and methods

2.1. Site description and measurements

The SWETHRO network includes measurements of bulk deposition (BD) in open areas, as well as throughfall deposition (TF) and soil water chemistry inside forest stands. Monitoring sites are positioned in closed, mature managed forests with no major roads or other pollution sources in the vicinity. The methodology is described in detail in Pihl Karlsson et al. (2011). In brief, soil water was sampled with three suction lysimeters (Fig. 1) with ceramic cups (P80), sucking water for two days. The water from the three lysimeters was combined into one composite

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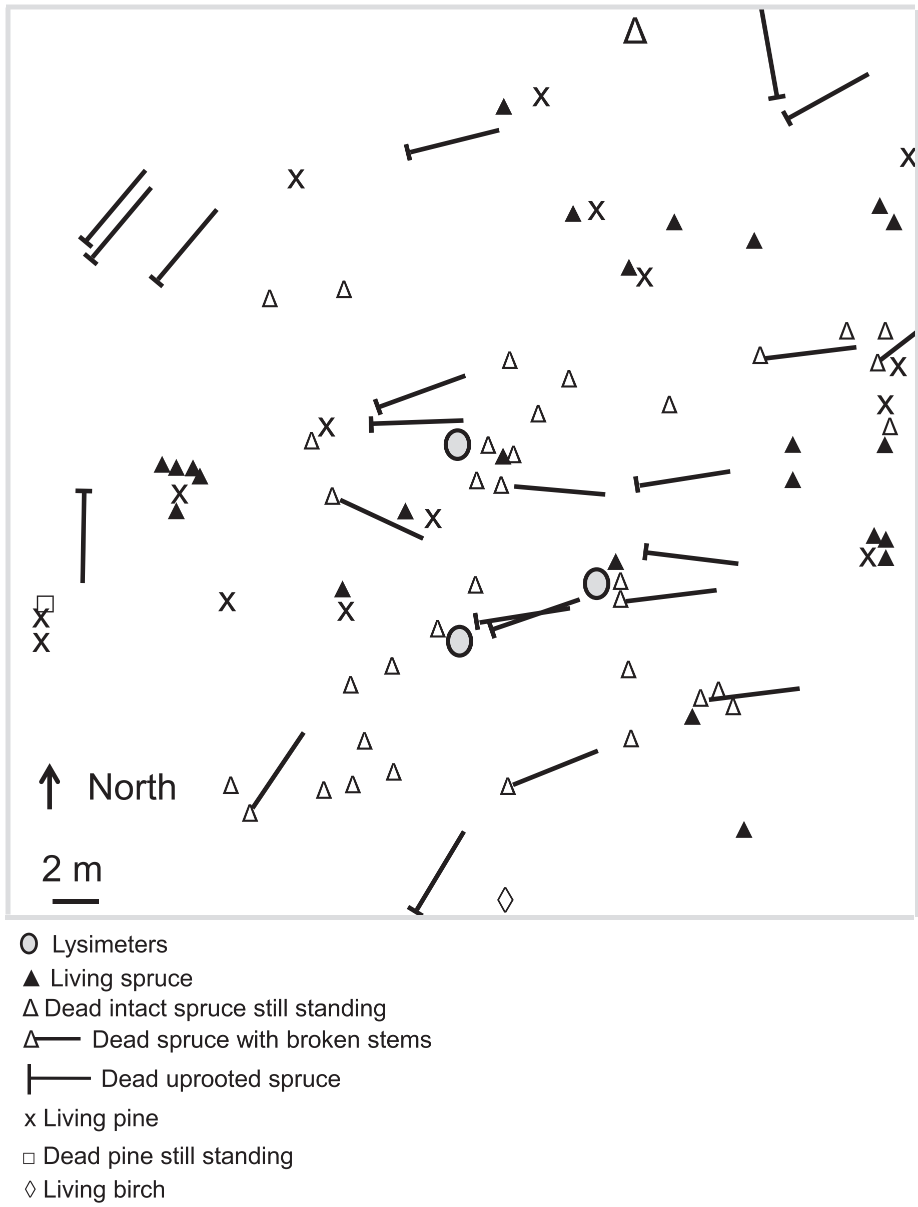

Fig. 1. Inventory of the trees at the monitoring site Klippan Aug 18th 2011. Grey lines represent a square 40 * 40 m.

sample. Soil water was sampled before, during and after the vegetation period (exact data depending on the weather situation). However, at some occasions soil water deficits prevented sampling. The samples were sent by mail and upon arrival at the laboratory pH, alkalinity and conductivity were measured directly. The water sample was then filtered (0.8 mm). A small subsample was preserved with sulphuric acid to be analysed for Kjeldahl-N and NH_4-N. Another subsample was preserved with nitric acid for analysis of Fe and Al. The remaining sample volume was not preserved, and used for the remaining analyses. SO_4-S, NO_3-N, Cl, Ca, Mg, Na, K, Mn were analysed by Ion Chromatography, IC. NH_4-N was analysed by Flow Injection Analysis (FIA). KJ-N was measured according to Foss-Tecators method AN 52212002-10-24. Fe, total, organic and inorganic aluminium were measured with ICP-MS according to SS-EN ISO 17294-2:2005.

The monitoring site “Klippan” is positioned in southwest Sweden, east of the city of Gothenburg (latitude 57.41.09 N, longitude 12.29.03 E, 100 m.a.s.l). The forest stand at the site was a 120-year-old Norway spruce forest with site index G22. The site index is an indirect measure of a forest’s potential natural productivity. In Sweden, the site index normally represents the average height of the largest (based on stem diameter) 100 trees per hectare at an age of 100 years. Scots pine trees were also present at the site (about 30% of the trees). The site was situated in a nature reserve, hence, damaged trees were not harvested and removed.

Measurements at Klippan started in 1989 with monthly measurements of TF and BD and measurements of soil water three times per year. The measurements of BD were terminated 2000/2001 while the measurements of TF and soil water (SW) ended in 2013. SW was sampled with suction lysimeters at 50 cm soil depth. There were three lysimeters in the plot positioned approximately 10 m apart (Fig. 1).

In 2015 there was a major storm affecting southern Sweden (Hellsten et al., 2015), but there was only minor forest damage at the site Klippan.

The deposition and soil water chemistry between 1990 and 2008, before the bark beetle attack, have been described in detail in Akselsson et al. (2013). The mean annual deposition of sulphur at Klippan during 1990–1999 was 11.8 and 7.9 kg S ha^{-1} yr^{-1} in throughfall and bulk deposition respectively. During 2000–2012 the corresponding value for throughfall was 3.8 kg S ha^{-1} yr^{-1}, while bulk deposition was not measured during this period. The mean annual deposition of inorganic