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Limnological effects on a first order stream after wood ash application to a boreal forest catchment in Bispgården, Sweden

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Abstract

In Sweden, whole tree harvest is common practice, possibly leading to the depletion of mineral nutrients. Furthermore, the increased use of forestry residues for heat production has caused an increasingly growing amount of by-product consisting of wood ash. Therefore, the Swedish Forest Agency has recommended wood ash application (WAA) to replace the mineral nutrients removed by whole tree harvesting, as well as a means to mitigate the acidification of boreal forests and surface waters. In a multidisciplinary study during 2003–2006 in Bispgården (Sweden), we have investigated the limnological effects on a first order stream after WAA (conducted in 2004; 3000 kg ha^{-1}) to a 50-ha forested catchment. In general, no significant effects on an annual basis were found for acidification parameters, such as pH, alkalinity and toxic forms of aluminum (Al). There was, however, evidence of an increased pH during the spring flood, accompanied by a simultaneous decrease in the frequency of low pH-values (<5.6). Moreover, alkalinity increased in the years 2005 and 2006 compared to that of 2003, although the increase in 2006 was not statistically different from that in 2005 or 2003. High concentrations of Al repeatedly occurred in the stream, and the WAA did not affect the frequencies of high concentrations of toxic Al forms (>50 μg l^{-1}). The benthic diatom community did not change as a result of the wood ash treatment and the diatom-based index IPS (Indice de PulluoSensibilité) indicated no nutrient enrichment or organic pollution of the stream water. There were, however, indices of elevated concentrations of potassium (K) in the aquatic moss *Fontinalis antipyretica* and in leaves from Alder (*Alnus incana*). We conclude that wood ash treatment of a forested catchment with the dose and form of ash applied in this study did not modify the freshwater ecosystem of a first order stream.

Keywords: Wood ash; Stream water; Mineral nutrients; pH; Aluminum; Diatoms; Boreal; Fontinalis; Invertebrates

1. Introduction

In Sweden, the silvicultural activities have been increasingly directed towards more sustainable harvesting methods. At present, whole tree harvesting is common practice, possibly leading to the depletion of mineral nutrients. Furthermore, the increased use of forestry residues for heat production has caused an increasingly growing amount of by-product consisting of wood ash. Therefore, the Swedish Forest Agency has recommended wood ash application (WAA) to replace the mineral nutrients removed by whole tree harvesting, as well as a means to mitigate the acidification of boreal forests and surface waters (Anon, 2001). One urgent question that needs addressing is if the wood ash can be recycled to the forest without environmental problems. Wood ash contains several beneficial mineral nutrients (e.g. calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), and silicon (Si)) and some less desired, potentially toxic metals, like cadmium (Cd), zink (Zn), copper (Cu), and lead (Pb). The effects of WAA depend on the characteristics of the wood ash, the dose and the specific site at which the wood ash was applied (Aronsson and Ekelund, 2004).

At present, the recommendations from the Swedish Forest Agency to practice WAA in forest management is more oriented towards the mitigation of acidification, than to the recirculation of mineral nutrients. No new recommendations from the Swedish Forest Agency have been officially presented at this date. To our knowledge, only one investigation has addressed the effects of WAA to freshwater ecosystems in boreal forests (Tulonen et al., 2002). This investigation showed an increase in several elements (K^+, Cl^-, SO_4^{2-}) in brooks, and an increase in phytoplankton biomass in two investigated lakes situated in the wood ash treated catchments. Tulonen et al. (2002) also observed a tendency of increased pH and alkalinity in a brook in the ash treated area. However, additional tank

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experiments conducted by Tulonen et al. (2002) showed a significant decrease in phytoplankton growth. Recent studies have shown that moderate concentrations (1–5 g l^{-1}) of wood ash can stimulate cell growth and movement of the freshwater alga *Euglena gracilis* (Aronsson and Ekelund, 2005), as well as promote stem and secondary branch growth of the freshwater moss *Fontinalis antipyretica* Hedw. (Aronsson and Ekelund, 2006). However, at concentrations above 5 g l^{-1} under alkaline conditions (pH > 8) only harmful effects were detected (Aronsson and Ekelund, 2005, 2006; Ekelund and Aronsson, 2006). The use of wood ash in boreal forests to prevent acidification of surface waters consequently need more understanding, prior to large scale implementation of WAA.

A multidisciplinary study of WAA at the catchment scale was initiated in the summer of 2003 in Bispgården, Sweden. The overall purpose was to describe the effects of WAA to biotic and abiotic components of this boreal ecosystem. In the present work, data compiled over a 4-year period have been analyzed with special emphasis on the effects of WAA to the first order stream Fanbergsbäcken in the catchment area. Based on previous limnological studies on the effects of wood ash, WAA and the ongoing liming activities in Sweden, we postulated the following hypotheses regarding the conditions in the stream Fanbergsbäcken after WAA: (a) an increase in pH and alkalinity, followed by a decrease of toxic forms of aluminum; (b) an increase of mineral nutrients in the water and the investigated biota; (c) a shift in the periphyton (diatom) community structure, due to an altered pH; (d) increased amounts of potentially toxic elements in the water and investigated biota; and (e) an immediate response of drifting invertebrates due to deteriorated water quality during WAA.

2. Materials and methods

2.1. Study area and experimental design

Two small streams in the vicinity of the village Bispgården, about 100 km NW from Sundsvall (Sweden), were included in the present study. The stream Fanbergsbäcken (FAN) is a first order stream with a 50-ha catchment. The whole catchment was treated with wood ash in September of 2004 (see details below). The Reference stream (REF) is situated approximately 900 m SW from FAN, and the catchment area is 40 ha (Fig. 1). The dominant tree species in both catchments is Norway spruce (*Picea abies* L.) and Scots pine (*Pinus sylvestris* L.), stand ages 40–80 years, growing predominantly on mineral soil (podzol) in the recharge area and arenosol in the discharge area. Only minor parts of the catchments consist of peatland. The annual average precipitation, run-off, and mean flow in the streams (2003–2006) were 800 mm, 400 mm, and 6.3 l s^{-1}, respectively. The Reference stream was primarily used to analyze chemical (pH) and biological (diatoms) data in terms of natural variations of the two creeks, in order to avoid misinterpretation of possible effects from WAA in the catchment of the stream Fanbergsbäcken. The wood ash was self-hardened crush-ash (1–10 mm grain size) originating from Jämtlamell, Östersund (Sweden). The ash contained approximately 50% water, and consequently 300,000 kg (3000 kg ha^{-1} DW; 50 ha) of ash was spread by tractor (99%) and by hand (1%) in the Fanbergsbäcken catchment in September of 2004 (27/9/2004–30/09/2004). The chemical properties of the wood ash are presented in Table 1. Water samples and biological materials were collected two seasons before (2003–2004), and two seasons after WAA (2005–2006).

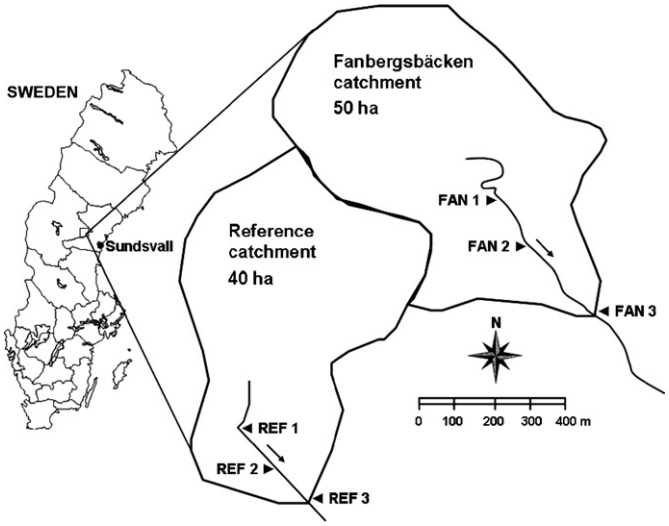

Fig. 1. Location of the investigation area and the three sampling sites in the stream Fanbergsbäcken (FAN 1–3) and the Reference stream (REF 1–3). Flow direction is indicated by arrows. The areas of the catchments are indicated in the figure.

2.2. Water chemistry

Water samples were collected once a month during the ice free season (additional sampling at high flows) at three different sites that were 200–300 m apart for each stream (FAN 1–3 and REF 1–3) (Fig. 1). The samples were kept in acid-washed

Table 1
The concentrations of ecologically important elements in the wood ash used in the present investigation in Bispgården, Sweden

Element	Wood ash (mg kg^{-1} DW)
Ca	205,492
Si	96,928
K	30,590
Al	29,677
Mg	15,678
Fe	13,009
Mn	12,390
P	9964
Na	6225
S	2030
Zn	831
Cu	64
Cr	40
Ni	24
Pb	7.9
Cd	4.0

Crush-ash from Jämtlamell, Östersund (Sweden).