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Afforestation, seasalt episodes and acidification – A paired catchment study in western Norway

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Seasalt episodes cause higher mobilization of toxic aluminum in sites afforested with spruce.

Abstract

As acid deposition has declined during the past 15–20 years in western Norway, afforestation and episodic seasalt deposition have become factors of increasing importance in explaining the mobilization of toxic aluminum (Al^{n+}) to rivers and lakes. We conducted a paired catchment at four sites in western Norway across a gradient in acid deposition to evaluate the importance of afforestation and seasalt episodes. Streamwater was sampled intensively before, during and after seasalt episodes over a three-year period. A seasalt episode in January 2003 caused considerable impact on the streamwater chemistry. pH dropped and concentrations of Al^{n+} increased due to cation exchange of Na^+ ions for H^+ and Al^{n+} in the soil. The response was larger in streams draining the catchments which receive high acid deposition and in those afforested with spruce as compared with adjacent catchments in native birch. The results indicate that acid pulses induced by episodic inputs of seasalts are exacerbated by land use change from native birch to planted spruce.

Keywords: Spruce plantation; Acid deposition; Seasalt; Episodic acidification; Storm event

1. Introduction

Acid deposition has been and still is a widespread environmental problem in southern, south-western and western Norway (SFT, 2003), even though anthropogenic sulfur (S) deposition has decreased by 60% from 1975 to 2000 and nitrogen (N) deposition has decreased by about 10% (Aas et al., 2003). As acid deposition in Norway decreases, the focus has turned to recovery of water quality and aquatic flora and fauna. Water quality has clearly improved, but the biota has yet to show widespread recovery (SFT, 2003; Stoddard et al., 1999). Salmon rivers are of special concern and the improvement in water quality after reduction of acid deposition has not yet yielded improvements in the wild salmon stock in many rivers along the Norwegian west coast (Kroglund et al., 2002). The lack of recovery of salmon stocks may be due to several factors, of which acidification is one.

Large-scale spruce plantations in acid-sensitive areas may exacerbate surface water acidification. Spruce afforestation may cause acidification due to several reasons: (1) increased dry deposition of gases and aerosols due to increased filtering in the canopy (Nisbet et al., 1995; Harriman et al., 2003; Puhr et al., 2000); (2) increased evapotranspiration (Allen and Chapman,

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2001); (3) increased base cation uptake (Hornung and Reynolds, 1995) and (4) increased acidity of litterfall (Pontynen, 1954; Alexander and Cresser, 1995; Ritter et al., 2003).

The effects of afforestation on surface water quality have been extensively studied in the uplands of the UK (Jenkins et al., 1990). Large areas in Wales and Scotland have been planted with spruce (mostly Sitka spruce, *Picea sitchensis* Bong. (Carr.)) and negative impacts on surface water quality have been well documented (Harriman and Morrison, 1982; Hornung and Reynolds, 1995; Ormerod et al., 1989; Alexander and Cresser, 1995; Helliwell et al., 2001; Cosby et al., 1990). Afforestation has not, however, been studied in Norway, although large areas in western Norway have been planted in spruce (mostly Norway spruce, *Picea abies* L.) during the past 50 years.

Effects on surface water from seasalt episodes, on the other hand, have been well documented in Norway. Particularly, clear impacts were seen after a major storm in January 1993, when fish kills due to high mobilization of aluminum (Al^{n+}) were reported in several rivers in the southwest (Hindar et al., 1994). In connection with this storm, there were differences in runoff chemistry that were ascribed to the vegetation in sub-catchments of a river basin in south-western Norway (Hindar et al., 1995). Episodic acidification of water was more pronounced at an afforested spruce catchment, as compared to nearby catchments with natural forests of mainly pine and birch and a non-forested catchment (Hindar et al., 1995). Episodic acidification from seasalts has also been demonstrated in a large-scale experiment at Sogndal, western Norway (Wright et al., 1988).

The fundamental processes involved in acidification by afforestation and episodic inputs of seasalts are relatively well understood, but their relative importance and their interaction are less known. In addition, it is uncertain to what extent the impacts of seasalt episodes may interact with other factors. Hindar et al. (1994) suggested that seasalt episodes may have more severe impacts in chronically acidified areas than in pristine areas. Seasalt episodes and afforestation are two important factors contributing to the adverse effects of chronic acid deposition.

In order to investigate the combined effect of afforestation and seasalt episodes on streamwater acidification, we used a paired catchment approach over an acid deposition gradient in western Norway. Four sets of catchments along the gradient in acid deposition were selected. At each site one catchment was planted in spruce while an adjacent catchment had native stands of pine and birch. Streamwater was sampled frequently before, during and after seasalt deposition events. Here we report results from a major seasalt episode of January 2003.

2. Materials and methods

2.1. Spruce afforestation in western Norway

Spruce covers about 1600 km^2, 17% of the total productive forest area in western Norway (NIJOS, 1997). All the spruce forest has been planted, as spruce is not native to the west coast of Norway, having not migrated that far west following deglaciation around 10 000 years ago. Pine (*Pinus sylvestris* L.) and deciduous (mainly birch, *Betula pubescens* L. and, to a lesser extent, alder *Alnus* spp.) forest are the typical natural trees in western Norway. Naturally occurring spruce is found only at a few places (e.g. Voss and Modalen). Near the end of the 19th century, spruce planting was initiated and as these forests grew faster than the naturally occurring species, more intense planting followed. Afforestation increased after 1950 through the 1970s. Most of the afforestation took place on former deciduous and pine forestland, but also a considerable amount of pasture and moorland was afforested (Table 1). Only a small fraction of the afforested areas were mature and ready for felling as of 2004.

Afforestation in western Norway is rather patchy, but covers a substantial part of the total forested area. In the four counties of western Norway, 16–49% of the forested area is spruce (Table 2). Due to the mountainous terrain, the total forested area is relatively low (15–28% for the different counties; Table 2).

2.2. Study sites

Four sites were selected in a north–south gradient along the western coast of Norway (Fig. 1). The sites are located in typical areas for afforestation in western Norway, where spruce replaces existing birch on hillslopes. The typical landscape has small-scale agricultural activities in the valley bottom, forest on the hillslope and mountainous terrain above. The sites are located approximately the same distance from the coast (50–70 km),

Table 1
Former land use in afforested areas in western Norway

Previous land use	Area	
	km^2	%
Deciduous	535	34
Pine	349	22
Spruce	31	2
Pasture	108	7
Moorland	234	15
Unknown	322	20
Sum	1578	100

Western Norway refers to the counties Møre og Romsdal, Sogn og Fjordane, Hordaland, and Rogaland.