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Post-restoration development of organic carbon and nutrient leaching from two ecohydrologically different peatland sites

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ABSTRACT

Restoration of drained peatland forests is an important tool in maintaining and improving biodiversity in the boreal region. It has been shown to cause leaching of nutrients from the restoration area to lower waterbodies. Two drained peatland systems of different ecohydrological types in the Nuuksio (60°18′N, 24°27′E) and Seitseminen (61°56′N, 23°26′E) national parks were restored and total organic carbon, nitrogen and phosphorus leaching was monitored for 6 years after restoration. The richer site proved to leach more nitrogen and less total organic carbon and phosphorus than the poor site although the per-treatment-area excess leaching of organic carbon caused by restoration was higher in the richer site. The pattern of excess leaching was more stable in the poor site. The differences in leaching reflect the ecohydrological differences between these two peatland basins.

1. Introduction

Finland is a mire-rich country, with around a third of the 30-million-hectare land area covered by mires and peatlands. More than half of this area has been drained, mostly for forestry. The earliest drainage programs were started at the beginning of the 20th century, and the peak years of drainage for forestry were in the late 1960s, when around 300,000 ha were drained per year. From this peak the yearly drained area slowly decreased until the late 1990s, when first-time drainage almost stopped (Turunen, 2008). Ditch-cleaning and complementary drainage were started in the 1970s and they continue to this day, with an area of 60–70,000 ha being treated yearly (Juntunen and Herrala-Ylinen, 2008).

Internationally, around 15-million hectares of peatlands have been drained for forestry purposes in the boreal and temperate regions. An area similar to that drained in Finland has been drained in Russia, mostly in the northwestern parts of the country (Minaeva and Sirin, 2005). Large areas of peatlands have also been drained for forestry in Sweden (Hånell, 1990) and in the Baltic countries, where the percentage of drained peatland is similar to Finland (Paavilainen and Päivänen, 1995). Restoration of peatlands could be important in these countries for maintaining and improving the integrity of drainage basins and particular ecosystems.

Due to the heavy, partly state-subsidised drainage programs (Päivänen, 2008), all mire types present in Finland have decreased in area, and most have become endangered (Raunio et al., 2008). Particularly in southern Finland, undrained mires have become scarce, with less than 20% of the original mire area still remaining undrained, and all site types but one are listed as endangered. Even many peatlands included into different nature conservation areas have been drained before protection. Therefore, restoration of peatlands drained for forestry is an important tool for protecting and restoring biodiversity. Peatlands have been restored at a pace of a few hundred to 2000 hectares per year. Up until the end of 2007, 15,000 ha of peatlands had been restored in protected areas (Aapala et al., 2008).

Peatland restoration can, however, have adverse effects on the quality of runoff water. Elevated concentrations of phosphorus have been reported after restoration (Sallantaus, 2004), as well as elevated concentrations of phosphorus and DOC in rewetted peatlands used as buffer zones for forestry drainage sites (Nieminen et al., 2005). This can affect the state of headwaters near the restoration areas. The fact that these waters have already been affected by peatland drainage in the 20th century stresses the importance of avoiding further loading.

In this study, the differences in nutrient and carbon leaching patterns in restored herb-rich, fertile spruce mires on one hand and pine-growing poor fens and bogs on the other hand are explored. The nutrient concentration data have also been used in (Sallantaus

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Table 1
Peatland percentages of the study basins.

Site	Basin area (ha)	Peatland percentage
Mustakorpi	48.5	29
Seitseminen	60.0	36–44

and Koskinen, 2010). This work focuses on the development of the nutrient load.

2. Materials and methods

2.1. Study sites

The study sites consisted of two different drained and restored peatland systems, Mustakorpi and Seitseminen, and one drained control area for method evaluation in southern Finland.

Mustakorpi is a mostly nutrient-rich minerotrophic spruce mire with a small ombrotrophic bog part in the Nuuksio national park (60°18′N, 24°27′E) in southern Finland (Mäntynen, 2001). The upland basin consists mostly of circa 100-year-old fresh heath site type forests according to the Finnish forest site type classification (Tonteri et al., 1990), with smaller areas of younger forests. The main tree species is Norway spruce.

Seitseminen is a mostly ombrotrophic, poor fen-pine bog system in the Seitseminen national park (61°56′N, 23°26′E) in central Finland (Heikkilä and Lindholm, 1994). The peatland percentages of the basins vary (Table 1). The upland basins consist mostly of young, 30- to 50-year-old Scots pine forests on dry heath site types (Tonteri et al., 1990), although also 50–70 and older than 90-year-old forests are present.

Mustakorpi mire system was drained in two phases, partially already in the 1930s and completed in the 1950s. The site responded greatly to the drainage, pre-restoration tree stand volumes, mostly *Picea abies*, exceeding 300 m^3 ha^{-1} on large parts of the area (Mäntynen, 2001). The long-term mean annual precipitation at a nearby weather station is 619 mm and average temperature 3.9 °C (The Finnish Meteorological Institute, 1991). The Seitseminen mires were drained in the 1960s and fertilized, and the site had had a low to moderate response to the drainage. The volume of the tree stand, mostly *Pinus sylvestris*, was about 50 m^3 ha^{-1} before restoration. The long-term mean annual precipitation is 666 mm and average temperature 2.9 °C (The Finnish Meteorological Institute, 1991). The climatological differences show up as lower summer runoff and earlier and more irregular snowmelt in the Mustakorpi basin (Sallantaus, 2006).

In Mustakorpi, the filling and damming of ditches took place in the late autumn of 2001, making 2002 the first and 2008 the seventh calendar year after restoration for Mustakorpi. The tree stand was left untouched. In Seitseminen, the peatlands were restored at different times. The first restoration treatments took place in late 1997 and the last in 1999. The tree stand was mostly harvested before filling in the ditches. Due to the gradual restoration, the first year after restoration was different for the three basins: the first year was 1998–2000 and the seventh year was 2004–2006. The calibration period for two of the Seitseminen areas was from spring to the end of November 1997 and for one area from spring 1997 to the end of November 1998.

The control area was located near the treatment areas in Seitseminen. Small-scale loggings were done on the neighbouring drainage basin in 2002, which could be seen as a small peak in nitrate leaching during the autumn of that year. In 2005 there was stormfall and logging, which rendered the area useless as a control. For Mustakorpi, a control area had not been selected at the start of restoration and a suitable nearby area could not be found afterwards.

2.2. Water sampling

The drainage basin of Mustakorpi was divided into three sub-basins, the eastern, northern and western basins. The eastern and northern basins drain through the western basin. Water samples were collected from ditches at the border of each basin. Also in Seitseminen the samples were collected from three points, but the basins were separate. Samples were collected 11 times per year on average in Mustakorpi and 10 times per year in Seitseminen. The most samples were collected during spring and autumn high flows. Fewer samples were collected during summer and winter months, when at times runoff ceased completely (Fig. 1). In Seitseminen there was a pre-restoration sampling period of less than 1–2 years, and in Mustakorpi of 6 months to determine the background water quality for calculations; that is, the water quality in the hypothetical case the areas had not been restored.

Water quality variables measured for this study were total phosphorus (P_{tot}), phosphate phosphorus (soluble reactive phosphorus) (PO_4-P), total nitrogen (N_{tot}), nitrate-nitrite nitrogen ($NO_{2\text{-}3}$-N), ammonia nitrogen (NH_4-N) and total organic carbon (TOC). The analyses were done at the laboratory of the Finnish Regional Environment center of Pirkanmaa. P_{tot} and N_{tot} were measured colorimetrically following oxidation with $K_2S_2O_8$. PO_4-P was measured by the molybdenium blue method after filtering with 0.45 μm membrane. $NO_{2\text{-}3}$-N was measured with the cadmium method and NH_4-N with a spectrophotometric method with hypochlorite and phenol. TOC was measured with high-temperature oxidation followed by IR gas measurements.

2.3. Calculations

Concentration values for days between the samplings were estimated with linear interpolation from the measurements. The runoff data used for calculation of leaching was simulated data for nearby similar drainage basins available from the Finnish Environment Institute.[1] The simulation is based on measured runoff data of larger drainage basins which is then divided into sub-basins with runoff models that apply temperature, rainfall, land use and geographical data (Vehviläinen et al., 2005). To get an estimate of leaching for the whole first year of measurements, concentration values were calculated for January 1st of that year as leaching before the end of May, calculated with interpolated concentration data, divided by the total runoff of the same period. The equation for calculating the yearly per-basin hectare total observed leaching was

$$L_{tot} = \sum_{t=1}^{n} c_{a_t} Q_t \tag{1}$$

where c_{a_t} is daily interpolated concentration, kg l^{-1}, and Q_t is simulated runoff, l ha^{-1} d^{-1} and n is the number of days in the year. The equation for calculating the two background concentration values was

$$c_{c_y} = \frac{\sum_{t=1}^{m} c_t Q_t}{\sum_{t=1}^{m} Q_t} \tag{2}$$

where y is spring or autumn, m is available days from December 1st to May 31st in the calibration period for spring values and from

[1] http://www.environment.fi/waterforecast.