Forest Ecology and Management 356 (2015) 234–242

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Increased concentrations of nitrate in forest soil water after windthrow in southern Sweden

Sofie Hellsten [a,*], Johanna Stadmark [a], Gunilla Pihl Karlsson [a], Per Erik Karlsson [a], Cecilia Akselsson [b]

[a] IVL Swedish Environmental Research Institute, Box 53021, SE-400 14 Gothenburg, Sweden
[b] Lund University, Department of Physical Geography and Ecosystem Science, Sölvegatan 12, SE-223 62 Lund, Sweden

ARTICLE INFO

Article history:
Received 19 April 2015
Received in revised form 2 July 2015
Accepted 10 July 2015
Available online 15 July 2015

Keywords:
Storm felling
Soil water
Nitrate
Nitrogen leakage
Eutrophication
SWETHRO

ABSTRACT

In January 2005, south-west Sweden was hit by a severe storm that caused large damage to the forests through massive windthrow. The aim of this study was to assess the effect of this windthrow on nitrate concentrations in the soil water below the root zone on 33 forest monitoring plots within the Swedish Throughfall Monitoring Network (SWETHRO). These sites were damaged to different extents by the storm. The analysis showed increased levels of nitrate concentrations in the soil water as a consequence of storm damaged forest. The present study concerned forest ecosystems with relatively low levels of nitrogen deposition, as compared with forests analysed in previous studies. The maximum soil water nitrate concentrations occurred 1–4 years after the storm. After 5–6 years, the concentrations were back at the same levels as before the storm event. It was not possible to demonstrate a significant correlation between increased nitrate concentrations in the soil water after the storm and the level of nitrogen deposition at the site. The potential impact on ground- and surface waters due to elevated nitrate concentrations in soil water after storm events is discussed.

1. Introduction

The frequency and intensity of natural disturbances, such as storm events, has increased in many forest ecosystems around the world (Schelhaas et al., 2003). During the last century damage due to storms in Swedish forests has increased (Nilsson et al., 2004). The main driving forces are expected to be a combination of climate change and changes in forest cover, tree species composition as well as changes in management regimes (Nilsson et al., 2004; Seidl et al., 2011; Usbeck et al., 2010). In Sweden, storm statistics have not shown clear indications of increased frequency and intensity of storms (Blennow et al., 2010). However, climate change may increase the probability of windthrow also due to a reduced resilience of forest ecosystems to wind damage. Finnish studies have shown that warmer winters in areas where ground frost occur increase the windthrow risk of trees at northern latitudes through reduced stability (Gregow et al., 2011; Peltola et al., 1999).

In January 2005, south-west Sweden was hit by a severe storm with wind speeds up to ~42 m s^{-1} (Swedish Forest Agency, 2006). The storm caused large damage through massive windthrow, corresponding to 110% of the average annual harvest rates (1998–2004) in Sweden derived from only 16% of the country's forest area (Seidl and Blennow, 2012). The drastic increase in deforested areas following the storm could be expected to result in increased levels of nitrate leaching, which may potentially contaminate groundwater and cause eutrophication of surface waters (Galloway et al., 2004; Gundersen et al., 2006; Kreutzweiser et al., 2008; Smith, 2003; Smith and Schindler, 2009). Furthermore, nitrate leaching also contributes to soil acidification, which causes potentially toxic metals to be released in soil and surface water (Reuss and Johnsson, 1986). Leaching of inorganic nitrogen (primarily nitrate) to the soil water increases as the nitrogen uptake to trees is disrupted. Disturbances in forest ecosystems, whether they are natural (e.g. storm events, insect attacks), or anthropogenic (forestry practices, such as clear-cut logging), can affect soil conditions and nutrient processes within the soil resulting in nutrient losses. Several studies carried out in boreal forests indicate that logging affects the retention of inorganic nitrogen in the forest soil, so that nitrate leaching in the runoff water increases (e.g. Emmet et al., 1991b; Futter et al., 2010; Gundersen et al., 2006; Kreutzweiser et al., 2008; Pardo et al., 1995; Rosén et al., 1996). The soil conditions of clear-cut areas are warmer and moister than in growing forests, due to decreased transpiration and increased sun exposure when the trees have been removed (Kreutzweiser et al., 2008). Moist, warm soil conditions are favourable for decomposition of organic material resulting in nitrate

* Corresponding author.
E-mail address: sofie.hellsten@ivl.se (S. Hellsten).

http://dx.doi.org/10.1016/j.foreco.2015.07.009
0378-1127/

formation after nitrification. Furthermore, most of the uptake of nitrogen by vegetation ceases in a clear-cut area, and the changed hydrological conditions (increased runoff and raised groundwater level) may further increase leaching of nitrate (Rosén et al., 1996; Sørensen et al., 2009). Increased nitrate leaching in runoff water occurs during a time period of three to six years in the south of Sweden, and up to 15 years in the north (Akselsson et al., 2004; Futter et al., 2010; Rosén et al., 1996; Wiklander et al., 1991).

The Swedish Throughfall Monitoring Network, SWETHRO, is an environmental monitoring network that measures air concentrations of pollutants, deposition and soil water chemistry at forest sites in Sweden (Pihl Karlsson et al., 2011). Many of these sites were damaged to different extents due to the storm in January 2005. In most cases there existed long time-series of measurements of soil water chemistry prior to the storm. Hence, this provided a unique opportunity to investigate the relations between the extent of damage to the forests and the change in the soil water chemistry during the following years. The plots within SWETHRO are not generally positioned within small well-defined catchments, so it was not possible to directly relate the impacts on soil water chemistry to changes in the chemistry of the surface water runoff.

The aim of this study was to investigate the effect of the different extents of windthrow on nitrate (NO_3–N) concentrations in soil water in forests. The study focused on the soil water concentrations of nitrate since this is the main inorganic nitrogen compound in soil water that is affected by logging, and the effect on ammonium is small (Gundersen et al., 2006; Lepistö et al., 1995). The effect of logging on organic nitrogen is also small (Lepistö et al., 1995) and was therefore not considered.

2. Materials and methods

2.1. Sites

The Swedish Throughfall Monitoring Network (SWETHRO) has been operated since 1985 (Pihl Karlsson et al., 2011). The monitoring network measures air concentrations of pollutants, deposition and soil water chemistry in forest ecosystems in Sweden. Monitoring plots (30×30 m) are positioned in closed, mature, managed forests with no major roads or other pollution sources in the vicinity. Currently SWETHRO includes measurements of soil water chemistry on 62 sites in Sweden, and the longest time series are 30 years (2015). Many of these sites, in southern Sweden, were damaged to different extents due to the storm Gudrun in 2005. Sites with short time series (<10 years) and sites with vague information about the extent of the storm damage were not included in the study and only coniferous sites were considered. In total 33 sites in the south of Sweden with Norway spruce and/or Scots pine forests were included in the study and their geographical positions are shown in Fig. 1. The 33 sites were divided into four different damage classes, depending on the extent of the storm damage (Table 1). As expected, the most damaged plots were all covered with Norway spruce.

About 45 SWETHRO sites are co-located with observation plots operated by the Swedish Forest Agency. For these plots, information is available for changes over time regarding vegetation cover, crown thinning, stem diameter growth, needle chemistry and soil chemistry.

2.2. Measurements

Soil water below the root zone was sampled three times a year, to represent the conditions before (Feb–May), during (Jun–Sep) and after the vegetation period (Sep–Dec). Soil water samples were obtained using suction lysimeters with ceramic cups (P 80), placed at 50 cm depth in the mineral soil. Based on a soil sampling campaign made in 2010–2011, the depth to the beginning of the undisturbed mineral soil (C-layer) was estimated to 40–60 cm for the plots included in this study. Hence, a 50 cm soil depth would be in the lower part of the B-layer or in the upper part of the C-layer. In general, five lysimeters were installed on each forest site, inside the canopy close to the throughfall collectors. However, some sites had fewer lysimeters due to difficulties with soil stoniness. Lysimeters were sampled by applying tension over a two day period. The water from the lysimeters was then combined into one composite sample for analysis. Only water samples containing >50 ml of water were included in the study, to eliminate uncertainties due to small sample volumes.

Throughfall (TF) and bulk (BD) deposition were measured monthly throughout the years. TF measurements were carried out at all sites during the entire period analysed, whilst BD measurements were carried out during different time periods at different sites. Further details about deposition measurements and chemical analysis can be found in Pihl Karlsson et al. (2011).

2.3. Estimates of nitrogen deposition

A considerable fraction of the atmospheric nitrogen deposition reaching the forests is taken up directly by the tree canopies (Adriaenssens et al., 2012; Eugster and Haeni, 2013; Ferm, 1993; Ferm and Hultberg, 1999). Hence, throughfall measurements cannot be used directly to estimate the total nitrogen deposition to forests. Therefore, bulk measurements, as well as throughfall measurements, were used in this study. Bulk deposition measurements mainly consist of wet deposition but there is also a small fraction of dry deposition to the samplers (Draaijers et al., 1996; Dämmgen et al., 2005).

Information on bulk deposition was not available for all years and sites analysed in this study. Bulk deposition of inorganic nitrogen varies geographically across Sweden in a consistent pattern (Fig. 2, Karlsson et al., 2011), based on the geographical position expressed as the sum of latitude and longitude.

Based on the relation in Fig. 2, the bulk deposition was estimated for the sites with moderate and large damage for the six-year period 1999–2004, prior to the occurrence of the storm (Table 3). The fraction of dry deposition contributing to the total nitrogen deposition declines towards northeast similarly to the decline of bulk deposition (Karlsson et al., 2011). Hence, it may be assumed that the relative difference regarding the estimated nitrogen deposition between the different sites in Table 3 is correct.

2.4. Weather data

Official interpolated weather data can be obtained for any location in Sweden from the Swedish Meteorological and Hydrological Institute (SMHI), regarding air temperatures and precipitation (http://luftwebb.smhi.se/). Data for annual mean air temperature and annual precipitation were obtained for all sites. Differences in annual mean air temperatures and annual precipitation were analysed for the two time periods before and after the storm, 2000–2004 and 2005–2009 (see below) for all sites classified with moderate or large damage.

2.5. Data analysis

A database was constructed with information about the level of damage caused by the storm at the different sites, Table 2. Data on storm damage is mainly based on notes from field protocols and contacts with field personnel collecting the samples.