



# Effects of forest harvest on soil nutrients and labile ions in Podzols of southwestern Canada: Mean and dispersion effects

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## ABSTRACT

Forest harvest can disrupt biogeochemical cycles with consequences for regenerating forest nutrition and drainage water quality. Few studies have examined harvest impacts on soil chemistry in conifer forests which have not been significantly affected by acid deposition, as found on the Canadian West Coast. This study investigates the effects of conventional clear-cutting on soil chemistry in Podzols of Roberts Creek Study Forest (southwestern Canada). We measured forest floor composition, soil pH and salt-extractable ions concentrations in undisturbed forested stands (control plots), stands harvested 2 to 5 years prior to sampling (cleared plots) and stands harvested 8 to 15 years prior to sampling (regenerating plots). We focused on the effects of forest harvest both on mean (differences in average values) and dispersion parameters (differences in variance between treatments). We found that forest floors of harvested plots had lower phosphorus and potassium concentrations than control plots. In the mineral subsoil, exchangeable K was however higher in harvested than in control plots. This suggests that some of the K lost from the forest floor was preferentially retained in mineral horizons, possibly due to sorption to poorly crystalline and free aluminum and iron mineral phases. The subsoil of harvested plots was slightly more acidic than control plots. In contrast to classic studies of forest harvest impacts conducted in the U.S. Northwest, we did not measure pronounced acidification, a loss of base cations or an increase in exchangeable Al, most likely due to the much lower prior acid deposition load at our sites. The most notable harvest effect was a large increase in the variability of inorganic N concentration. This suggests an increase in micro-heterogeneity of post-harvest nutrient availability which has implications for the nutrition of regenerating vegetation, nutrient leaching potential as well as our ability to detect harvest-induced changes.

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## 1. Introduction

Forest harvesting has the potential to significantly alter site biogeochemical cycles. Biocycling elements are directly affected by the removal of biomass, while elements predominantly under inorganic control are indirectly affected by chemical (e.g. pH) and physical (e.g. profile disturbance) changes in the soil. Changes in soil labile or exchangeable element pools are of particular concern because these pools are immediate sources of nutrients for plants and affect forest regeneration and productivity. Exchangeable ions also equilibrate rapidly with soil solution composition, so that changes in ions prevalence on exchange complexes act as indicators of changes in soil solution composition, which in turn influences drainage water composition (Sudduth et al., 2013).

### 1.1. The N cycle

Because of its role in northern forest nutrition and its potential impact on water quality, N is one of the most widely studied nutrient in forest ecosystems. In cut forests, increases in mineralization rates (Spielvogel et al., 2006), lack of plant uptake (Burns and Murdoch, 2005) and lack of canopy interception (Klopatek et al., 2006) can combine to increase N availability, with a peak often reported at 3 to 5 years following harvest (Bradley et al., 2001; Dahlgren and Driscoll, 1994). One of the factors that complicates understanding and predicting N response to forest harvest is that site-specific interactions between environmental conditions, biological variables and substrate quality greatly influence N dynamics (Grenon et al., 2004; Schimel and Bennett, 2004). The increase in N leaching from cut forests is variable, ranging from non-existent to more than 50 times the baseline leaching rate in experiments controlling vegetation regrowth (Likens et al., 1970). The largest N exports after logging were reported in northern hardwoods ecosystems, while coniferous forests are generally thought to be less susceptible to N losses (Binkley and Brown, 1993; Lamontagne et al., 2000; Martin et al., 1984).

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Vitousek et al. (1982) proposed that N availability prior to disturbance was one of the main factors determining N leaching losses after disturbance, with N-poor sites having better N retention after disturbance as a result of lower N mineralization rates and higher N immobilization capacity. Several N-poor sites also exhibited lags in nitrification, probably due to small initial nitrifier populations. Conifers in particular are known to produce allelopathic chemicals that inhibit nitrifiers (Paavolainen et al., 1998; White, 1994). This nitrification lag may prevent N export to stream altogether if vegetation re-establishment is rapid enough (Vitousek et al., 1982).

### 1.2. Acidification and base cations

Classic studies of forest harvest impacts conducted in the northern hardwood forest biome showed that in many watersheds, clear-cutting results in soil acidification, increase in soluble Al, and a short-lived increase in  $\text{NO}_3^-$  concentration in soil and drainage water (Dahlgren and Driscoll, 1994; Hendrickson et al., 1989; Johnson et al., 1991; Likens et al., 1970, 1978; McHale et al., 2007). Likens et al. (1970) proposed that the increases in  $\text{NO}_3^-$  and acidity were linked since increases in nitrification rates result in the production of  $\text{H}^+$  ions. More generally, decarboxylation of organic anions and ammonification of organic N tend to increase soil pH (Mengel, 1994; Xu et al., 2006) while nitrification of mineralized N (Conyers et al., 1995; Dahlgren and Driscoll, 1994), production of organic acids and oxidation of reduced S (Devries and Breeuwsma, 1987) all tend to decrease it. Actual soil acidification or alkalization following disturbance will depend on the relative importance of these processes.

In watersheds experiencing strong acidification after harvest, the base saturation of soil exchange complexes tends to be reduced as base cations are displaced by acid forming ones and eventually flushed out of the system (e.g. Lawrence et al., 1987; Neal et al., 1992). On the other hand, when acidification is mild, base cation prevalence on exchange complexes either remains constant or increases as decomposing organic matter releases significant amounts of Ca and K (Hendrickson et al., 1989; Johnson et al., 1997; Snyder and Harter, 1985).

Of the base cations, K shows the most frequent change after logging (see for instance Johnson et al., 1991; Likens et al., 1970; Mann et al., 1988; Mroz et al., 1985). This is not surprising since the control on K concentration is mainly organic while Ca, Mg and Na are thought to be predominantly influenced by mineral weathering (Vitousek, 1977). Although forest harvesting is thought to increase weathering rates (Johnson, 1989; Likens et al., 1970), the resulting release pulse is generally not as dramatic as changes in the concentration of elements under strong biotic control.

### 1.3. Objectives

The objectives of this study are to determine the effects of forest harvest on soil acidity, nutrients and labile ions in an economically important, managed coastal forest of southwestern Canada. We complement prior chronosequence studies focused on long-term (>200 years) soil ecological dynamics conducted in the region (e.g. Fons and Klinka, 1998; Preston et al., 2002) by exploring nutrient dynamics for the first 15 years post-logging, which is the timeframe in which acute negative environmental effects are most likely to occur. We focus on the detection of treatment (harvest) mean effects as well as dispersion effects (difference in variance between treatments), which are not commonly emphasized in the literature but can have important ecological impacts on regenerating vegetation and nutrient leaching potential. We relate our findings to stream chemistry studies previously conducted in our study forest.

We hypothesize that changes in nutrients and labile ions concentrations in harvested plot will be relatively small, because (1) soils are not nutrient-rich and (2) harvested plots showed a good retention of their soil organic matter stock (Grand and Lavkulich, 2012). In particular,

we expect the increase in inorganic N concentration on cut sites to be limited due to the low initial soil N availability. We however expect that the loss of biotic regulation (Bormann and Likens, 1979) induced by forest harvest will have an impact on the variability of soil chemical attributes. Finally, we hypothesize that Roberts Creek's low pH soils may be at risk of acidification and decreasing base saturation following logging, which could negatively impact soil quality.

## 2. Methods

### 2.1. Field sites

This study was conducted at the Roberts Creek study forest (49° 27' N, 123° 41' W) on the Sunshine Coast of southwestern British Columbia (BC). The study forest lies within the Coastal Western Hemlock, Drier Maritime variant (CWHdm) biogeoclimatic zone (Pojar et al., 1991) and experiences a mean annual temperature of 10.2 °C and mean annual precipitation of 1369 mm (Environment Canada, 2013). Elevation ranges from 350 to 590 m above sea level and the forest is situated on a gentle (~15%) southerly slope (Hudson, 2001).

The current forest originated following wildfires approximately 140 years (D'Anjou, 2002). The dominant canopy species consisted of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) interspersed with smaller diameter western redcedar (*Thuja plicata* (Donn. Ex E. Don) Spach) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). The cedar and hemlock components gained dominance later in succession. The shrub and herb layers mostly comprised salal (*Gaultheria shallon* Pursh) and brackenfern (*Pteridium aquilinum* (L.) Kuhn) characteristic of the Salal site series of coastal BC (Green and Klinka, 1994). Vegetation in harvested stands was dominated by the herb layer (particularly fireweed, *Epilobium angustifolium* L.) for the first 3 to 5 years post logging, then by Douglas-fir saplings.

Soils of Roberts Creek were Albic Gleyic podzol (IUSS Working Group WRB, 2006) of sandy loam to loamy sand texture that developed following glacial retreat from a basal till deposited on granodioritic bedrock. The sola ranged from 40 to over 120 cm in thickness. The following sequence of horizon was observed: Oi, Oe + Oa, E, Bs1, Bs2, BCg and Cr. Description of a typical soil profile and average horizon properties are reported in Grand and Lavkulich (2011).

### 2.2. Experimental design

We sampled a disturbance chronosequence of forest plots that had been clear-cut 2 to 15 years prior to sampling to determine short to medium-term differences in nutrient and labile ions concentrations. Nine soil pits were located on undisturbed forested plots (control), 11 were located on cleared stands (logged 2–5 years before sampling) and 7 in regenerating stands (logged 8–15 years before sampling). The harvest method was a clearcut with bole-only removal by cable yarding and slash left untreated on site. Variable retention occurred in some of the harvested plots; in this case, we sampled clear-cut portions of the plot, maintaining a minimum distance of at least 12 m to the nearest retained tree. Samples from harvested stands spanned seven harvest clusters distributed throughout the experimental forest. Control locations were interspersed in the undisturbed forest between and around logged plots and at a distance of at least 30 m from the edge of the disturbance. The distribution of sampling sites is recorded in Grand and Lavkulich (2012). Sampling was carried out during the dry season (August 2005).

When sampling harvested plots, our objective was to gain insight about the *in-situ* effects of vegetation removal over time, rather than the extent of mechanical disturbance caused by logging equipment. We sampled morphologically undisturbed soil profiles with no signs of mechanical disruption or water erosion. We avoided old logging roads, equipment tracks and preferential flow channels. The use of a cable yarding system for timber extraction limited soil disturbance;

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