Forest Sciences

Northern Interior Forest Region

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Soil Biogeochemical Dynamics in Hypermaritime Ecosystems of North Coastal British Columbia

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Introduction

Soil biogeochemistry and changes to its dynamics can have important effects on forest management and other resource values. For example, plant productivity is affected by nutrient availability, which in turn can be affected by the water table height and oxygen availability (aeration) in the soil. Both water table height and aeration can be changed by forest harvesting practices.

Carbon cycling is another biogeochemical process that could be affected by harvesting. Carbon cycling in the highly organic soils of the north coast involves the movement of large amounts of dissolved organic carbon (DOC) within the soil profile. DOC increases water acidity and darkens the colour of the water. The latter effect can be seen in the naturally "tea-coloured" water in most streams and lakes of the area. The dark-coloured water lowers light penetration and the higher acidity can influence nutrient availability and increase the ability of the water to transport metals.

The transport of ions through the soil by illuviation and leaching is also an important biogeochemical process. The rate and amount of ion movement, and deposition patterns of ions such as iron (Fe) and aluminum (Al), could change through altered hydrology and biogeochemistry.

Soil biogeochemistry dynamics of north coast forests were investigated as part of the HyP^3 Project. This is an integrated forest research project aimed at developing ecologically-based guidelines for the management of lower-productivity cedar-dominated forests in north coastal British Columbia (for more details see Banner and Shaw 1999).

The objectives of this study were to:

1) Document the biogeochemistry of the blanket bog – upland forest complex.

2) Predict how disturbances from forest harvesting change biogeochemical dynamics.

3) Assess the potential impacts of these changes on forest succession.

Study Area and Approach

Two locations were used as study areas, one in Diana Lake Provincial Park, 15 km southeast of Prince Rupert, and the second on Smith Island, 20 km south of

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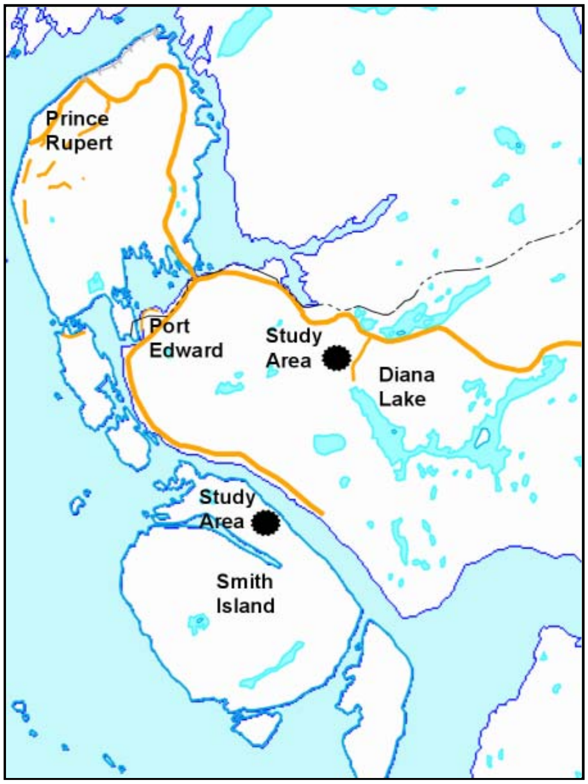

Figure 1. Location of study sites.

Prince Rupert (Figure 1). The areas were selected as being representative of the bog/forest complex under study. Both areas are located in the Coastal Western Hemlock biogeoclimatic zone, Very Wet Hypermaritime subzone – Central variant (CWHvh2) (Banner et al. 1993). The study area contained a mix of forest types typical of the CWHvh2, including scrub forest (site series 01), bog forest (11), bog woodland (12), open bog (32), upland forest (04), and swamp forest (13). Forests were comprised primarily of western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), yellow-cedar (*Chamaecyparis nootkatensis*), and amabilis fir (*Abies amabilis*). Shore pine (*Pinus contorta* var. *contorta*), Sitka spruce (*Picea sitchensis*), and mountain hemlock (*Tsuga mertensiana*) also occur in lesser amounts.

The climate of the study area is oceanic in character with mild temperatures, high rainfall, and low potential evapotranspiration. The winters are extremely wet and relatively mild, except when colder continental Arctic air masses cover the area. The Pacific Ocean moderates temperatures and the Coast Mountains tend to protect the outer coast from cold winter and hot summer continental air masses. Most of the precipitation occurs as rain, with little snowfall, and many days with fog. With over 220 days/year with rainfall and dry sunny spells being rare, there is a very high moisture surplus during the growing season (Banner and Pojar 1987). More climatic data can be found in Maloney et al. (2002).

The biogeochemistry of the study areas was investigated using piezometers and wells installed in a variety of vegetation types and at different soil depths. These were used to record water table depth and hydraulic gradient, and collect water samples for chemical analysis. These data were combined with stream discharge measured at gauging stations, meteorological data collected in open bogs at both sites, and topographic surveying done across the two study sites (Lortie 2002; Emili 2003).

Results and Discussion

Groundwater Biogeochemistry

Water tables were much deeper in the upland forest than in the other vegetation types, with the open peatland having the shallowest water table (Table 1). The mean groundwater pH for all forest types combined was lower in the organic horizons than the mineral horizons (Table 1). The differences in pH between horizons is likely due to the acidifying abilities of sphagnum mosses in the organic layer and the mineral soil being a source of alkalinity. In the mineral horizon, pH was highest in the upland forest and lowest in the bog forest, though the differences were not statistically significant.

Vegetation type and soil type were important factors in the ionic make-up of groundwater, while slope, water table depth, and groundwater flow were not significant factors for any of the ions measured. The productive forest (04) had significantly higher concentrations of bicarbonate, sulphate, Calcium (Ca), Magnesium (Mg), and Sodium (Na) than the lower productivity 01, 11, 12, and 32 vegetation types. Potassium (K) was higher in the forested communities (01, 04, and 11) than the peatland communities (12 and 32) (Table 2). Groundwater from mineral soils tended to have higher concentrations of nutrients than that from organic soils (Table 3), though the differences were not statistically significant. This indicates that groundwater contact with mineral soils accounts for the higher concentration of nutrients in the forested vegetation types

Table 1. Water table depth by vegetation type, and pH and Dissolved Organic Carbon (DOC) of groundwater from mineral and organic soil horizons by vegetation type (Emili 2003)

Vegetation type	Mean water table depth - cm (std. dev.)	pH		DOC (mg/L)	
		Organic horizon	Mineral horizon	Organic horizon	Mineral horizon
Upland forest	93.0 (7.1)	n/a	6.03	n/a	8.2
Scrub forest	22.2 (7.6)	5.04	5.52	17.6	11.1
Bog forest	14.3 (6.5)	n/a	5.19	12.6[A]	7.5[A]
Bog woodland	15.3 (5.0)	4.89	5.44		
Open peatland	7.9 (6.9)	4.85	5.62	16.6	10.2
Swamp forest	3.2 (5.4)	n/a	n/a	n/a	n/a

n/a – not available
A – DOC data combined for these two vegetation types

Table 2: Mean ionic composition of groundwater (mg L^{-1}) by forest vegetation type at Diana Lake (1997-98), means within a column followed by a different letter are significantly different ($p<0.05$, n=153)

Vegetation type	HCO_3^-	Cl^-	NO_3^-	NO_2^-	PO_4^-	SO_4^-	Ca^+	Mg^+	Na^+	K^+	Fe^+	Mn^+	Al^+	Zn^+
Upland Forest	35.0*a*	3.2	0.12	0.03	0.03	3.6*a*	10.2*a*	1.2*a*	3.2*a*	1.1*b*	0.0	0.03	0.1	0.0
Scrub Forest	10.5*b*	2.1	0.05	0.01	0.02	2.9*b*	1.5*b*	0.3*b*	2.6*b*	1.0*b*	0.6	0.03	0.4	0.2
Bog Forest	9.0*b*	2.5	0.04	0.01	0.01	<1.04	1.5*b*	0.9*b*	2.3*b*	1.2*b*	0.8	0.05	0.3	0.2
Bog Woodland	13.7*b*	1.6	<0.02	0.01	0.01	<1.04	2.7*b*	0.3*b*	1.9*b*	0.5*a*	0.9	0.01	0.1	0.3
Open Peatland	27.8*b*	1.5	<0.02	0.01	0.02	1.9*	3.8*b*	0.5*b*	2.3*b*	0.6*a*	1.1	0.02	0.1	0.5

*one sample above detection limit
<indicates concentration below specified detection limit

Table 3. Mean ion composition of groundwater (mg L^{-1}) in the organic and mineral subsoil horizons at Diana Lake (1997-98) n=153

Soil Type	HCO_3^-	Cl^-	NO_3^-	NO_2^-	PO_4^-	SO_4^-	Ca^+	Mg^+	Na^+	K^+	Fe^+	Mn^+	Al^+	Zn^+
Organic horizon	13.4	2.2	0.04*	0.02	0.02	1.9*	2.0	0.3	3.5	1.1	0.7	0.02	0.2	0.2
Mineral subsoil	16.0	2.1	0.07	0.02	0.02	3.3	2.6	0.4	3.8	0.8	0.6	0.03	0.3	0.3

*one sample above detection limit

Table 4. Mean seasonal ionic composition of groundwater (mg L^{-1}) at Diana Lake 1997-98, means within a column followed by a different letter are significantly different ($p<0.05$, least squares test) N=153

Season	HCO_3^-	Cl^-	NO_3^-	NO_2^-	PO_4^-	SO_4^-	Ca^+	Mg^+	Na^+	K^+	Fe^+	Mn^+	Al^+	Zn^+
Summer	20.7*b*	2.5 *b*	0.12	0.01	0.02	2.3	2.9	0.6	3.6	0.9	1.6 *b*	0.03	0.5 *b*	0.9 *a*
Fall	---	1.5*ab*	<0.02	0.01	0.02	3.4	3.3	0.4	1.3	0.7	0.5 *a*	0.03	0.2*ab*	0.1 *b*
Winter	12.1*a*	3.2 *a*	0.4	0.01	0.01	<1.04	1.3	0.2	2.9	0.9	0.4 *a*	0.03	0.1 *a*	0.2*ab*
Spring	6.2*b*	1.4*ab*	0.5	0.01	0.01	3.7	1.3	0.3	2.7	1.3	0.2*ab*	0.02	0.2*ab*	0.1 *b*

<indicates concentration below specified detection limit

where organic soils are shallower. Many ions also tended to have higher concentrations in the summer than in other seasons (Table 4). At Diana Lake, nitrate, sulphate, and phosphate concentrations were very low in the vegetation types where the water table was high, and reducing conditions were present (Emili 2003).

Ion transport

The transport of ions through the soil by illuviation and leaching is an important biogeochemical process. The rate and amount of ion movement and deposition patterns could change through altered hydrological regimes. Although little detail is known about the process of hardpan formation at this time, cemented horizons in podzolic soils have often been associated with poor drainage. It is thought that over long periods of time these horizons may be formed by the precipitation of metal ions (Fe and Al), in mineral soils in the zone of water table fluctuation (Klinger 1996).

At Diana Lake, elevated concentrations of Fe and Al have been found in the zone of water table fluctuation (Figure 2). The accumulation of these metals in the mineral horizon may promote the formation of cemented soil

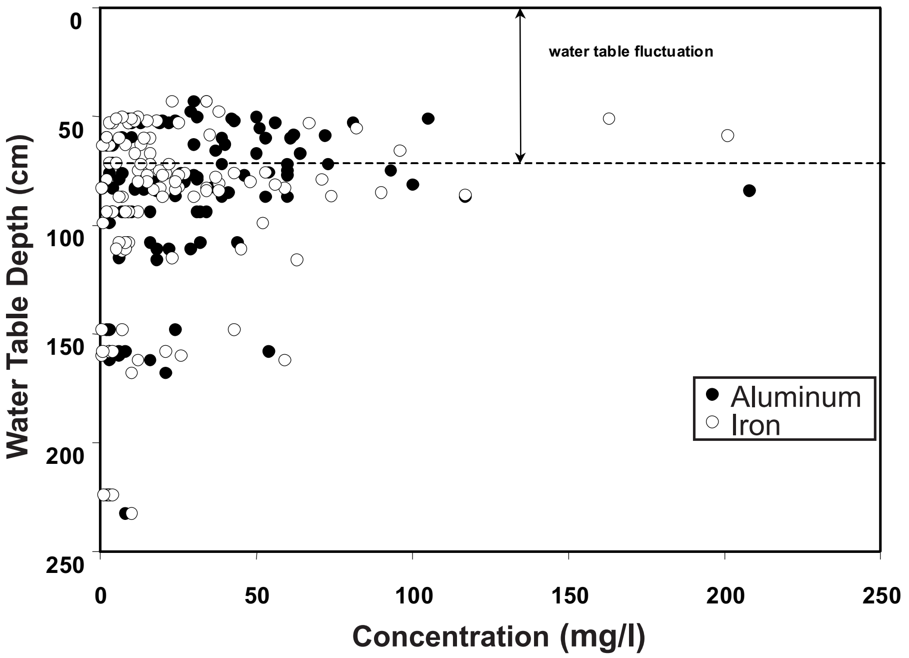

Figure 2. Distribution of aluminum and iron in groundwater relative to depth and water table.

horizons, or hard pans, eventually impeding drainage and raising the water table. Because these soil processes occur very slowly, their effect on long-term forest dynamics is not fully understood.

Dissolved organic carbon

DOC concentrations differed with vegetation type (Table 1), season, and soil type. DOC was higher in the swamp forest and open peatland than in the bog forest, bog woodland and upland forest, each having progressively lower values (Emili 2003). This pattern was likely due in part to the relative thickness of the organic horizon in the various vegetation types. DOC was highest in summer, likely due to increased microbial activity when temperatures are warmer and less flushing due to smaller amounts of rainfall. DOC was also highest in the shallow groundwater with much lower values in the deep groundwater (Figure 3) (Gibson et al. 2000). This pattern results from significant amounts of DOC being produced in the organic-rich surficial deposits, and less DOC being produced in the underlying mineral soils (Schiff et al. 1990). In addition, water that moves to deeper mineral layers loses some of its DOC by consumption and absorption as it moves down through the soil profile. The positive relationship between DOC and discharge indicates that a flushing of DOC occurs from the groundwater system to the stream during rainfall events.

Operational Implications

The scrub forests of the north coast are thought to be transitional between productive forest and

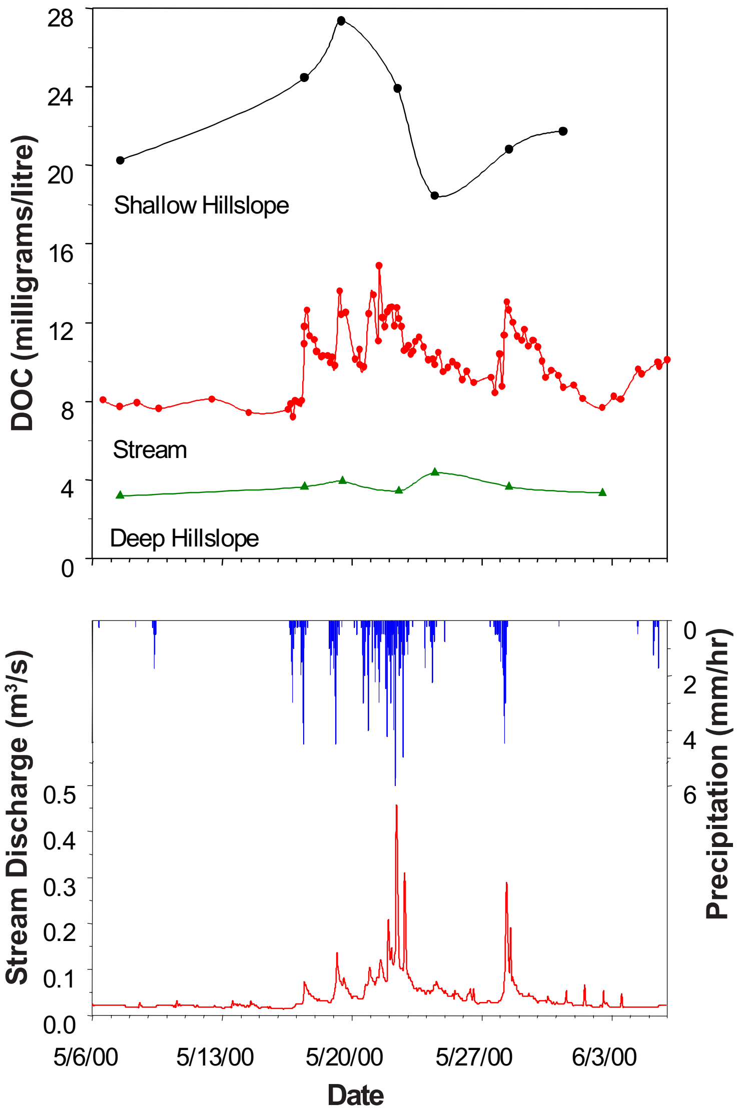

Figure 3. top – DOC response to rainfall events, bottom – Rainfall and stream discharge response during the rainfall event.

wetland forests. Dubé et al. (1995) have shown that in Quebec, the forest types that are transitional between upland forest and peatland are the most susceptible to water table rises following harvesting. High water tables and the high levels of acidity in peatland systems limit the nutrient cycling and plant productivity of these ecosystems. Nutrient availability can also be limited by phenolic acids, which inhibit mineralization of nitrogen (N) and P (deMontigny and Weetman 1990), and by high concentrations of lignins in cedar foliar litter (Prescott et al. 1995).

A high water table limits nutrient availability, and thus site fertility because it maintains anaerobic soil conditions. A high water table, therefore, controls reduction / oxidation conditions and the cycling of some important nutrient ions. Under aerobic conditions, N, sulphur (S), and P are released from decomposing soil organic matter, and are oxidized to the ions NO_3, SO_4, and PO_4, respectively (Devito and Dillon, 1993). When the water table is high, during wet periods and on poorly drained slopes, anaerobic conditions predominate and the nutrients are not oxidized to available forms. Therefore, a sustained rise in the water table due to forest harvesting will further lower the availability of these nutrients, possibly lowering tree productivity. In this study, well-drained vegetation types, with deeper water tables and thicker aerobic zones, had the highest ion concentrations in soil water. The monitoring of nutrient availability during pre- and post-harvest periods should be carried out on an operational trial basis to determine what, if any, changes occur.

In this study, DOC data were only collected in a pre-harvest setting and there is relatively little post-harvest data from similar settings, so the conclusions must be considered in that light. Following harvesting, greater water inputs to the site (Maloney et al. 2002) could increase the amount of DOC transported by water. Also, the concentration of DOC is likely to rise due to the decomposition of logging slash and debris and increased microbial activity due to warmer soils (Moore 1989). Dissolved organic carbon levels in stream waters may remain elevated for up to 8 to 10 years post-harvest, though the results from other studies in similar settings are varied (Moore 1989, Moore and Jackson 1989). If DOC increases a large amount after harvesting, it could effect water quality in several ways including: increasing water acidity, darkening the water and lowering light penetration, and increasing the ability of the water to transport metals. These changes could lower drinking water quality and have an undesirable effect on aquatic vegetation and fish populations. The inclusion of a detailed soil and water monitoring program in future operational trials in the lower productivity western redcedar – hemlock forests would help to address these areas of concern.

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