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INFLUENCE OF WATERSHED COMPOSITION ON STREAM OUTLET CHEMISTRY IN A NORTHERN TEMPERATE FORESTED LANDSCAPE IN CENTRAL ONTARIO

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Introduction

It has been known for some time that timber harvesting within eastern North America's northern temperate forest (NTF) results in significant losses of terrestrial nutrients which may, in some cases, permanently decrease forest site productivity (Bormann and Likens 1979, Kimmins 1987). If the environmental impacts of forestry operations are to be understood and successfully mitigated it would be most advantageous to (1) develop a basic understanding of the ecology of northern temperate watersheds under pristine conditions and (2) use some pristine watersheds as scientific reference sites against which to quantify the impact of logging. Studies of pristine or semi-pristine landscapes that have focused on relationships between watershed composition and stream nutrient concentration have included only a few stream chemistry parameters, have examined only one or a few watersheds, or have not included samples with the full range of northern temperate ecosystem types (e.g. lakes, wetlands, forests and streams) (Likens et al. 1967, Vitousek 1977, Martin 1979, LaZert and Dillon 1984, Cronan et al. 1987, Jeffries et al. 1988, Dillon et al. 1991).

The purpose of this study is to (1) describe baseline watershed conditions including numerous stream chemistry parameters and (2) identify the biophysical watershed variables (e.g. tree species cover, wetland area, etc.) that have a significant influence on the chemical composition of the streamwaters draining pristine watersheds that are typical of the central Ontario forested landscape. The study area, approximately 50,000 ha in size, is located within the Lower Spanish Forest area of central Ontario, about 50 km north of Webbwood.

Methods

A total of 25 pristine, ancient forested watersheds ranging in size from 20 to 700 ha were studied. For each watershed, two water samples for Al (total and exchangeable), Ca, DOC, K, Mg, NH_4, NO_3, N, pH, P, and SO_4 were taken 50 m apart at each of the watershed outlets. Shortly after collection, the water samples were taken to the Ontario Ministry of Environment and Energy's Dorset Research Station for analysis. Chemical concentrations obtained from the two water samples were averaged for each stream. For data analysis and interpretation, chemical values were considered the dependent variables and biophysical watershed variables were considered the independent variables. The biophysical composition of the watershed was determined from Forest Resource Inventory maps and topographic maps (1:20,000), and included the following variables: area occupied by *Abies balsamea, Acer rubrum, Acer saccharum, Betula lutea, Betula papyrifera, Fraxinus nigra, Larix laricina, Picea glauca, Picea mariana, Pinus banksiana, Pinus resinosa, Pinus strobus, Populus spp., and Thuja occidentalis*, mean age of forest stands, age of the oldest forest stand, age of the youngest forest stand, area occupied by conifer species, deciduous species, terrestrial vegetation, wetlands adjacent to streams, upland wetlands, total wetlands, lakes, exposed rock, elevation change, length of all streams above the watershed outlet and distance from watershed outlet upstream to the nearest lake or wetland. Data were analyzed using principal components analysis (PCA), Pearson product-moment correlations and the rank sum test (Mann-Whitney U statistic) (Analytical Software 1994).

Results

First, PCA was used to identify an indicator of the primary water chemistry gradient. The highest PCA loadings on the first principal component (43% variance explained) were Ca and pH, -.3978 and -.3870 respectively. Because it is considered to be a master variable of water chemistry, pH was chosen over Ca as the indicator for the primary water chemistry gradient. Next, Pearson product-moment correlations were used to examine relationships between the biophysical watershed variables and the primary water chemistry gradient indicator - pH (Table 1).

TABLE 1. Biophysical Watershed Variables that are Significantly Correlated with pH, the Primary Water Chemistry Gradient Indicator

Biophysical Variable	Correlation with pH	Level of Significance
ELEVCH	.6332	$p<.01$
POPLAR	.5854	$p<.01$
DECIDU	.5501	$p<.01$
SPRCBL	.5294	$p<.01$
CONIFE	.5257	$p<.01$
WATRPR	-.4844	$p<.05$

Six biophysical watershed variables are significantly correlated with stream water pH including elevation change (ELEVCH), poplar (*Populus* spp.) (POPLAR), deciduous spp. (DECIDU), black spruce (*Picea mariana*) (SPRCBL), conifer spp. (CONIFE) and the distance to the nearest upstream water body from a sampling point (WATRPR). Of these six biophysical watershed variables, the two variables that most logically stratify the 25 watersheds into two groups for descriptive purposes at the landscape level are the coniferous and deciduous variables. They represent the most basic division of the most common type of biophysical watershed variable - the trees.

The PCA and correlation analyses provided the basis for the third step - generating the testable hypothesis that coniferous- and deciduous-dominated watersheds differ with respect to outlet stream chemistry. When this hypothesis was tested, it was found that the mean concentrations of five stream chemistry (dependent) variables differ significantly including Ca, Mg, Na, pH and SO_4 (Table 2). In addition, a comparison of the means of the biophysical watershed (independent) variables between coniferous- and decidous-dominated watersheds showed that eight variables differ significantly including poplar, white birch (*Betula papyrifera*), white pine (*Pinus strobus*), deciduous spp., coniferous spp., total area occupied by vegetation, mean age of the forest and elevation change (Table 3).

Based on these findings, the coniferous-dominated watersheds have a much greater abundance of white pine, an older-aged forest and more acidic stream water conditions. The deciduous-dominated watersheds have a greater abundance of white birch and poplar, a greater watershed slope (elevation change), a greater amount of total vegetation cover and higher concentrations of those nutrients showing differences being exported in the stream water.

TABLE 2. Outlet Stream Chemistry Variables that Show Significant Differences Between Coniferous- and Deciduous-Dominated Watersheds

Variable	Coniferous Watershed Mean (n=15)	Deciduous Watershed Mean (n=10)	% Difference
Ca (calcium - mg/l)	2.51	3.42	36.0
Mg (magnesium - mg/l)	0.66	0.86	29.4
Na (sodium - mg/l)	0.93	1.19	27.5
pH	6.27	6.66	6.1
SO_4 (sulphate - mg/l)	5.72	7.01	22.5

TABLE 3. Biophysical Watershed Variables that Show Significant Differences Between Coniferous- and Deciduous-Dominated Watersheds (all species means expressed as relative abundance; all variable differences significant at p<.05 for the Mann-Whitney U statistic)

Variable	Coniferous Watershed Mean (n=15)	Deciduous Watershed Mean (n=10)	% Difference
poplar	6.3	24.1	280.3
white birch	18.2	26.8	47.1
white pine	15.7	4.8	225.6
deciduous spp.	29.3	57.5	96.5
coniferous spp.	55.6	33.8	64.7
total vegetation	84.6	91.5	8.2
forest age	102.3	81.6	25.4
elevation change	0.0465	0.0640	37.6

Discussion

Stratification of the 25 study sites into coniferous- and deciduous-dominated watersheds provides a convenient perspective for making basic ecological comparisons at the landscape level. Although the results show that pH is only 1.1 times higher in the deciduous-dominated watersheds, pH considered in terms of H^+ concentration is 2.5 times higher in the coniferous-dominated watersheds compared to the deciduous-dominated watersheds. Many European studies have also found that an increase in the conifer component within a watershed causes an increase in streamwater acidity (Harriman 1978, Harriman and Morrison 1982a, Stoner et al. 1984, Nilsson 1985, Ormerod et al. 1989, Durand 1992).

In addition, higher concentrations of H^+ in conifer forest stemflow versus deciduous forest stemflow have been found in central Ontario (Neary and Gizyn 1992), the northeastern U.S. (Cronan et al. 1980) and Sweden (Nihlgard 1970, Nihlgard 1972). A portion of the stemflow drains through the soil eventually reaching surface waters and, in the case of conifer forests, contributes to the acidity of these waters (Daubenmire 1974, Barbour et al. 1987). Outlet streams tend to acidify as the soils within the watershed lose their ability to neutalize the acidic conditions (Harriman and Morrison 1982b).

The significantly lower concentration of H^+ and the significantly higher concentrations of Ca, Mg, Na and SO_4 in the deciduous-dominated watershed outlet streams likely reflects the greater buffering capacity of the deciduous-dominated watersheds compared to the coniferous-dominated watersheds. Through foliar leaching and litter decomposition, greater amounts of cations may be available for buffering soil acidity in deciduous forests due to a greater concentration of cations in their biomass compared to conifer species. For example, in Minnesota, Alban et al. (1978) found that poplar (24% mean relative abundance in the deciduous-dominated watersheds) had up to five times more Ca and up to two times more Mg in their biomass compared to spruce, red pine and jack pine (39% combined mean relative abundance in the conifer-dominated watersheds). Also in Minnesota, up to twelve times more Ca and up to five times more Mg was leached from poplar foliage compared to red pine foliage (Comerford and White 1977, Verry and Timmons 1977).

Intensive forest harvesting can result in the acidification of both soils and streams, which can be further exascerbated by acidic deposition (Hornbeck 1992). Those conditions within forested landscapes that may facilitate elevated H^+ concentration include low amounts of weatherable minerals (e.g. Ca, Mg, etc.), low cation exchange capacity, shallow soils, low sulfate adsorbtion capacity and atmospheric input of concentrated mineral acids (Binkley and Richter 1987). Due to the likelihood of their low capacity to buffer high H^+ concentrations and to the addition of acidic deposition resulting from Sudbury smelting operations, timber harvesting in the conifer-dominated watersheds of the Lower Spanish Forest should proceed with careful consideration of their sensitivity to acidification.

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