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Lakes, Wetlands and Dissolved Organic Carbon in Stream Outlets of Small Northern Temperate Watersheds

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INTRODUCTION

Dissolved organic carbon (DOC) in marine and freshwater ecosystems is one of the Earth's largest actively cycled reservoirs of organic matter (Bushaw et al. 1996) and it is the most abundant dissolved substance entering oligotrophic boreal lakes (Shindler et al. 1997). The main source of DOC for these lakes is allochthonous entering through precipitation, leaching, and decomposition primarily in the form of dissolved fulvic and humic acids. Autochthonous DOC in the form of photosynthate (mainly carbohydrates and amino acids), which is produced by phytoplankton and aquatic macrophytes, makes up only a small portion of the total DOC in freshwater ecosystems (Gergel et al. 1999).

The numerous ecological values of DOC in freshwater ecosystems have been discussed by Shindler and Curtis (1997) and Gergel et al. (1999), and include the following. It affects acid-base chemistry influencing the cycling of metals such as copper, mercury, and aluminum which, in turn can affect the concentration of trace metals found in aquatic organisms; it influences the availability of some forms of phosphorous and nitrogen (e.g. ammonium) (Bushaw et al. 1996); it alters sedimentation rates; it is a source of energy and nutrients to the microbial food chain; and by attenuating UV radiation, it protects aquatic organisms from the harmful effects of this radiation, it restricts the depth of the euphotic zone, it stabilizes the depth of the thermocline, and it depresses primary productivity in lakes. There is growing concern, however, that anthropogenic influences such as global warming, acidification, and intensive logging are altering the concentration and distribution of DOC resulting in adverse effects to freshwater ecosystems.

To better understand DOC-landscape dynamics, this study identifies and discusses those biophysical watershed factors that have the greatest influence on DOC concentrations in stream outlets of small northern temperate watersheds. The study area is approximately 50,000 ha in size and is located within the Lower Spanish Forest area of central Ontario, about 80 km northwest of Sudbury.

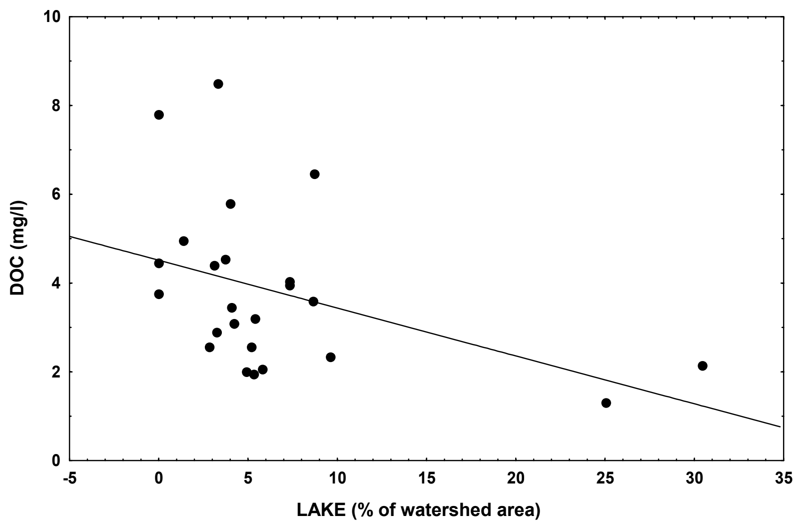
METHODS

A total of 25 pristine, ancient (unlogged) forested watersheds of the first and second orders ranging in size from 20 to 700 ha were studied. For each watershed, two water samples were taken 50 m apart at each of the watershed outlets during the summer of 1993. Shortly after collection, the water samples were taken to the Ontario Ministry of Environment and Energy's Dorset Research Station for analysis including determination of DOC. For analysis, the two DOC concentration estimates (mg/l) obtained for each stream were averaged. Using Forest Resource Inventory maps and topographic maps (1:20,000) that included each watershed, the relative aerial cover of each of the following biophysical features was determined: lakes, wetlands, *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., Thuja occidentalis*, conifer species, deciduous species, terrestrial vegetation, and exposed rock. In addition, the mean age of all forest stands, the elevation change, the length of all streams above the watershed outlet, and the distance from the watershed outlet upstream to the nearest lake or wetland were determined for each watershed. Relationships between these 24 biophysical variables and DOC were analyzed using Pearson product-moment correlations (Analytical Software 1994).

RESULTS

The correlation analysis using the 25 watershed samples showed that, of all 24 biophysical variables, only lake area (r= -3674, p=.071) and wetland area (r= .3750, p=.065) were closely related to DOC concentrations in streams at watershed outlets. By removing one outlier sample (reducing N to 24), significant correlations were obtained for both lake area (r= -.4175, p=.042) and wetland area (r= .3930, p=.057) with DOC. Thus, as lake area increases from 0% of the watershed area to 30.4%, DOC concentration in outlet stream water decreases (Figure 1). However, as wetland area increases from 0% of the watershed area to a maximum of 11.6%, DOC concentrations increase (Figure 2).

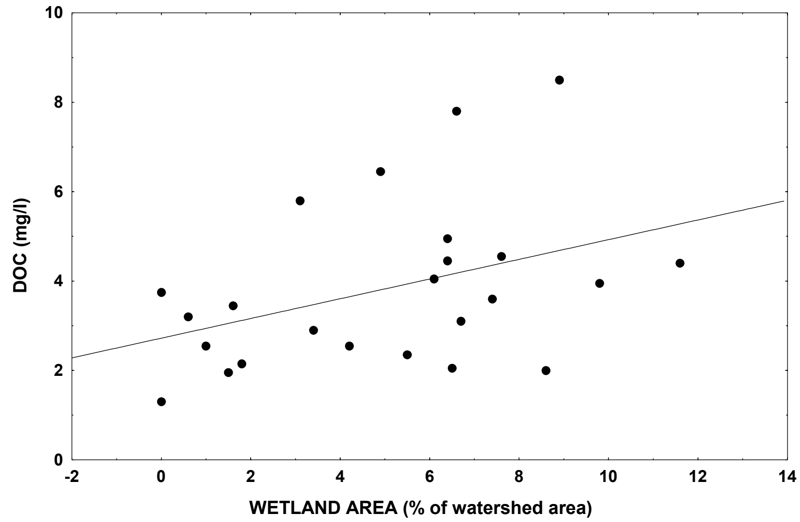
Figure 1. Relationship between Lake Area and Dissolved Organic Carbon (DOC) in Small Watersheds in the Lower Spanish Forest of Central Ontario (n=24; r=-.4175; p=.042)



DISCUSSION

These results show that DOC concentrations in watershed outlet streams increase with increasing wetland area in the watershed and decrease with increasing lake area. The positive influence of increasing wetland area on DOC concentrations in freshwater ecosystems is due primarily to leaching of DOC from wetlands into lakes (Urban et al. 1989, Schindler et al. 1997, Carpenter et al. 1998, Gergel et al. 1999). For example, in the Experimental Lakes Area of northwestern Ontario, Schindler et al. (1997) found that DOC concentrations doubled as water passed through a small bog lake and also increased when wetland areas around the edge of the lake were flooded. In northern Wisconsin, Gergel et al. (1999) found that the proportion of total wetlands in the watershed explained most of the

Figure 2. Relationship between Wetland Area and Dissolved Organic Carbon (DOC) in Small Watersheds in the Lower Spanish Forest of Central Ontario (n=24; r=.3930; p=.057)



variability of DOC in lake waters – DOC concentration increased with an increase in wetland area. Although the negative influence of increasing lake area on DOC concentrations may be related to a simultaneous decline in wetland area, it is also likely that declines in freshwater DOC result from the dilution effects of the additional lake water volume relative to land area (Wetzel 1975). In the present study, however, a significant inverse relationship between lake area and wetland area was not detected (r= -.3161, p=.132). DOC concentrations in freshwater ecosystems may also decrease as a result of global warming, acidification, and logging.

For a 20-year period (1970-1990) in the Experimental Lakes Area of northwestern Ontario, Schindler et al. (1997) found that both climatic warming and acidification caused declines in DOC inputs to lakes. A decline in precipitation of 40% and increased evaporation due to warmer temperatures combined to reduce catchment runoff by 70%. This reduced hydrological flow caused a decline in DOC transport into the lakes. In addition, both warming and experimental acidification caused increased removal of DOC within the lake. Acidification probably increased the rates of DOC sedimentation and mineralization, whereas warming probably increased the residence time of lake water increasing the opportunity for flocculation.

In central Ontario, studies have documented an increase in DOC concentrations in both wetlands and streams following logging. In the Temagami area, Whitfield and Hall (1996) found that spring DOC concentrations in wetlands of coniferous forests increased by 51.8% following clearcutting up to the wetland edge, whereas a 30 m buffer resulted in a 15.8% loss of DOC. Although not considered significant by Whitfield and Hall (1996) due to a wide range of values, the mean fall DOC concentration in wetlands of clear-cut coniferous forests was 68.3% higher than the reference wetland where there was no buffer and 72.7% higher with a 30 m buffer. Further to the west in central Ontario, Quinby et al. (1996) found that after an average of 3.5 years following clearcutting in mixed forest, the DOC concentrations in watershed outlet streams was 133% higher than in unlogged, reference streams. These losses may result in temporary increases in stream and lake water DOC, however, they also represent losses from the terrestrial and wetland reservoirs of organic matter. The decline in these reservoirs will eventually result in lower concentrations of DOC in lakes and streams.

In conclusion, DOC fulfills many roles in maintaining the integrity of freshwater ecosystems, however, a number of human activities such as climate warming, acidification, and logging are causing declines in this critical component of lake and stream water. Further study of the impacts of human activity on DOC including the design of conservation strategies to minimize these impacts are required.

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