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SHORT PAPER

On the Role of Forested Catchment in Acid Lake Limnology

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Abstract

Delamere Lake is a small, shallow, acid lake (pH 4.5) on the edge of a coniferous forest in Cheshire, England. Its surface water catchment is 19 ha with water retention period of 53 weeks. The lake showed high total nutrients (total nitrogen, mean 2.2 ± standard error of the mean 0.1 mg L^{-1}; total phosphorus, 200 ± 14 µg L^{-1}) and humic acid content (water colour, minimum 40 mg Pt L^{-1}) and very high phytoplankton biomass (chlorophyll *a*, 290 ± 31 µg L^{-1}). The soil of the catchment was sampled to test its contribution to chemical characteristics of the lake water. The pH of the soil was found to be very low (3.20). Dissolved organic carbon content of soil was positively correlated with NO_3-N, SRP and NH_4-N concentrations in the soil. The conifer-forested catchment was, therefore, suggested to be the main source maintaining low pH, high total nutrient concentrations and high humic content in the lake water.

Keywords: Dissolved organic carbon; eutrophication; phosphorus; coniferous forest.

Introduction

Over the last 150 years or so, human-induced acidification of surface water has increased significantly mainly owing to industrialisation and also because of immense changes in land use. The latter includes afforestation (especially with conifers) as vegetation composition and management practices can increase the susceptibility of waters in a forested catchment to acidification (Kreiser *et al.*, 1990; Harriman *et al.*, 1994; Kortelainen and Saukkonen, 1995; Reynolds, 2004). In addition to that, catchment vegetation has been identified as an important factor governing the nutrient composition of a lake (Kortelainen and Saukkonen, 1998; Kopacek *et al.*, 2000; Stendera and Johnson, 2006).

Delamere Lake (latitude 53°13'45″ N, longitude 2°39'30″ W) is located on the east edge of Delamere Forest Park, Cheshire, UK (Figure 1). This forest is situated on the glacial sand and gravel deposits overlying the Mercia Mudstone Group in the north Cheshire Plain. The aquifer type of this area is classified as Minor with soil having high leaching potential (Groundwater Vulnerability Map, Sheet 16, West Cheshire, National Rivers Authority, 1994). Permeability to ground water is low in the Delamere Forest area in general because of overlying peaty deposits. The main soil type of the forest is Crannymoor (acidic – pH around 3, well-drained with a tendency to draughtiness). The surface area of Delamere Lake is ca 1.8 ha, mean depth 1.7 m and surface water catchment 19 ha. The west-half of the lake is within the Delamere Forest Park area and the east-half is owned by the adjacent farm (Windyhowe Farm). There is no discrete surface inlet or outlet, and there is no evidence of any underground springs. Hence the lake hydrology entirely depends upon precipitation, surface run-off and sub-surface percolation. The water retention time of the lake is about 53 weeks. Detailed limnology of Delamere Lake has been described by Irfanullah and Moss (2005). The lake has some unusual features: very low pH, high nutrient concentrations, very high phytoplankton biomass (Table 1), very high monospecific growth of a colonial alga *Dictyosphaerium pulchellum* Wood (Chlorococcales) (on average ca 80%, maximum > 99% of total phytoplankton biovolume) (Irfanullah and Moss, 2006), and low Cladocera abundance. Water colour, as an indicator of dissolved organic carbon (DOC) content, usually ranged between 40 and 70 mg Pt L^{-1}.

In the present study, following two hypotheses were tested by extracting leachable compounds (nutrients and humic substances) from soil samples collected from different locations and depths in the catchment of Delamere Lake:

1) the lake's surface catchment is a potential source of nutrient and dissolved organic carbon thus causing acidic, eutrophic, humic condition in the lake; and

2) vegetation types existing in the catchment influence the soil chemistry.

Materials and Methods

Soil cores ((30-) 40 (-50) cm deep) were collected on 23 April 2004 from six randomly selected points in the Delamere Lake catchment using

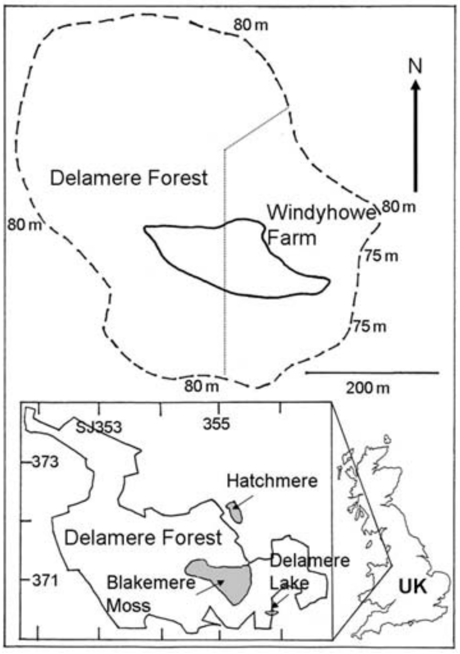

Figure 1. Delamere Lake catchment area (dashed line). Dotted line demarcated the areas of the lake and the catchment owned by different owners. Whole catchment is predominantly covered with conifers, except the Farm area containing broad-leaved trees as well. Altitudes are given in meter.

Table 1. Mean values (±SE, n=44) of different variables in Delamere Lake (November 2001 – October 2003) (after Irfanullah and Moss, 2005)

	Mean±SE		Mean±SE
pH	4.45	NO_3-N (mg L^{-1})	0.07±0.03
Conductivity (µS cm^{-1})	43.0±0.7	TP (µg L^{-1})	200±14
Oxygen (mg L^{-1})	11.6±0.3	TN (mg L^{-1})	2.2±0.1
Light extinct. coeff. (k, m^{-1})	5.1±0.3	Silicate-Si (mg L^{-1})	2.23±0.04
SRP (µg L^{-1})	3.6±0.5	Chlorophyll *a* (µg L^{-1})	290±31
NH_4-N (µg L^{-1})	26.8±7.9	Carotenoids (µg L^{-1})	260±28

a 2-cm diameter soil corer, and were separated into three sections: top layer (0-30 cm, semi-decomposed plant debris topped with litter), middle layer (31-35 cm, dark humus with sand) and bottom (36-40 cm, orange-brown sand with low organic matter). These samples were kept in vertical plastic tubes (diameter 5 cm; surface area 0.002 m^2) with mesh at the bottom end. Distilled water was dripped on the tops of these columns for ca 24 hours and the first 300 mL of leached waters were collected. All these waters were filtered through Whatman glass microfibre filters (GF/C, 47 mm) and were analysed for NO_3-N, NH_4-N and soluble reactive phosphorus (SRP) concentrations (Mackereth *et al.*, 1989) and colour (Cuthbert and del Giorgio, 1992).

Water colour was expressed as mg Pt L^{-1} first by measuring the absorbance at 440 nm then using suggested equations and was used as an indicator of dissolved organic carbon (DOC) content or humic acid content. The nutrient concentrations (mg or µg L^{-1}) were converted into mg L^{-1} kg^{-1} and interpreted as amount of nutrient present in the first one litre of water passed through one kg soil (dry wt, at 105°C for 36 h). Likewise, the unit for water colour was g Pt L^{-1} kg^{-1}. These values can be considered as the concentrations of 'readily leachable compounds' and only to be used as indicative values of soil chemical contents.

T-test was done to determine significant difference among two data sets, whereas one-way ANOVA followed by Tukey test was done to compare more than two data sets. Pearson correlation coefficients were calculated to determine correlations among variables. An Anderson-Darling test was done to determine the normality of every data set. Log_e-transformed data were used where necessary.

Results and Discussion

pH (mean 3.20), NO_3-N, NH_4-N and SRP concentrations in the forest-owned catchment soil extracts were not different from those in the privately-owned catchment (Figure 2A). However, higher humic concentrations were recorded in the forest catchment (*t*-test, P=0.011). The pH values and NH_4-N and SRP concentrations were not different among the three depths (one-way ANOVA, P>0.05). The top-most layer had higher NO_3-N and DOC concentrations than the deepest layer (one-way ANOVA, P<0.05) (Figure 2B). On the other hand, SRP and NH_4-N concentrations were not different at different levels. Soil DOC content was positively correlated with NO_3-N (r = 0.806, P<0.001), and SRP and NH_4-N (r > 0.520, P<0.05) concentrations in the soil.

Conifer-covered catchments can be important sources of acidity (Kortelainen and Saukkonen, 1995), nutrients (Kortelainen and Saukkonen, 1998) and humic contents (Hemond, 1994; Hongve, 1999; Peichl *et al.*, 2007) for associated water-bodies and the present findings agreed with that. The present study, however, does not agree with another related study (McDowell *et al.*, 2004) which implies that DOC concentrations may not be related to N concentrations of catchment as the former was not influenced even by N fertilization in pine-forested area. In the absence of discrete inflow, nutrients and DOC are primarily entering into Delamere Lake through surface run-off and sub-surface percolation as shown by their high concentrations in the catchment soil even along the depths. But, rainfall (mm day^{-1}) did not correlate with the nutrient concentrations in the lake water (Irfanullah and Moss, 2005). It is probably because rainfall data did not reflect the subsurface movement of water to the lake.

Despite the presence of two houses on the catchment, there is no evidence of direct or indirect input of nutrients from them. There is no public toilet in the catchment. But excreta of visitors and their dogs in the forest may also add nutrients in the catchment to a limited extent.

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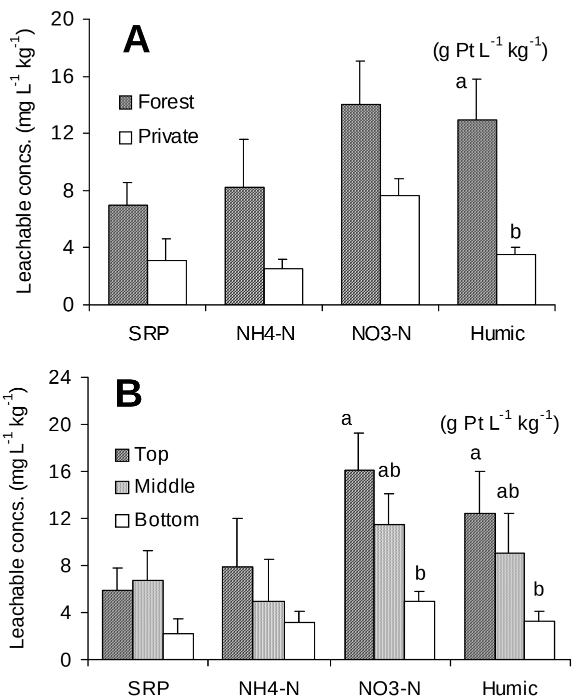

Figure 2. Mean concentrations (±SE) of SRP, NH_4-N, NO_3-N (mg L^{-1} kg^{-1}) and dissolved organic carbon or humic content expressed as water colour (Humic, g Pt L^{-1} kg^{-1}) in; A) forest and private catchment areas (n = 9) and B) top (0-30 cm), middle (31-35 cm) and bottom (36-40 cm) soil layers (n = 6). Means with different small letters are different from their counterparts at P<0.05 significance level following a *t*-test (Figure A) or one-way ANOVA and Tukey test (Figure B).

References

Cuthbert, I.D. and del Girogio, P. 1992. Towards a standard method of measuring color in freshwater. Limnol. Oceanogr., 37: 1319-1326.

Harriman, R., Likens, G.E., Hultberg, H. and Neal, C. 1994. Influence of management practices in catchments on freshwater acidification: afforestration in the United Kingdom and North America. Steinberg, In: C.E.W. Steinberg and R.F. Wright (Eds.), Acidification of Freshwater Ecosystems: Implications for the Future, John Wiley & Sons, Chichester, West Sussex: 83-101.

Hemond, H.F. 1994. Role of organic acids in acidification of fresh waters. In: C.E.W. Steinberg and R.F. Wright (Eds.), Acidification of Freshwater Ecosystems: Implications for the Future, John Wiley & Sons, Chichester, West Sussex: 103-115.

Hongve, D. 1999. Production of dissolved organic carbon in forested catchments. J. Hydrol., 224: 91-99.

Irfanullah, H.M. and Moss, B. 2005. Limnology of an unusual eutrophic acid forest lake. J. Freshwater Ecol., 20: 441-449.

Irfanullah, H.M. and Moss, B. 2006. Ecology of *Dictyosphaerium pulchellum* Wood (Chlorophyta, Chlorococcales) in a shallow, acid, forest lake. Aquatic Ecol., 40: 1-12.

Kopacek, J., Stuchlik, E., Straskrabova, V. and Psenakova, P. 2000. Factors governing nutrient status of mountain lakes in the Tatra Mountains. Freshwater Biol., 43: 369-383.

Kortelainen, P. and Saukkonen, S. 1995. Organic vs minerogenic acidity in headwater streams in Finland. Water Air Soil Poll., 85: 559-564.

Kortelainen, P. and Saukkonen, S. 1998. Leaching of nutrients, organic carbon and iron from Finnish forestry land. Water Air Soil Poll., 105: 239-250.

Kreiser, A.M., Appleby, P.G., Natkanski, J., Rippey, B. and Battarbee, R.W. 1990. Afforesttation and lake acidification: a comparison of four sites in Scotland. Philos. T. Roy. Soc. B., 327: 377-383.

Mackereth, F.J.H., Heron, J. and Talling, J.F. 1989. Water Analysis: Some Revised Methods for Limnologists. Freshwater Biological Association, Scientific Publication, No. 36, Cumbria and Dorset, England, 120 pp.

McDowell, W.H., Magill, A.H., Aitkenhead-Peterson, J.A., Aber, J.D., Merriam, J.L. and Kaushal, S.S. 2004. Effects of chronic nitrogen amendment on dissolved organic matter and inorganic nitrogen in soil solution. Forest Ecol. Manag., 196: 29-41.

Peichl, M., Moore, T.R., Arain, M.A., Dalva, M., Brodkey, D. and McLaren, J. 2007. Concentrations and fluxes of dissolved organic carbon in an age-sequence of white pine forests in Southern Ontario, Canada. Biogeochemistry, 86: 1-17.

Reynolds, B. 2004. Continuous cover forestry: possible implications for surface water acidification in the UK uplands. Hydrol. Earth System Sci., 8: 306-313.

Stendera, S. and Johnson, R.K. 2006. Multiscale Drivers of Water Chemistry of Boreal Lakes and Streams. Environmental Manag., 38: 760-770.