The effects of acidification on metal budgets of lakes and catchments

P.J. DILLON¹, H.E. EVANS² & P.J. SCHOLER³

¹Dorset Research Centre, Ontario Ministry of the Environment, Dorset, Ontario POA 1EO; ²Dept. of Zoology, University of Toronto, Toronto, Ontario M5S 1G2, Canada

Revised and accepted 3 August 1987

Key words: metals, mass balances, acidification, lakes, catchment

Abstract. Metal (Cu, Ni, Zn, Fe, Mn and Al) budgets were measured for 5 lakes and their catchments near Sudbury, Ontario, an area severely affected by the emission and deposition of strong acids (H₂SO₄/SO₂) and metals. Three of the lakes were circum-neutral (pH 6.3–7.1) during the study period, while one lake had a pH of ~4.8 and a fifth had very low pH (~4.4).

The lakes' catchments were all sources of Al, Mn and Ni, but were sinks for Cu and Zn. The Fe results were inconsistent; two lakes' catchments were sources while three were sinks. The acidic lakes were conservative (i.e. net retention of zero) with respect to Cu and Ni, while the circum-neutral lakes were effective sinks for these 2 metals. All of the lakes were sinks for Zn and Al, but the acidic lakes were less effective. All lakes were also Fe sinks. While there was no pattern relative to the lakes' pH's, there was a trend towards increasing Fe retention with increasing water replenishment time. The most acidic lake was actually a source of Mn, while the others were sinks.

Introduction

The interaction between the biogeochemical effects of both the wet and dry deposition of acids to the earth's surface (i.e. "acid precipitation") and the increase in trace metals of anthropogenic origin has been a topic of numerous investigations (Anon. 1985). For example, the loss of fish from acidified, metal-contaminated lakes in Ontario, Canada (Beamish & Harvey 1972), the effects of trace metals on the survival of freshwater zooplankton (Biesinger & Christensen 1972; Baudouin & Scoppa 1974), the result of increased acidity on the mobility of trace metals in lake sediments and watersheds (Cronan & Schofield 1979; Schindler et al. 1980; Johnson et al. 1981) and the effects of high acidity and metal levels on terrestrial flora (Hutchinson & Whitby 1977; Linzon 1978; Freedman & Hutchinson 1980) have been studied extensively.

To date, however, few attempts to quantify the fluxes of metals to and
from any lake, acidic or not, have been made. The few exceptions include Lee (1962) who measured the Fe and Mn budgets of Lake Mendota, Nriagu et al. (1979, 1983) who measured metal budgets for Lake Erie and a portion of Lake Ontario, Cross & Rigler (1983), who reported on the Fe budget of Bob Lake, Ontario, and White & Driscoll (1985, 1987a, b), who measured the budgets for several metals in Dart's Lake, New York. With the exception of Dart's Lake, these lakes were not affected by acidic deposition.

In addition, a few metal budgets for catchments have been measured (Andren et al. 1975; Swanson & Johnson 1980; Calles 1983; Schut et al. 1985) while input-output budgets for strong acids and related substances (eg. SO₄) have been quantified more frequently for both lakes and catchments (eg. Schindler et al. 1976; Wright & Johannessen 1980; Galloway et al. 1983; Wright 1983). The scarcity of metal mass balance information is unfortunate because these data could be used to assess the relative importance of the different sources and loss mechanisms to and from a lake (LaZerte 1986) or to predict metal concentrations in lakes as a function of source strength. They may also be useful for studying the effects of acidic deposition on the behaviour of trace metals in both terrestrial and aquatic systems.

The purpose of this study was to construct the input-output budgets for Cu, Ni, Zn, Fe, Mn, and Al for five lakes (two acidic lakes with average annual pH < 4.8 and three circum-neutral lakes with average annual pH > 6.3), and their catchments, and to use these mass balances to evaluate the effects of lake acidification on the behaviour of these metals.

**Study area**

Major Cu and Ni deposits were discovered near Sudbury, Ontario, Canada over 100 years ago. The resulting mining and smelting activities have resulted in the emission of extremely large quantities of SO₂, the precursor of H₂SO₄ (0.5–2.5 × 10⁶ tonnes yr⁻¹ during the 1970's), and of Cu and Ni (500–1100 tonnes yr⁻¹; Jeffries 1984; Ontario Ministry of the Environment 1982). As a consequence, there are elevated metal and acidity levels in the surrounding aquatic and terrestrial ecosystems (eg. Allan 1974; Beamish 1974; Hutchinson & Whitby 1977; Scheider et al. 1979; Amiro & Courtin 1981). Levels of many metals in the lake waters are extremely high; for example Yan & Miller (1984) measured Cu, Ni, Zn, Fe, Al and Mn levels in Clearwater Lake in 1977 of 81, 280, 39, 88, 380 and 290 μg L⁻¹ respectively. This lake, and many others in the region, have been acidified such that their pH in 1973–74 was between 4.1 and 4.4.