

Recovery Pathways of Zooplankton Communities in Acidified Lakes of Killarney Provincial Park, Ontario

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Abstract

The acidification of lakes has resulted in severe environmental damage including decreases in species richness and losses of sensitive species. Reductions in SO₂ emissions have allowed limited water quality improvements. Nowhere has the rise in pH been more evident than in Killarney Provincial Park (Ontario). Temporal trends in zooplankton species richness and composition were examined in 1971-3 and 2000 in 46 Killarney Provincial Park lakes to assess the biological recovery in lakes with significant water quality improvements (i.e. pH now >6) compared to 2 other groups: (1) lakes which never acidified, and (2) lakes which are still acidified (pH<6). Recovery pathways varied among lake groups. The lakes which rose in pH to above 6 exhibited a recovery pathway to a state typical of neutral lakes, which mirrored damage pathways. However, the acidic lakes (which experienced change in median pH from 4.6 to 5.0) experienced some recovery in species abundances, though the recovery trajectory did not mirror that of damage trajectories. Changes in species abundances were not accompanied by increases in species richness. These results suggest that: (1) biological recovery does occur in lakes which experience sufficient water quality improvements, and (2) recovery pathways are not always predictable from damage pathways.

Introduction

Recent reductions in acidic SO₂ emissions across Europe and North America have resulted in wide-spread decreases in S deposition accompanied by some increases in lake pH and alkalinity (Stoddard *et al.* 1999). Biological recovery from acidification has been documented, but has not been as extensive and has lagged behind improvements in water quality (Schindler *et al.* 1991). Examples of zooplankton community recovery are limited to: (1) individual lake studies, (2) experimentally neutralized lakes, and (3) a few regional lake studies. The individual lakes studies are too few to apply to regional-scale recovery. Studies of experimentally neutralized lakes are characterized by short time scales and conditions which do not replicate those of natural recovery (Appelberg *et al.* 1995, Stenson and Svensson 1995, Yan *et al.* 1996). Regional studies have not documented recovery to a state typical of neutral lakes (Locke *et al.* 1994). We are therefore uncertain if wide-spread recovery will occur given water quality improvements.

Identifying recovery is not straightforward as recovery pathways are often unpredictable. Classic ecosystem theory assumes that recovery trajectories will follow a simple reverse of damage trajectories. However, simple predictable recovery seldom occurs (Appelberg *et al.* 1995; Frost *et al.* 1998). Instead, multiple alternate recovery pathways exist, which do not mirror damage pathways (Frost *et al.* 1998; Keller and Yan 1998; Schindler *et al.* 1991). These recovery trajectories are influenced by: (1) transient ecosystem dynamics, (2) biological resistance, and (3) stochastic dispersal rates. For example, the recovery pathways of zooplankton communities are influenced by invasion sequence. In the first stages of recovery from acidification, unusual zooplankton species from the littoral zone (e.g. *Sida crystallina*, *Chydorus sphaericus*) often temporarily expand into the pelagic zone due to the relative facility of dispersal of these littoral species (Keller and Yan, 1998; Yan and Strus, 1980). Once acid-sensitive species recolonize the lake, littoral species are lost from the pelagic zone. Therefore, recovery pathways do not necessarily mirror the sequence at which species are lost.

The extent and pathway of zooplankton community recovery given current reductions in S emissions is unknown. The objective of this study was to examine the extent and pathway of zooplankton recovery in a set of Killarney Park lakes which have experienced significant water quality improvements. Two specific questions were addressed. (1) Have the lakes which were acidified recovered to a state typical of neutral lakes? (2) Do the recovery pathways reflect what would be expected from damage pathways?

Study Sites

The 46 study lakes lie in and around Killarney Provincial Park, within 84 km of Sudbury. The lakes vary in size (3-1088 ha, mean 137 ha) and maximum depth (2-61 m, mean 22m). The current pH of the lakes also ranges widely (4.3-7.7), though a large portion are acidic (median pH 5.97). The lakes are mostly oligotrophic (mean TP 12.3 µg/L) and soft (mean Ca of 96.2 µeq/L), as is typical of Precambrian Shield lakes.

Data collection

Sprules (1975) collected zooplankton and water quality samples from 47 lakes between June and September, 1971-1973. Samples were taken from a single mid-lake station, except in multi-basin lakes where a sample was taken from each major basin. One vertical zooplankton haul was taken at each lake with a 25-30 cm diameter net of mesh size 75-110 µm. We collected zooplankton samples and water quality data again in July and August of 2000. Three vertical zooplankton hauls were taken at each lake with a metered 12.5 cm diameter net of mesh size 80 µm. The mean haul efficiency was 77%. To determine the influence of net size on the zooplankton species composition sampled, four lakes were sampled with both a 30 cm diameter net of mesh size 80 µm and a 12.5 cm diameter net of mesh size 80 µm. No significant differences in species richness or abundances of the 17

dominant species were detected, except for *Holopedium gibberum* and *Neobosmina tubicen*, neither of which are known to be acid-sensitive.

Crustacean zooplankton were identified and counted. Taxonomic discrepancies among studies (1971-3 and 2000) necessitated pooling several species. *Diaphanosoma brachyurum* and *D. birgei* were pooled into *Diaphanosoma spp.* (Korínek, 1981). *Daphnia pulex* and *D. pulicarea* were pooled as well (Dodson, 1981). *Tropocyclops prasinus mexicanus*, *T. prasinus prasinus* and *T. extensus* were pooled into *Tropocyclops spp.* (Dussart and Fernando, 1990). The following species have recently been re-identified, necessitating the renaming in the 1971-3 records: (1) *Daphnia galeata mendotae* has been re-identified as *Daphnia mendotae*, (2) *Bosmina longirostris* has been re-identified as *Sinobosmina spp* (DeMelo and Hebert, 1994). At least 250 individuals were counted from each sample. Immature cladocerans were included with adults. Immature copepods and nauplii were not counted.

The 46 lakes from the combined 1971-3 and 2000 data sets were then divided into 3 groups according to water quality changes about pH 6. A pH of 6 has been widely used to discriminate between lakes damaged by acidification and those not damaged (Doka *et al.* 1997; Hindar and Henriksen, 1998). These groups were: (1) lakes which have increased in pH to >6.0 (n=11), (2) lakes which are still acidic (pH <6.0) (n=23), (3) lakes which were not acidic during the study period (pH >6.0) (n=7). The lake groups will be referred as: (1) lakes in which the pH rose to >6, (2) acidified lakes, and (3) neutral lakes. Though only the first group of lakes increased to pH >6, both the acidified and the neutral lakes experienced an increase in pH over time.

Statistical analyses

To compare changes in zooplankton communities over time among lake groups, 2 metrics were used: (1) species richness and (2) ordination scores from correspondence analysis based on species abundances.

To determine if recovery to state typical of neutral lakes occurred, the zooplankton community metric of the neutral lakes was compared to the lakes which increased in pH to >6 and the acidified lakes using t-tests. Non-significant test statistics indicated recovery to a state typical of neutral lakes.

Recovery pathways were compared among the three lake groups. Increases in species richness prior to, or concurrent with, changes in species abundances indicated recovery pathways that mirrored damage pathways.

Results

Species richness from single mid-lake hauls varied from 1 to 17 (mean 7.7 species). Species abundance data from both studies were combined in a correspon-

dence analysis. The first CA axis was most highly correlated with pH ($r = 0.62$, $p < 0.001$) compared to the other 3 axes ($r = 0.30$, $r = -0.15$ and $r = -0.24$), and explained 22% of the total variance. Therefore CA axis 1 was used for further analysis.

Species richness of lakes which rose in pH to >6 was not significantly different than that of neutral lakes in both 1971-3 and 2000 ($t = -0.56$, $df = 14$, $p > 0.2$, $t = 0.29$, $df = 14$, $p > 0.2$) (Fig. 1a). The acidified lakes had a significantly lower mean species richness than the neutral lakes in both years ($t = -6.90$, $df = 28$, $p < 0.01$, $t = -3.89$, $df = 28$, $p < 0.01$).

The CA scores of species abundances were lower for the lakes which rose in pH to >6 than that of neutral lakes in 1971-3 ($t = -1.60$, $df = 14$, $p = 0.066$) (Figure 1b). In 2000, there was no significant difference in CA scores between these two groups of lakes ($t = -0.46$, $df = 14$, $p > 0.2$), suggesting recovery to state typical of neutral lakes. The CA scores of the acidified lakes did increase over the study period, though they were significantly different than the neutral lakes in both 1971-3 and 2000 ($t = -7.41$, $df = 28$, $p < 0.01$, $t = -3.61$, $df = 28$, $p < 0.01$).

Discussion

Recovery of zooplankton species composition to a state similar to neutral lakes was documented in lakes in which the pH rose to > 6 . Some recovery of the acidified lakes was also documented, though not to a state typical of neutral lakes.

The comparison of trajectories of the lakes in which the pH rose to >6 and the acidified lakes suggests that recovery is not a simple process, but instead has several alternate pathways. It has commonly been assumed that as both zooplankton species richness and composition are damaged during acidification, they will recover in a similar manner (as in zooplankton recovery in Yan *et al.* (1996)). In the present study, however, the acidified lakes (which experienced a pH increase to >5) showed some recovery in zooplankton composition towards a state typical of neutral lakes, though no recovery in species richness. Recovery in this case did not follow a simple predictable pathway, but instead was most likely influenced by other abiotic and biotic factors.

The unpredictability of recovery trajectories corresponds well to the understanding of ecosystems as complex, dynamic systems (Power, 1999). We now know that stable climax ecosystems do not exist, but are instead continually in a state of change due to changing abiotic and biotic conditions. The recovery process itself is influenced by changing environmental conditions, biological interactions and dispersal barriers. For example, declining in-lake calcium levels may limit future recovery of zooplankton species (Keller *et al.* in review). Calcium is an essential element for zooplankton and is currently declining in Killarney Provincial Park lakes (Alstad *et al.* 1999; Keller *et al.* in review). As well, the recolonization of acid-sensitive fish species may be restricted in lakes without inflows or outflows

(Keller and Yan, 1998). The absence of vertebrate predators may influence zooplankton community structure and prevent recovery to a state typical of neutral lakes (Nyberg, 1984; Stenson and Svensson, 1995). Therefore, it cannot be assumed that recovery will consist of a simple reverse of damage trajectories.

This study adds to our evidence that recovery can occur given sufficient habitat quality improvements, though pathways that do not mirror those of damage can be expected.

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