# Liming of acidified lakes in southwestern Sweden: short-term effects on waterbird densities

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## Introduction

Lime treatment has proven to be an efficient method for restoring fish stocks in acidified lakes (e.g. Bengtsson *et al.* 1980; Eriksson *et al.* 1983; Nyberg 1984; Nyberg *et al.* 1986; Eriksson and Tengelin 1987). It is now frequently applied in Sweden, and since 1977 more than 3,000 lakes have been limed (Statens Naturvårdsverk, unpubl.). But changes in fish density also affect the conditions for waterbirds. Fish-eating birds are, of course, favoured by an increase in fish density, but this benefit can be counteracted by a decrease in water transparency, which makes it more difficult to detect fish (Eriksson 1985). Also non-piscivorous anatids are affected by changes in fish density (Andersson 1981); in oligotrophic lakes susceptible to acidification and thus the target for liming, competition between fish and ducks for common food organisms (aquatic insects) may affect the density and distribution of waterfowl (e.g. Pehrsson 1979, 1984; Eriksson 1979, 1983; Eadie and Keast 1982; DesGranges and Darveau 1985). Thus, for conservation and management it is important to find out how waterbirds are affected by liming.

In the present study, the effects of liming were investigated through comparing densities of fish and waterfowl in eight lakes in 1983 before they were limed that summer-autumn, and again in 1985, after liming. Simultaneous studies were done in six control lakes that were not limed. It was predicted that fish density increases and transparency decreases in the limed lakes, but not in the control lakes. The investigation has the character of a pilot study, as an extended following-up over a period longer than two years was made impossible due to the introduction of different liming routines in study lakes, and the liming of some of the control lakes after 1985. Parts of the data from 1983 have earlier been used for a test of predictions of a model for the selection of lakes by fish-eating birds (Eriksson 1985).

## Study area

A total of 14 lakes in an area south-east of Göteborg (approximately 57°20′–57°40′N, 12°10′–12°40′E), Sweden, were investigated (Figure 1). Lake surface areas ranged between 0.46 and 1.90 ha, and shore-lengths between 5.5 and 12.5 km (for details, see Eriksson and Tengelin 1987). The catchment areas are dominated by coniferous forests of *Picea abies* and *Pinus silvestris*. Before liming, pH-values regularly below 5.4 were reported in all lakes apart from two of the controls (Eriksson and Tengelin 1987), and Morling (1981) documented an acidification process and slight increase in average transparency in a study of 19 lakes in the same geographical area (out of which four lakes were included in the present study).

Black-throated Diver *Gavia arctica* is the most common fish-eating bird in the area; less numerous are Goosander *Mergus merganser*, Red-breasted Merganser *M. serrator*, Grey Heron *Ardea cinerea*, Osprey *Pandion haliaetus*, Greater Black-backed Gull *Larus marinus* and Common Tern *Sterna hirundo*. Among non-piscivorous ducks, Mallard *Anas platyrhynchos*, Teal *A. crecca* and Goldeneye *Bucephala clangula* are common.

The fish fauna in dominated by Perch *Perca fluviatilis*; Pike *Esox lucius* is also wide-spread but less numerous. Roach *Rutilus rutilus* was recorded in three lakes; this species is known to disappear early during the acidification process (Almer and Hanson 1980), and probably the populations have been eradicated in many of the investigated lakes. Small populations of salmonids, such as White-fish *Coregonus* sp., Cisco *Coregonus albula* and Smelt *Osmerus eperlanus* exist in some of the lakes.

In 1983, ice broke up during the first week of April, which is quite normal for this part of Sweden, while break up of the ice was delayed until around 1 May 1985.

## Methods

Liming was done during summer-autumn 1983. Fine-grained $CaCo_3$ was spread into


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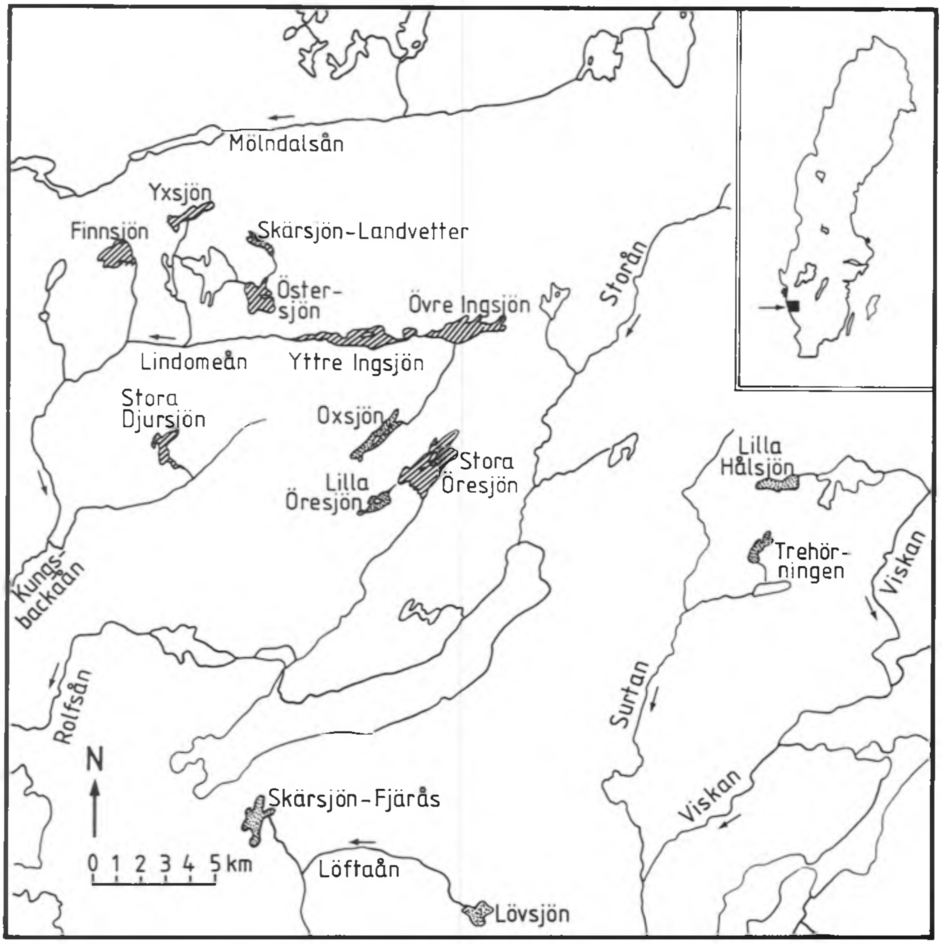


**Figure 1. The study area in Sweden.** Hatched – lakes limed, dotted – lakes not limed.

the water from shore or from a raft, with 115–1,120 tons, or 17–55 g per $m^3$, in each lake.

Fish samples were obtained with gill nets during 24th May–21st June 1983 (except for Lake Trehörningen, which was fished on 19th–20th July) and again during 20th May–13th June 1985. For details of net size, thread dimensions and mesh sizes, see Eriksson (1985). Fish catches were quantified as the mean number of fish per catch effort; one catch effort equals one gill net placed in the lake during 20 hours, including one night with 5–6 hours of darkness. Fish lengths were measured with an accuracy of ±0.5 mm.

Fish detectability was measured with a "fish detectability index", FDI, through which fish density and water transparency were weighted together. For a bird with a maximal diving depth of **d** metres, the fish detectability index in a lake with a relative fish density corresponding to a gill net catch of $\bar{\mathbf{F}}$ fish per catch effort and with a water transparency of **t** metres is:

$$\mathrm{FDI} = \bar{F} \times \frac{\pi . d(3t^2 - d^2)}{3} \times 10^{-2};$$

see Eriksson (1985) for the deduction of this formula. When the maximal diving depth exceeded transparency, i.e., **d>t**, **d** was replaced with **t**. During field work, transparency was measured with a Secchi disc.

As Black-throated Diver and Goosander seldom catch fish longer than about 25 cm. (e.g. Madsen 1957; White 1957), fish above this size were excluded in the calculations of fish detectability indices. For Black-throated Diver, maximal diving depth (according to Niethammer *et al.* 1966; Lehtonen 1970) exceeds the transparency recorded in any of the lakes; for Goosander, a maximal diving depth of 4.0 m. was assumed (Cramp and Simmons 1977).

Each season, every lake was visited twice; in 1983 during 29th April–10th May and 27th May–2nd June, and in 1985 during 8th–14th May and 1st–4th June. At each visit, the total lake area and the whole shoreline (incl. islands) was observed from a canoe, and the time for covering one lake ranged between 0.75 and 2.0 hours. Mean number of birds per $km^2$ lake area were used as estimates of bird densities. Mean number of birds per km shoreline were also calculated. The counts included fledged individuals of all potentially fish-eating species and of all anatids, but species recorded in less than five lakes were excluded from the analyses (this applies to Grey Heron, Tufted Duck *Aythya fuligula,* Mute Swan *Cygnus olor,* Osprey, Greater Black-backed Gull and Common Tern). In 1985, ice broke very late (see above), and migrating birds might have been included in the counts during the first period. To avoid this problem, estimates of bird densities were calculated based only on the second counts in each year. However, this did not in general alter the trends found. The exceptions are noted in text or table as appropriate. Recreational activities, such as boating and fishing, were considered not to be of such intensity that the counting results were affected.

## Results and discussion

### *Density and detectability of fish*

In the limed lakes, a significant increase in average fish density and a significant decrease in average water transparency were recorded, while these two parameters remained unchanged in the control lakes (Table 1; for details regarding Perch, see Eriksson and Tengelin 1986). No consistent trends in the fish detectability index could be found (Table 1); the increase of fish density was, in some lakes, counteracted by the reduction in transparency. In one of the lakes, Lake Stora Öresjon, fish density increased more than a hundredfold (Eriksson and Tengelin 1986), after a successful reproduction of Perch in 1984. Omission of the exceptional data from this lake did not change the general trends.

### *Density of birds*

#### *Piscivorous species.*

Density of Black-throated Diver increased significantly in the limed lakes, but the same trend, although insignificant, was also recorded in the control lakes. Thus, this result probably reflects a general increase.

Goosander was recorded in five lakes only, and thus the sample of this species is too small to allow any definitive conclusions. However, an insignificant increase of average density could be recorded among the limed lakes, while a decrease occurred in the control lakes (Table 2).

**Table 1. Comparisons of density and detectability of fish in limed lakes and control lakes.** Means±S.E. P–values refer to Wilcoxon matched pairs signed ranks tests, two-tailed. N.S.=not significant.

| | Limed lakes (n=8) | | | Limed lakes, excluding Lake Stora Öresjon (n=7) | | | Control lakes (n=6) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1983 | 1985 | P | 1983 | 1985 | P | 1983 | 1985 | P |
| No. of fish per lake and catch effort: | | | | | | | | | |
| Total catch | 16±4 | 124±96 | <0.01 | 18±4 | 28±2 | <0.02 | 11±4 | 12±6 | N.S |
| <25 cm | 15±4 | 122±96 | <0.01 | 17±4 | 26±3 | <0.02 | 9±4 | 10±6 | N.S |
| Secchi disc transparency, m | 5.3±0.4 | 4.6±0.3 | <0.05 | 5.3±0.5 | 4.5±0.3 | <0.05 | 5.5±0.5 | 5.6±0.7 | N.S |
| Fish detectability index | | | | | | | | | |
| Black-throated Diver | 49±22 | 428±377 | N.S. | 54±25 | 52±13 | N.S. | 48±20 | 56±34 | N.S |
| Goosander | 46±19 | 379±331 | N.S. | 42±17 | 48±10 | N.S. | 39±43 | 43±25 | N.S |

**Table 2. Comparison of mean bird densities in limed lakes and control lakes for 2 counts each year.** P–values refer to the Wilcoxon matched pairs signed ranks two-tailed. N.S.=not significant.

| | Limed lakes (n=8) | | | Control lakes (n=6) | | |
|---|---|---|---|---|---|---|
| | 1983 | 1985 | P | 1983 | 1985 | P |
| No. of birds per $km^2$ lake area | | | | | | |
| Black-throated Diver | 1.1±0.4 | 1.8±0.5 | <0.02 | 2.1±0.6 | 2.7±0.8 | N.S. |
| Mallard | 5.6±1.9 | 3.2±1.1 | N.S. | 2.6±0.8 | 1.2±0.4 | N.S. |
| Teal | 0.9±0.4 | 0.3±0.3 | =0.06 | 0.3±0.2 | 0.1±0.1 | N.S. |
| Goldeneye | 5.9±1.1 | 9.7±4.2 | N.S. | 2.8±1.9 | 2.8±1.4 | N.S. |
| Goosander | 0.0±0.0 | 0.3±0.1 | N.S. | 0.2±0.2 | 0.0±0.0 | N.S. |
| No. of birds per km shoreline | | | | | | |
| Black-throated Diver | 0.14±0.05 | 0.22±0.05 | <0.02 | 0.20±0.04 | 0.24±0.05 | N.S. |
| Mallard | 0.66±0.19 | 0.39±0.10 | N.S. | 0.24±0.06 | 0.11±0.03 | N.S. |
| Teal | 0.11±0.04 | 0.02±0.02 | =0.06 | 0.03±0.02 | 0.01±0.01 | N.S. |
| Goldeneye | 0.82±0.21 | 1.14±0.37 | N.S. | 0.23±0.15 | 0.27±0.11 | N.S. |
| Goosander | 0.00±0.00 | 0.04±0.02 | N.S. | 0.02±0.02 | 0.00±0.00 | N.S. |

*Non-piscivorous ducks.*

Average densities of Mallard and Teal decreased insignificantly in both the limed lakes and the control lakes. For Goldeneye, no significant trends could be detected from data covering both counts in each year; but regarding the second counts only, a significant decrease in average density was recorded in the limed lakes, 5.4±1.3 per $km^2$ dropping to 2.8±1.3 and 0.76±0.27 per km dropping to 0.43±0.22, both with $P<0.05$. A similar but insignificant trend was found in the control lakes the second count pairs being 3.3±1.8 v. 1.4±0.7 per $km^2$ and 0.29±1.5 v. 0.14±0.07 per km.

From the present results it seems doubtful that liming itself affected duck densities; when densities before and after liming were significantly different, similar significant trends were found in the control lakes (Table 2).

Omission of Lake Stora Öresjon data did not change any of the relationships noted above.

*Changes in bird densities versus changes in fish densities*

The present data also allows an evaluation of simultaneous changes in the densities of birds and fish over a period of two years, disregarding whether the lakes were limed or not. In a series of 2 x 2 contingency tables (Table 3, 4) the 14 lakes included in the study are grouped with reference to increases or decreases of the properties investigated.

*Piscivorous birds*

For Black-throated Diver, changes in density could not be related to changes in density of detectability of fish (Table 3). A

**Table 3. Changes between 1983 and 1985 in densities of Black-throated Diver and Goosander in relation to changes in density and detectability of fish.** Not significant using Fisher test, one-tailed.

| | Number of fish <25 cm per catch effort: | | Fish detectability index: | |
|---|---|---|---|---|
| | No. of lakes with increase | No. of lakes with no change or decrease | No. of lakes with increase | No. of lakes with no change or decrease |
| BLACK-THROATED DIVER | | | | |
| Increase | 7 | 3 | 5 | 5 |
| No change or decrease | 2 | 2 | 3 | 1 |
| GOOSANDER | | | | |
| Increase | 3 | 1 | 2 | 2 |
| No change or decrease | 7 | 3 | 6 | 4 |

**Table 4. Changes between 1983 and 1985 in densities of Mallard, Teal and Goldeneye in relation to changes in density of fish.** P values refer to Fisher test, one-tailed.
N.S.=not significant.

| | No. of fish (total catch) per catch effort: No. of lakes with increase | No. of lakes with no change or decrease |
|---|---|---|
| MALLARD | | |
| No change or increase | 1 | 3 |
| Decrease | 8 | 2 |
| | $P<0.10$ | |
| Second count only | | |
| No change or increase | 0 | 5 |
| Decrease | 9 | 0 |
| | $P=0.001$ | |
| TEAL | | |
| No change[2] | 4 | 4 |
| Decrease | 5 | 1 |
| | N.S. | |
| Second count only | | |
| No change[2] | 5 | 5 |
| Decrease | 4 | 0 |
| | N.S. | |
| GOLDENEYE | | |
| No change or increase | 7 | 2 |
| Decrease | 2 | 3 |
| | N.S. | |
| Second count only | | |
| No change or increase | 1 | 3 |
| Decrease | 8 | 2 |
| | $P<0.10$ | |

[2]No lakes with increase between 1983 and 1985.

possible explanation for this relates to the general increase in density recorded between 1983 and 1985 (see above) in combination with the strong territoriality of the species (Sjölander 1968, 1978; Dunker 1975); new birds might have been expelled from attractive lakes by previous occupants.

*Non-piscivorous ducks*

From earlier research on interactions between ducks and fish it can be hypothesized, that the ducks should react negatively to increases in fish density, as fish might reduce the availability of common food organisms (see Introduction). In the present study, changes in densities of ducks could be related to changes in fish density in the predicted way (Table 4); the differences in Mallard density recorded from comparisons of the second counts in each year were highly correlated to changes in fish density. Similar but insignificant trends were recorded for Teal and Goldeneye. From a comparison of densities of ducks and fish in 58 lakes in southwestern Sweden, Eriksson (1983) concluded that factors other than fish density are important for the local distribution of Mallard and Teal (but not for Goldeneye). The density of Mallard were higher in lakes with a long shorelength in relation to lake area, and for Teal the occurrence of emergent vegetation was important (Eriksson 1983, Table 1). But if other factors important for the local distribution remain constant, it appears from the present results that Mallard respond significantly to changes in density of fish (Table 4).

*General aspects on effects of liming on waterbirds*

The five bird species included in the present study are widespread in the kinds of oligotrophic lakes which are the main target for lime treatment in Sweden. In the present study no changes in bird densities could be related to liming itself (Table 2), although this conclusion is based on scanty information about bird densities. But densities of nonpiscivorous ducks decreased after changes in the densities of fish (Table 4), which support earlier results indicating the possibility of competition between ducks and fish for common food items (see Introduction). It is also important to realise, that the possibility of detecting fish for fish-eating birds which search for food while swimming with their eyes below the water surface is not necessarily improved after a lime treatment (Table 1), as a reduced water transparency may counteract the benefits of an increase in fish density (Eriksson 1985).

The present study has only dealt with changes in densities of fledged birds, but more interesting is perhaps to evaluate effects on the breeding success. The only information hitherto available on this topic comes from a study of Black-throated Diver in southwestern Sweden; no significant changes in the mean number of young per pair per year were detected in 13 lakes after liming (Eriksson 1987).

A different aspect concerns the risk of an increased exposure to metals to birds feeding on organisms from acid lakes (e.g. Eriksson 1984). Impaired reproduction has been reported among passerines breeding near the shores of acidified lakes, probably after exposure to aluminium (Nyholm and Myhrberg 1977; Nyholm 1981; but see Carriere *et al.* 1986). High contents of mercury have been detected in invertebrates and fish from acid lakes (e.g. Johansson 1980; Björklund *et al.* 1984), as well as in eggs of Black-throated Diver in southwestern Sweden (Ahlgren *et al.* 1986) although sample sizes are too small for a comparison of eggs from breeding sites at acid and non-acid lakes. Reduced contents of mercury in aquatic organisms can be expected to occur after liming (e.g., Fiskeristyrelsen and Statens Naturvårdsverk 1981; Björklund *et al.* 1984) which should be considered as a potential benefit to waterbirds.

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**Summary**

Densities of two piscivorous birds, *Gavia arctica* and *Mergus merganser*, and three non-piscivorous ducks, *Anas plathyrhynchos*, *A. crecca* and *Bucephala clangula*, were investigated in eight oligotrophic and acidified lakes in spring-early summer 1983, before liming, and again in 1985, after liming. Simultaneously, six control lakes, not limed, were investigated. Average fish density increased and water transparency decreased in the limed lakes, while these parameters remained unchanged in the control lakes. Densities of birds were not affected by liming in itself; although there were significant changes in the limed lakes, similar trends were recorded in the control lakes.

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