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Diverse ecological effects in Swedish lakes after termination of liming

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Background

Liming has for three decades been applied at large scale to mitigate the effects of acidification in Swedish surface waters. Currently 2600 lakes are main targets for lime treatment. However, since 2006 the number of limed lakes has decreased with 20%, a trend that is predicted to continue as acid deposition has decreased in the region.

Termination of liming may lead to reacidification but little is known how lime-adapted ecosystems will respond. Studies of the effects of reduced and terminated liming have therefore become a major theme within ISELAW , a Swedish national monitoring and research program. We present long-term integrated monitoring data from four lakes situated in Tyresta National Park, Sweden, including one limed, one reference and two previously limed lakes (Fig. 1). Our objective is to determine how fast and to what extent the organism communities in previously limed lakes approach the situation in the reference lake.

Conclusions

The long-term effects of terminated liming on water chemistry and plankton were studied in two lakes, and on fish and benthic fauna in one lake. All variables were monitored in parallel in a limed lake and an untreated reference lake.

The rates of alkalinity and pH decline after termination of liming differed between the two lakes, which may be attributable to size, catchment and liming history.

The response on plankton differed greatly between the two lakes. In the more rapidly reacidifying lake, plankton composition approached the state of an acidified lake. The plankton communities in the other lake were not affected by termination of liming after 15 years.

Observed changes in roach and perch populations could not clearly be coupled to reacidification.

Diversity of littoral, sublittoral and profundal invertebrates were not affected, although the decline of a multimetric acidification index for littoral fauna suggests reacidification after terminated liming.

We show that two lakes in the same system can show markedly different ecological responses after liming is terminated. Future monitoring will show whether differences persist or if responses eventually will converge. However, current results indicate that termination of liming requires careful planning and continued monitoring. In event of a much worse trend than anticipated, resumed liming should be considered.

Water chemistry (Fig. 2)

Acidity and alkalinity increased during the limed periods but varied much between the initially infrequent limings. After the last liming pH and Alk have decreased continuously, although more and faster in the smaller L. Trehörningen, where mean pH reached the reference lake's level after 10 years. Lake Långsjön had not reached the reference levels after 15 years. Both lakes have experienced acidic episodes with depleted alkalinity during the last decade.

Zooplankton (Fig. 2)

Zooplankton species richness decreased rapidly with reacidification in L. Trehörningen and leveled off at below the species richness in the reference lake. In contrast the number of species has increased after termination of liming in Lake Långsjön. Zooplankton increased also in the still limed Lake Stensjön.

Most cladoceran plankton are known to be sensitive to low-alkaline conditions. The contribution of cladocerans to the species richness decreased after liming in L. Trehörningen but were unaffected by the decreasing pH and alkalinity in L. Långsjön.

Phytoplankton (Fig. 2)

Species richness of phytoplankton increased during the first years after termination of liming in both lakes. Thereafter phytoplankton richness in L. Långsjön remained at levels comparable to the limed L. Stensjön for an extended period, whereas the richness dropped in L. Trehörningen. During the last five years there is signs of declining species richness in both lakes, maybe as a result of more frequent acidic episodes.

The phytoplankton community composition with respect to acidification is in Fig. 2 exemplified by ratio of the combined dinoflagellate and cryptophyte biomasses to total biomass. These two groups typically dominate acidified lakes and in L. Trehörningen the species composition appears to have reverted to the state before first liming as especially dinoflagellates increased after termination of liming. In contrast, the trend In L. Långsjön is comparable to the still limed lake. Total phytoplankton biomasses show small differences between the lakes and no clear trends during the entire studied period (no figure).

Fig. 2. Monthly Samples of Water Chemistry and Plankton

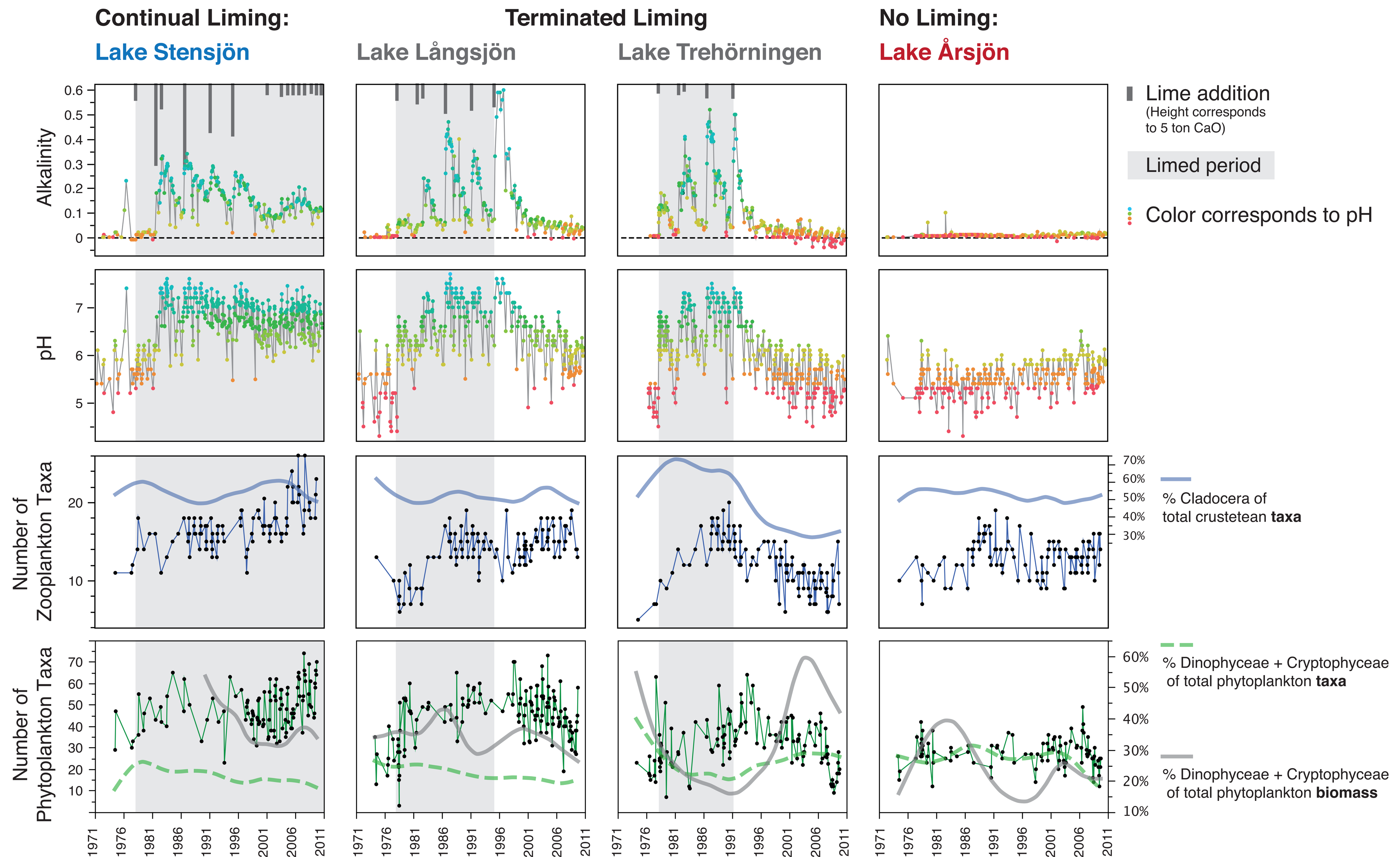
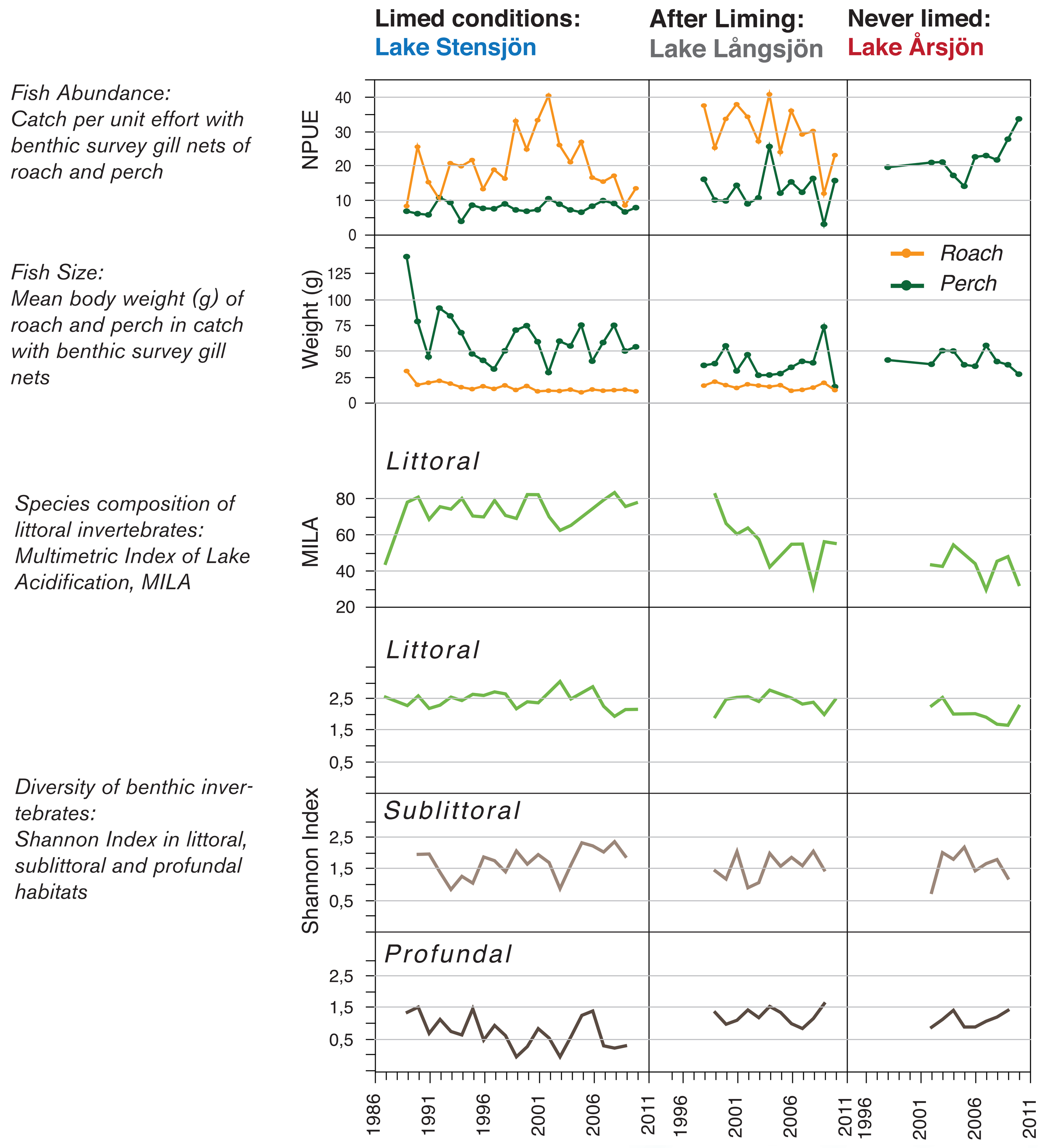


Fig. 2. The top two panels illustrate the development of alkalinity and pH during the years 1971-2010. The top panel also indicates timing and amount of limestone addition (grey bars).

The lower panels show zooplankton and phytoplankton species richness during the same period. Each point represents a sample. The splines illustrate long-term variation in richness or biomass contribution of reacidification-indicative plankton groups (see legend)

Fig. 3. Annual samples of Fish and Benthic Invertebrates



Fish (Fig. 3)

Fish abundance data is typically highly variable between years and trends must be assessed critically. But, the number of roach *Rutilus rutilus*, the most acid sensitive species in these lakes, appears to have decreased in L. Långsjön during the latest period as water has become increasingly acidic.

However, roach has decreased also in the limed lake making it difficult assess the cause. Changes in the mean body weight can indicate changes in recruitment but the data reveal no sign of depletion of small roach. Thus, there are not (yet) any evidence for reacidification effects on the roach population in L. Långsjön.

Perch *Perca fluviatilis* abundance shows no trend in the limed or previously limed lakes but increases in the reference lake after 2008. L. Trehörningen lacks fish since many years before termination of liming.

Benthic Invertebrates (Fig. 3)

The MILA index in L. Långsjön drops sharply after 1999 and is approaching the index of the reference lake, while the index is stable in the limed lake. The littoral invertebrate community, in contrast to fish and plankton, thus indicates reacidification of Lake Långsjön.

In contrast, there is no clear effect of terminated liming on invertebrate diversity in none of the three studied habitats. However, in the limed L. Stensjön where we have the longest time series the profundal fauna shows a declining diversity.

Sampling

Monitoring of water chemistry and plankton started in the 1970's. Water chemistry was sampled from ice in February and then monthly Apr-Oct.

Phyto- and zooplankton were typically sampled 7 and 4 times annually, respectively, during the productive ice-free season, although during some periods plankton sampling was less intensive.

Annual sampling of fish (summer) and benthic invertebrates (fall) started in the late 1980's in Lake Stensjön and even later in the other lakes. Lake Trehörningen lacks fish and long time-series of benthic invertebrates.

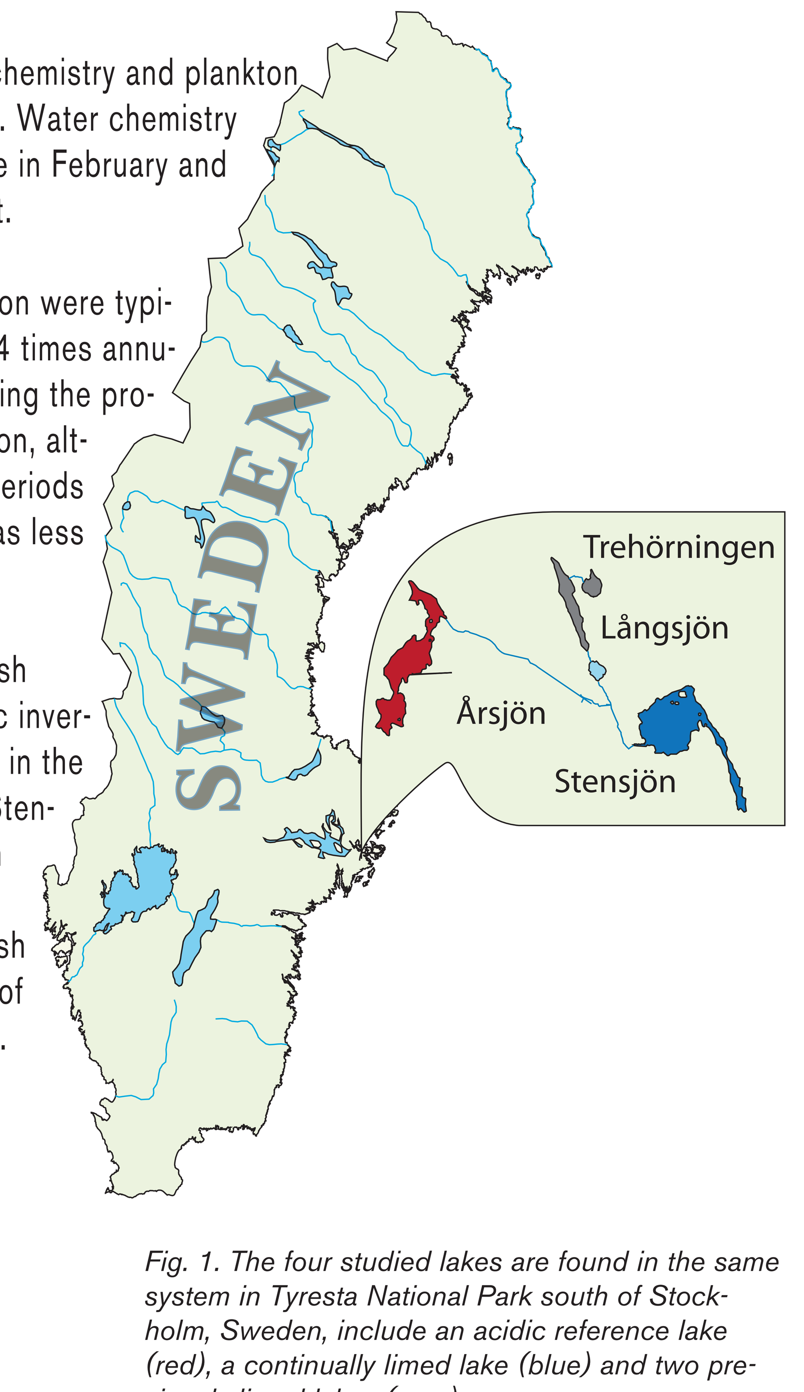


Fig. 1. The four studied lakes are found in the same system in Tyresta National Park south of Stockholm, Sweden, include an acidic reference lake (red), a continually limed lake (blue) and two previously limed lakes (grey).

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