Ecological response of 80 lake restorations in Denmark

Martin Søndergaard, Lone Liboriussen and Erik Jeppesen
National Environmental Research Institute, Aarhus University, Silkeborg, Denmark

During the past 20 years about 80 Danish lakes have been restored by various measures to combat eutrophication. Restoration methods include sediment dredging (1 large lake and many small), aluminium treatment (6 lakes), hypolimnetic oxygenation (6 lakes), pike (*Esox lucius*) stocking (50 lakes) and removal of plankti- and benthivorous fish (mainly roach, *Rutilus rutilus*, and bream, *Abramis brama*) (36 lakes).

The results obtained have been very diverse depending on the method used, the restoration intensity and pre-conditions of the lake (external nutrient loading, etc.). The best results were obtained by aluminium treatment and fish removal, whereas the other methods showed less clear effects. Aluminium addition had very marked and immediate effects on lake water quality, but long term effects (> 5 years) are still not well described. In lakes where less than 200 kg fish ha^{-1} were removed within a 3-year period only minor effects were observed, but at higher removal rates both chemical and biological variables were markedly affected. Here the concentrations of chlorophyll, total phosphorus, total nitrogen and suspended solids decreased to 50-70% of the level prior to removal.

The most significant and long-lasting effects were found for suspended solids and Secchi depth, while the most modest effects were seen for chlorophyll *a*. This probably reflects an efficient and persistent reduction of the bream stock which reduced resuspension and suspended solids, while the biomass of roach quickly returned to former levels, decreasing the zooplankton grazing with less control on chlorophyll *a*. Total algal biomass also declined after fish removal, particularly that of cyanobacteria, whereas the biomass of cryptophytes increased, indicating enhanced grazing pressure by zooplankton. The abundance and species number of submerged macrophytes increased in the majority of the lakes. For most variables the effects of the fish removal were significant for 6-10 years, after which many lakes tended to return to pre-restoration conditions, probably mainly because of consistently high external and internal phosphorus loading. This indicates that although fish removal is an efficient tool to create clear water with cascading effects on most trophic levels, repeated fish removal is presumably required to obtain long-term effects in the most nutrient rich lakes.