36th SIL Congress, Berlin, Germany, 7-10 August 2022

Chemical precipitation of phosphorus with polyaluminium chloride: water quality development 6 and 20 years after treatment in two eutrophicated lakes

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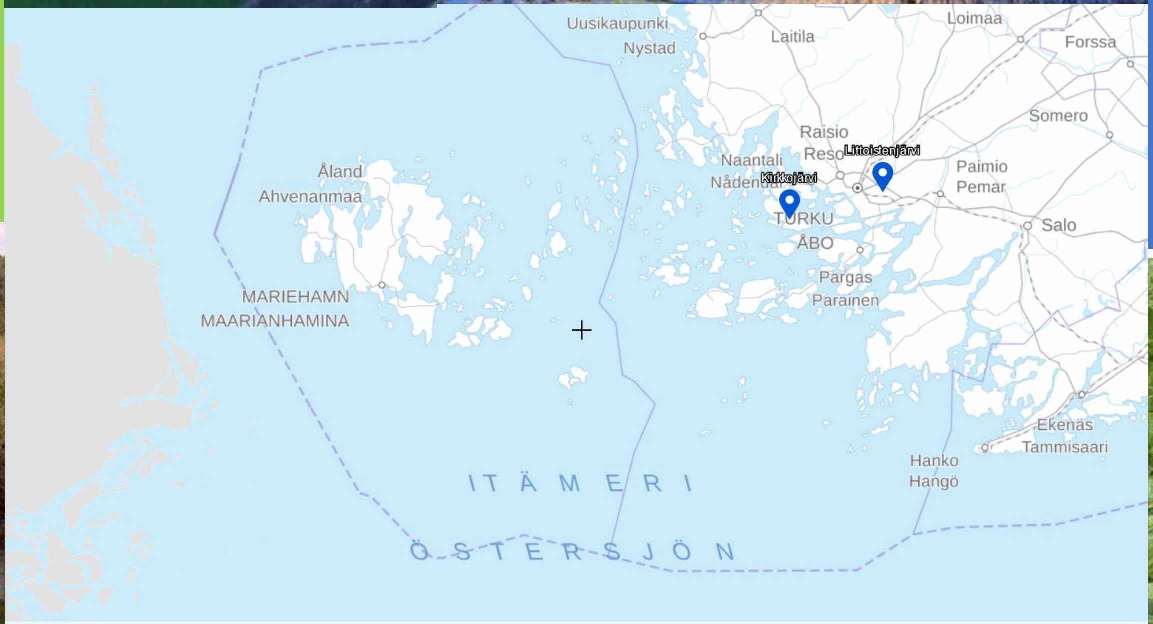
To improve the ecological status of two eutrophicated shallow Finnish lakes, Kirkkojärvi and Littoistenjärvi, phosphorus in water and surface sediment was precipitated with polyaluminium chloride, in Kirkkojärvi in June 2002, in Littoistenjärvi in May 2017. Here we examine the results of the chemical restoration during the six and twenty years elapsed from the treatment.

Data on the major nutrients and chlorophyll *a* have been recorded from these lakes since the 1960s (Littoistenjärvi) or 1970s (Kirkkojärvi). In Littoistenjärvi an intensive ecosystem monitoring program was started in 1992 and it is still running. Kirkkojärvi was subject to ecosystem monitoring in 1996 – 2006, and routine monitoring continues. For methods and parameters involved, see Sarvala et al. (2020).

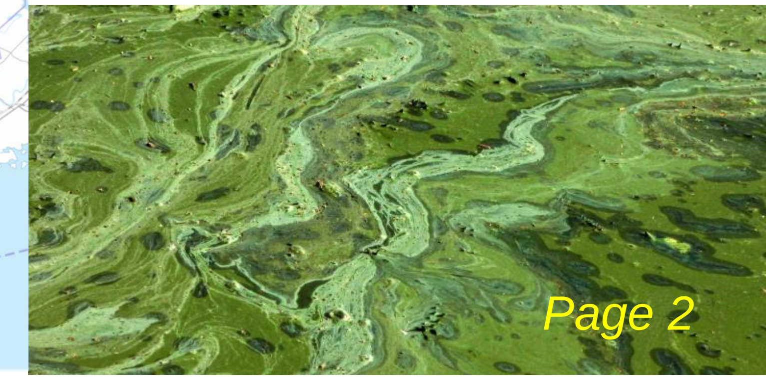
Kirkkojärvi
60.37°N, 21.93°E

Area	44 ha
Mean depth	2.9 m
Maximum depth	4.8 m
Drainage area	314 ha



Littoistenjärvi
60.45°N, 22.39°E

Area	150 ha
Mean depth	2.2 m
Maximum depth	3.0 m
Drainage area	389 ha



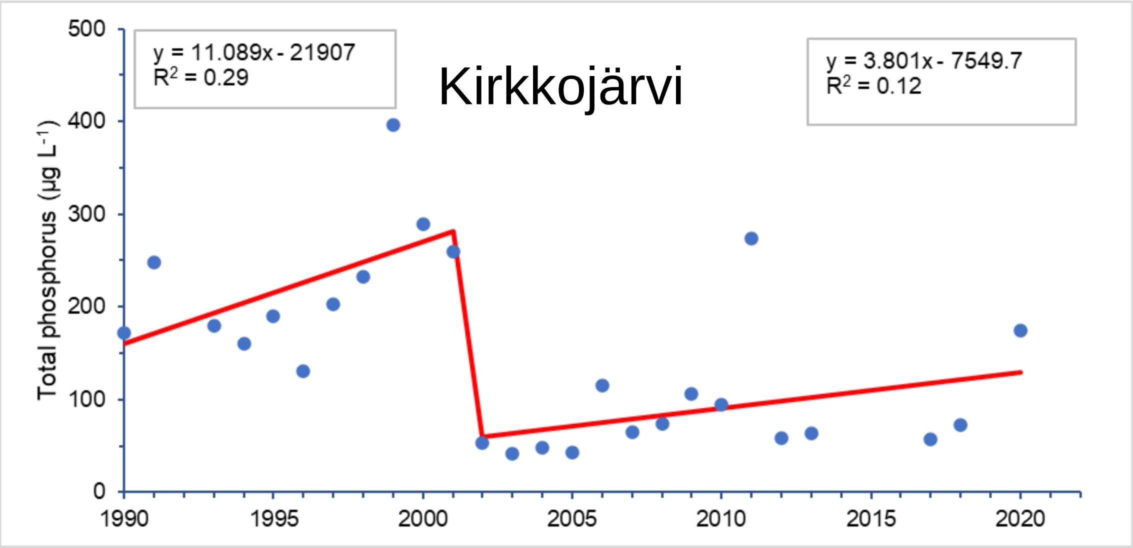
In Kirkkojärvi, eutrophication was initially due to historical sewage loading as well as to diffuse load from agriculture, but with time internal loading became the dominant source of nutrients. In Littoistenjärvi, the external load was only moderate, but mass occurrences of the invasive submerged plant *Elodea* caused anoxia in winter and high pH in summer, resulting in release of phosphorus into water. Decline of *Elodea* in the 2000s led to strongly increased internal loading.

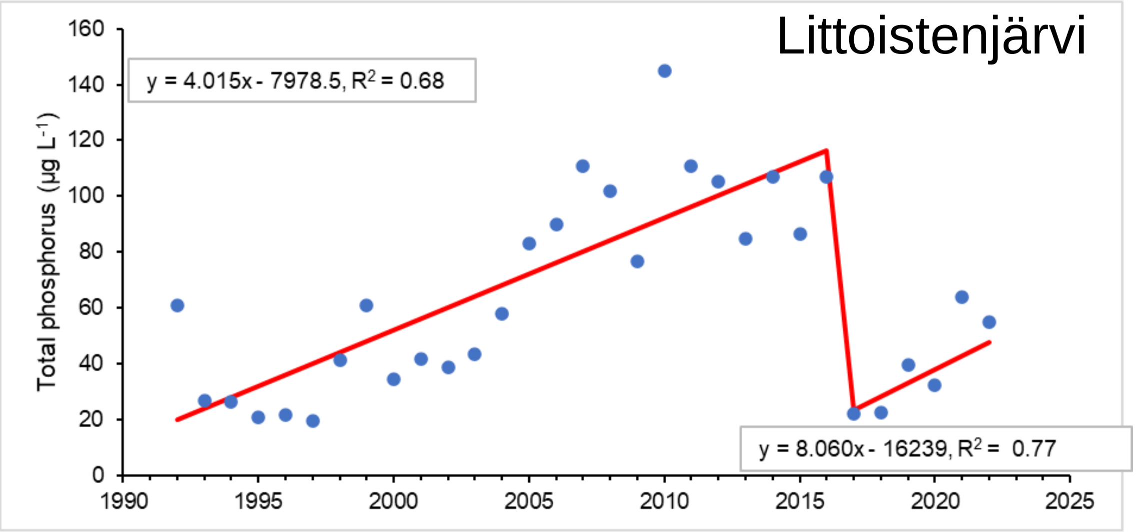
During the 1990s and 2000s, water quality in both lakes deteriorated so badly as to finally prevent any human uses. All feasible restoration methods, including aeration and the reduction of external loads and fish populations, were applied. These interventions were not sufficient, however, and as the last opportunity, chemical restoration was attempted.

One week before the application

Same place 26 h after the start of Al application

Polyaluminium chloride was chosen as the restoration chemical. The efficiency of the application depended on the dosage. In Kirkkojärvi the first dose (4 June 2002: 75 mg L^{-1}) was too cautious, and the application had to be repeated to achieve clear water; then (17 June 2002) the dose was 83 mg L^{-1}. In Littoistenjärvi the dose was 44 mg L^{-1}, and water became clear in hours.



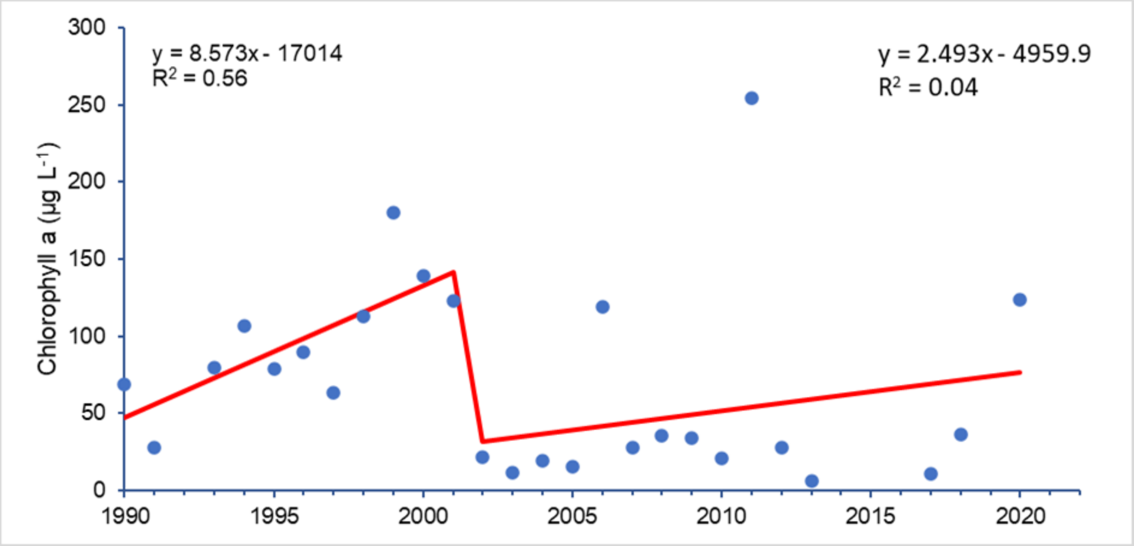


Before the treatment, total phosphorus (TP) and chlorophyll *a* (Chl) levels (here June – September averages) were gradually increasing in both lakes, indicating ongoing eutrophication (in Kirkkojärvi in 1990 – 2001 TP 160→282, Chl 47→141 µg L^{-1}; in Littoistenjärvi 1992 – 2016 TP 20→145, Chl 4→103 µg L^{-1}).

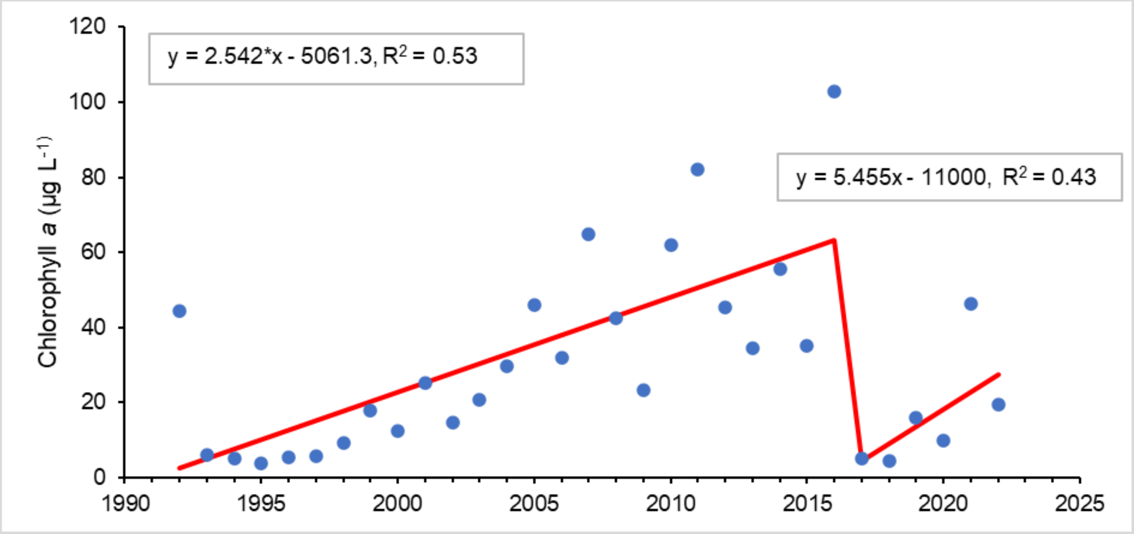
To save the fish, the dosage in Littoistenjärvi was tuned so that the pH would not go below pH 6. Yet the chemical treatment resulted in an abrupt decline of the TP and Chl levels from 87-107 and 35-103 µg L-1 in 2014 – 2016 to 22-40 and 5-16 µg L-1 in 2017 – 2019 (72 and 87%), respectively. Total nitrogen (TN) decreased with 67%.

In Kirkkojärvi, after the second application, TP declined with 79% and Chl with 78% from 250-400 and 125-180 µg L^{-1} in 2000-2001 to 60 and 40 µg L^{-1} in 2003-2005, respectively. TN declined by 70%.

Kirkkojärvi



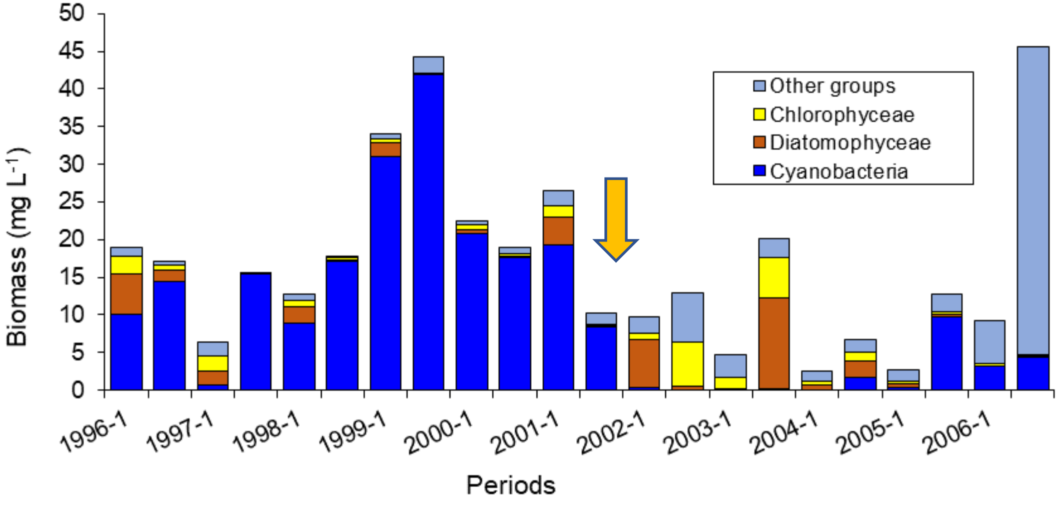
Littoistenjärvi



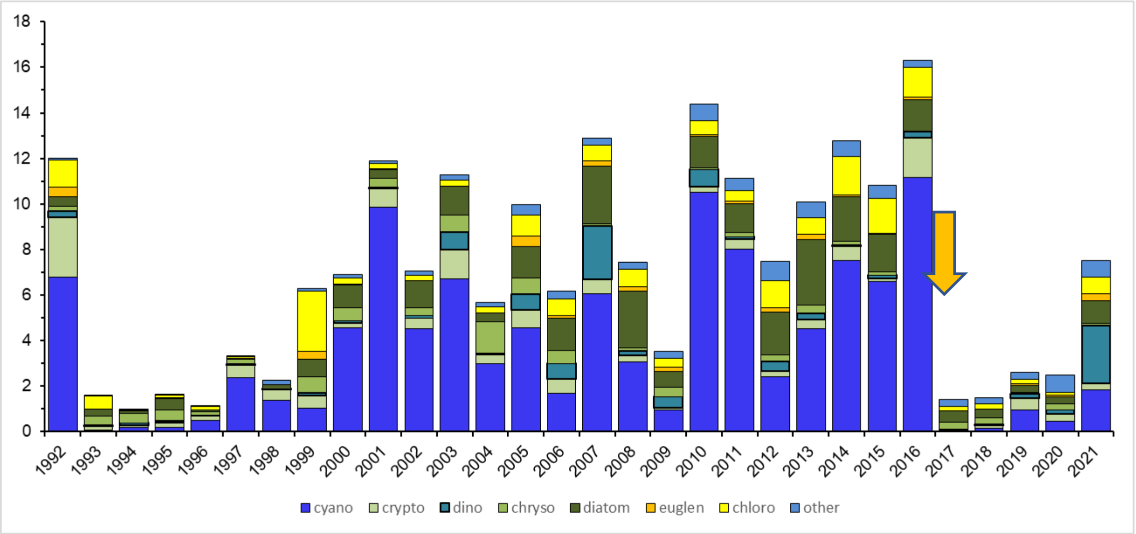
In Littoistenjärvi, hot weather spells in June and July 2019 and 2020 (maximum water temperatures of 21.3 and 23.7ºC) induced short-term increases of TP and Chl, and in the particularly hot summer 2021 (June – July mean temperature 22.6ºC) high levels prevailed until September.

After the treatment, TP and Chl apparently started to increase again with approximately similar slope as before treatment. This pattern was consistent in both lakes. From 2011 – 2016 to 2017 – 2020 the internal loading of phosphorus in Littoistenjärvi declined from 131 to 12 mg m^{-2} a^{-1} but increased to 99 mg m^{-2} a^{-1} in 2021. In Kirkkojärvi, the much higher internal TP loading decreased from 1101 mg m^{-2} a^{-1} in 1996 – 2001 to 218 mg m^{-2} a^{-1} in 2002 – 2009, a drop of 80%.

Kirkkojärvi phytoplankton



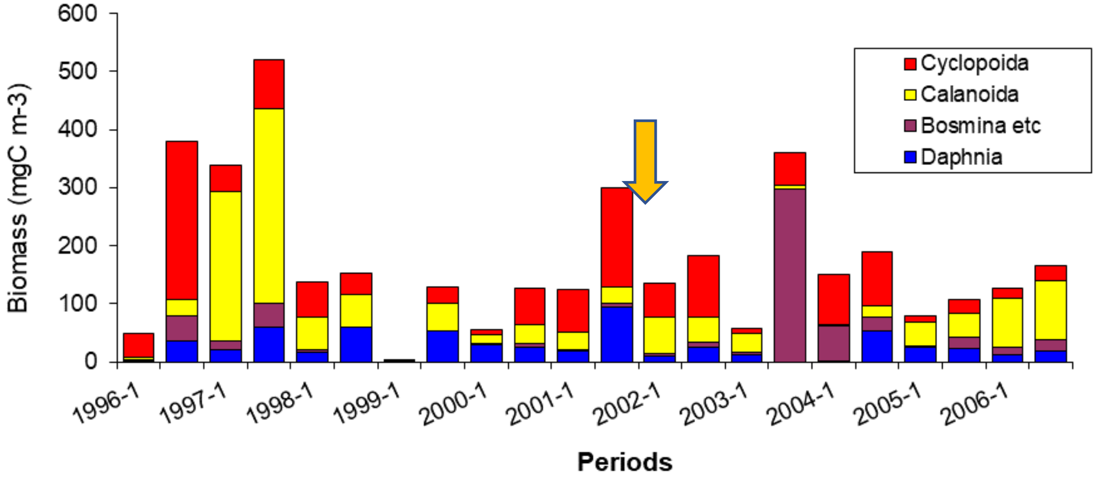
Littoistenjärvi phytoplankton



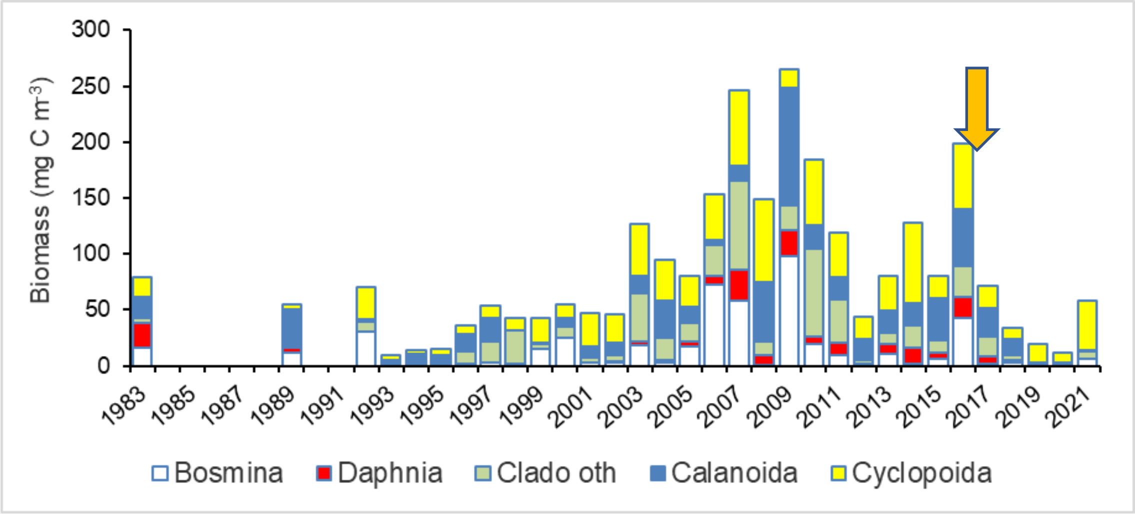
All phytoplankton disappeared during the chemical treatment (orange arrow), but recovered in about four weeks. During the first four years after the treatment, consistent with the reduced TP and CHL levels, the average summer biomass of phytoplankton remained low with few cyanobacteria. Occasional short-lived and relatively low cyanobacterial peaks developed later during hot weather spells. In both lakes, the highest post-treatment phytoplankton biomass consisted mainly of Dinophyceae. Overall, the post-treatment phytoplankton composition seemed unstable with dominant species varying from year to year.

In Littoistenjärvi, mass occurrences of the invasive submerged plant *Elodea* were expected, but in spite of clear water the submerged macrophytes showed only moderate growth.

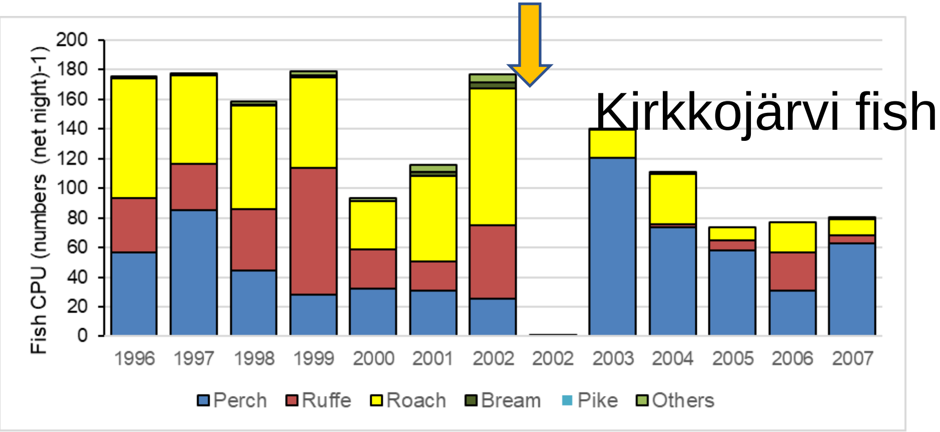
Kirkkojärvi zooplankton

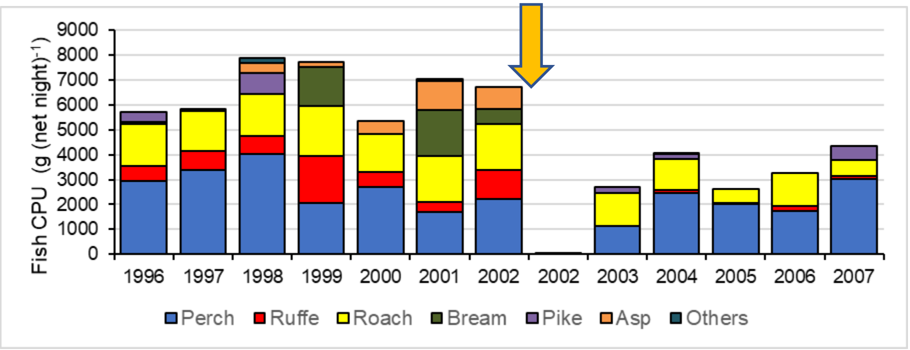


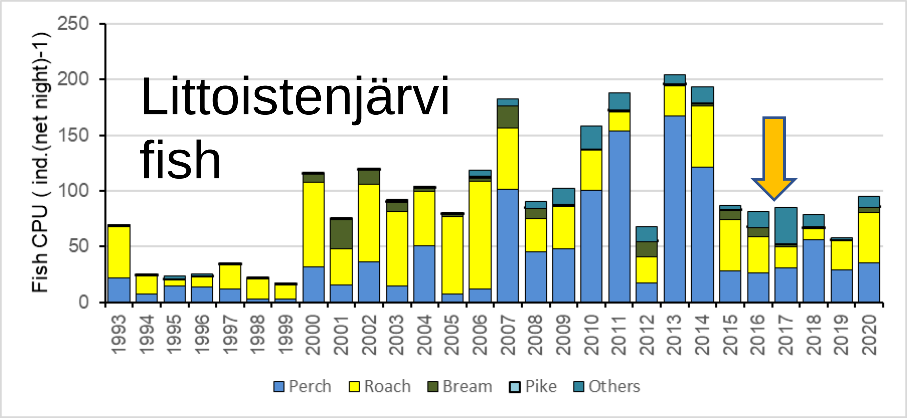
Littoistenjärvi zooplankton

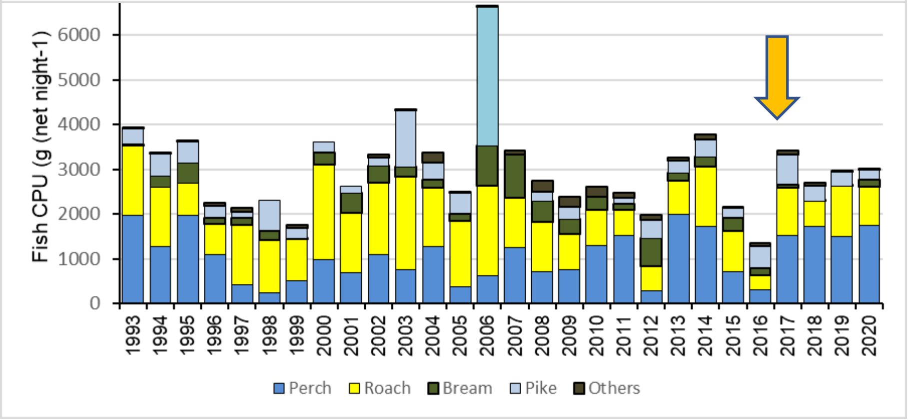


Crustacean zooplankton also disappeared during the chemical treatment (orange arrow), but recovered in about two months. In Kirkkojärvi, zooplankton biomass and composition were variable even before the treatment, and were little affected. Zooplankton abundance in Littoistenjärvi increased through the 1990s with the eutrophication to peak values in the 2000s and 2010s, followed by a steep decline during the treatment. Then the zooplankton biomass was lower than expected from the abundance of phytoplankton food. The small effect of the chemical treatment on the zooplankton in both lakes was explained by the fact that planktivorous fish were very abundant both before and after the treatment, keeping zooplankton biomass low and the individuals small. Therefore, for most of the time, crustacean zooplankton did not have the capacity to control phytoplankton abundance which was almost solely dependent of nutrient availability.









Experimental fishing with the standard Nordic gillnets revealed very high abundances of both planktivorous and benthivorous fish in both lakes. In Kirkkojärvi, the chemical dose was intentionally set so high that all fish died: 15 tons of dead fish were collected from the shores. Surprisingly, the fish assemblage recovered already next summer (probably because of migration from the Baltic Sea), after which the fish biomass remained at about 50% of the previous level. In Littoistenjärvi, the chemical dose was tuned so as to save the fish. Due to windy weather, however, mixing was uneven, and temporarily lower pH occurred downwind, and ca. 5 tons of big bream died. Otherwise the fish were little affected.

Conclusions

In both lakes, the chemical restoration could be considered successful, because of the drastic 70-90% decline of TP and Chl, accompanied with the disappearance of the rampant blooms of cyanobacteria. Chemical precipitation of phosphorus seems thus suitable for treating waterbodies with heavy internal loading of phosphorus. Although not directly affected by the chemical treatment, nitrogen declined almost as much as phosphorus, showing that the nitrogen level was determined by the nitrogen fixation of cyanobacteria, in turn regulated by the phosphorus level.

Because of the hypertrophic starting conditions, even the successfully restored lakes fulfilled only for a short time the requirements of a good ecological status according to the Water Framework Directive of the EU. The eutrophication process preceding the restoration apparently continued after the treatment, but starting from a distinctly lower nutrient level. Interestingly, the regressions after the treatment allow to predict when the TP or Chl will reach the 50% of the starting condition (often regarded as the success criterium); this might be the time to prepare for a new treatment to achieve more permanent good status.

The effects of the chemical treatment were clearest in the TP and Chl, although the latter already showed more variation. And when moving upwards on the trophic ladder, this variability increased so that at the crustacean zooplankton and fish levels, the immediate effects of the TP reduction were almost invisible. Trophic interactions have an important role in determining water quality, and biomanipulation through removal fishing might be recommendable to follow the chemical precipitation of phosphorus unless the fish are eliminated using a high dose of aluminium chloride.

Acknowledgements

Thanks are due to the numerous people involved in the monitoring and management of the study lakes. The actual restoration projects became possible thanks to the dedication of Eeva Ståhle (Kirkkojärvi) and Jukka Heikkilä (Littoistenjärvi). Funding was provided by the local municipalities, the Ministry of Environment and the Academy of Finland.

More info:

Sarvala, J., Helminen, H. & Heikkilä, J. 2020. Invasive submerged macrophytes complicate management of a shallow boreal lake: a 42-year history of monitoring and restoration attempts in Littoistenjärvi, SW Finland. Hydrobiologia 847(21): 4575-4599. https://doi.org/10.1007/s10750-020-04318-7 (Open access)