ENVIRONMENTAL EVIDENCE

SYSTEMATIC REVIEW PROTOCOL   Open Access

What is the influence on water quality in temperate eutrophic lakes of a reduction of planktivorous and benthivorous fish? A systematic review protocol

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Abstract

Background: In lakes that have become eutrophic due to sewage discharges or nutrient runoff from land, problems such as algal blooms and oxygen deficiency often persist even when nutrient supplies have been reduced. One reason is that phosphorus stored in the sediments can exchange with the water. There are indications that the high abundance of phytoplankton, turbid water and lack of submerged vegetation seen in many eutrophic lakes may represent a semi-stable state. For that reason, a shift back to more natural clear-water conditions could be difficult to achieve.

In some cases, though, temporary mitigation of eutrophication-related problems has been accomplished through biomanipulation: stocks of zooplanktivorous fish have been reduced by intensive fishing, leading to increased populations of phytoplankton-feeding zooplankton. Moreover, reduction of benthivorous fish may result in lower phosphorus fluxes from the sediments. An alternative to reducing the dominance of planktivores and benthivores by fishing is to stock lakes with piscivorous fish. These two approaches have often been used in combination. The implementation of the EU Water Framework Directive has recently led to more stringent demands for measures against eutrophication, and a systematic review could clarify whether biomanipulation is efficient as a measure of that kind.

Methods: The review will examine primary field studies of how large-scale biomanipulation has affected water quality and community structure in eutrophic lakes or reservoirs in temperate regions. Such studies can be based on comparison between conditions before and after manipulation, on comparison between treated and non-treated water bodies, or both. Relevant outcomes include Secchi depth, concentrations of oxygen, nutrients, suspended solids and chlorophyll, abundance and composition of phytoplankton, zooplankton and fish, and coverage of submerged macrophytes.

Keywords: Biomanipulation, Planktivore, Benthivore, Piscivore stocking, Fish removal, Lake restoration, Eutrophication, Water quality, Phytoplankton

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Background

Over the past century, many lakes in urban or agricultural regions of the world became eutrophic due to sewage discharges or nutrient runoff from land. The excess of nutrients, especially phosphorus, stimulated the growth of phytoplankton, often to such an extent that the water became turbid [1]. The reduced light penetration and increased sedimentation of dead planktonic algae put submerged macrophytes at a disadvantage, in some cases even eliminating them, often with strong impacts on ecosystem interactions and dynamics [2]. Certain species of phytoplankton – cyanobacteria in particular – could give rise to massive 'algal blooms' in the summer. The decomposition of dead plankton could lead to oxygen depletion and fish kills [3].

Problems of these kinds have often persisted even when nutrient supplies from the surroundings have been reduced, e.g. through sewage treatment. One important reason is that phosphorus stored in the sediments of eutrophic lakes can exchange with the water and thereby keep it nutrient-rich for decades [4]. There are indications that eutrophication has caused many lakes to shift from one state to another, the former characterised by moderate abundance of phytoplankton, transparent water and vegetated bottoms, the latter by high abundance of phytoplankton, turbid water and little or no submerged vegetation. Once a lake has reached the latter stage, it may tend to remain there even if nutrient concentrations in the water decrease. As implied below, this lack of ecological response to reduced nutrient supplies could at least partly be a consequence of the feeding habits of common fish species [5].

In some cases where eutrophic lakes have failed to recover after a reduction of nutrient supplies, attempts have been made to remedy the problems through intervention in the lakes themselves. Several of the methods tried, including dredging, are very expensive but by no means always successful [6,7].

At least in the short term, however, notable improvements in water quality have been achieved through biomanipulation, usually in the form of decimating the planktivorous fish which typically dominate the fish fauna of eutrophic lakes [8,9]. (Here and in the following, 'planktivorous' is to be understood as 'zooplankton-feeding'.) In northern Europe and several other parts of the world, cyprinids such as roach (*Rutilus rutilus*) and bream (*Abramis brama*) are among the most common planktivores in nutrient-rich lakes. Reducing the stocks of cyprinids enhances survival of the zooplankton that such fish feed on, and this in turn can reduce the abundance of planktonic algae that serve as food for the zooplankton [10,11].

Another reason why removal of planktivorous fish may improve water quality is that the adults of some of these species (e.g. bream) are also benthivorous. They grub for food in the sediments, dispersing nutrient-rich silt and thereby adding to the turbidity and high phosphorus content of the water in eutrophic lakes. Their feeding behaviour may also contribute to the lack of benthic vegetation in such lakes.

Ideally, then, a reduction of the populations of planktivorous and benthivorous fish may shift a eutrophic lake back to a more natural state, increasing transparency, allowing benthic vegetation to regain lost ground and decreasing the risk of disturbances such as algal blooms and fish kills. Such changes of lake ecosystem properties – and of the plankton flora in particular – may be driven both 'bottom-up' (i.e. by nutrient availability) and 'top-down' (via the upper parts of the food web) [10]. Numerous studies have indicated that many aquatic ecosystems have the potential of being controlled both ways [12].

Removal of planktivores and benthivores for the purpose of lake restoration is usually carried out through intensive fishing, although there are also cases where all fish have been eradicated with that kind of intent, e.g. through rotenone treatment or temporary emptying of ponds or reservoirs [13,14].

An alternative to removing planktivorous and benthivorous fish through direct intervention may be to reduce their dominance by stocking lakes with predatory fish (piscivores) such as pike (*Esox lucius*) [15]. These two approaches have frequently been used in combination – following removal of planktivores and benthivores, piscivores have been stocked in order to prevent zooplankton-feeding fish from regaining their former dominance.

In recent decades, a fairly large number of attempts have been made to restore eutrophic lakes through planktivore decimation or other forms of biomanipulation. For instance, Olin *et al.* [16] describe the effects of cyprinid reduction in ten lakes in Finland, and Liboriussen *et al.* [17] have compiled data from 40 similar cases in Denmark.

Interventions of these kinds have also been the subject of several reviews over the years, e.g. by Søndergaard *et al.* [6,12], Gulati *et al.* [7], Meijer *et al.* [10], Jeppesen *et al.* [11], Hansson *et al.* [18], Drenner & Hambright [19] and Hansson [20].

No strictly systematic review of available knowledge in the field seems to have been carried out, though, and there is evidence of publication bias – seemingly, negative results have not been reported to the same extent as positive experiences [7]. Therefore, it would be useful to examine the results of lake biomanipulation using a systematic approach. This method is designed to avoid publication bias and permit quantitative conclusions by means of meta-analysis.

Objectives of the review

The implementation of the EU Water Framework Directive has recently led to more stringent demands for measures against eutrophication. Sweden is one of the countries that have to meet these requirements, and Swedish authorities have identified biomanipulation as a potential tool for such efforts. For instance, Swedish river basin district authorities have mentioned depletion of fish stocks as one of several possible methods of improving the ecological status of coastal eutrophic lakes [21,22].

Until a few years ago, only a handful of Swedish lakes had been subject to biomanipulation. These included Lakes Ringsjön and Finjasjön in the southernmost part of the country, where cyprinid removal began in the early 1990s [23,24]. Interest in this kind of treatment is increasing, however, and fish removal has recently been initiated in Lakes Ryssbysjön, Lilla Nätaren, Skundern and Vallentunasjön in southern or south-central Sweden.

The Swedish Agency for Marine and Water Management is a key actor when it comes to measures against eutrophication in Sweden, and representatives of this agency have declared themselves to be highly in favour of a systematic review of the effects of biomanipulation in eutrophic lakes. The agency is also likely to be the primary Swedish recipient of the outcomes of this review.

Since the review is based on Swedish initiatives and funding, it will focus on eutrophic lakes of the kinds found in urban or agricultural areas in Sweden. Lakes with similar ecosystems and symptoms of eutrophication occur in many other temperate parts of the world, though. This means that any study of lake restoration through reduction of fish populations that has been carried out in these regions may be useful as input to the review. It also means that the results of the review have the potential of being relevant not only for Sweden but for many other temperate regions as well.

The review will mainly examine full-scale applications of biomanipulation. While small-scale experimental studies of such interventions can be valuable for clarifying the mechanisms involved, studies of whole-lake treatment are more relevant when assessing the method as a tool for environmental management.

Prior to completion of the draft review protocol, a meeting was arranged with Swedish stakeholders with an interest in biomanipulation and other actions against eutrophication. The meeting was attended by representatives of the Swedish Ministry of the Environment, the Swedish Ministry for Rural Affairs, the Swedish Agency for Marine and Water Management, the Swedish Board of Agriculture, Sportfiskarna (the Swedish association for recreational fishing), the environmental foundation Baltic2020 and several municipalities and consultants currently involved in biomanipulation projects. Written comments had also been received from the Swedish Society for Nature Conservation and the Rural Economy and Agricultural Society of Kalmar-Kronoberg-Blekinge.

The stakeholders discussed a number of factors that could affect the results of a biomanipulation project, including past and present activities in the surroundings of treated lakes and other mitigation efforts (such as dredging) carried out before or in parallel with fish removal. Several of these factors had already been considered by the authors of this protocol; others have been added to the list of potential effect modifiers below. In response to a stakeholder suggestion, moreover, change of oxygen concentrations in lake water (below the thermocline) has been added as an outcome of biomanipulation to be covered by the review.

Another issue brought up by stakeholders was the importance of evaluating different techniques for fish removal, including negative environmental consequences such as disturbances of benthic biota and by-catches of red-listed species. Although the review will focus on water-quality effects, consequences of these kinds also deserve to be discussed.

Finally, several of the stakeholders proposed that effects of fish removal should be studied not only in lakes but also in semi-enclosed, low-salinity coastal waters. Such water bodies can be found along many parts of the coast of the Baltic Sea, and their fish fauna has much in common with that of lakes in the Nordic region. Many of them are eutrophic, and a few have been subject to biomanipulation. Therefore, in addition to evaluating effects of such interventions in lakes, the review will explore the possibility of making a similar assessment of biomanipulation in brackish coastal waters.

Although a number of conventional syntheses on the subject already exist, it would be of interest to conduct a systematic review of whether decimation of planktivorous and benthivorous fish helps to prevent eutrophication problems in lakes. Since the systematic approach is designed to avoid bias and permit quantitative evaluation of all available data, the review could provide an objective basis for deciding if and when biomanipulation should be used as a tool for lake management. The initiative to launch this study comes from Sweden, but the review will cover biomanipulation of eutrophic lakes in all temperate parts of the world.

Primary question

What is the influence on water quality in temperate eutrophic lakes of a reduction of planktivorous and benthivorous fish (performed directly or indirectly through stocking of piscivores)?

Components of the primary question

Subject (*population*): Temperate eutrophic lakes.
Intervention: Reduction of populations of planktivorous and benthivorous fish.
This includes removal of planktivorous and/or benthivorous fish (if possible quantified as fractions of total populations before intervention), stocking of piscivorous fish and any combination of such interventions. It may include unintentional fish-community changes (caused e.g. by fish management practices) as well as deliberate interventions intended to alter water quality.
If the review tends to become very extensive, however, it may prove necessary to restrict its scope, e.g. by excluding studies of biomanipulation solely based on piscivore stocking and/or studies of the effects of unintentional fish-community changes.
Comparator: No intervention.
Outcomes: Changes of the following water-quality parameters: Secchi depth, concentrations of oxygen, nutrients, suspended solids and chlorophyll, and abundance of phytoplankton.
If available, data on changes of the following community-structure parameters will also be recorded: Composition of phytoplankton, abundance and composition of zooplankton and fish, and coverage of submerged macrophytes.

Methods
Search terms
The review team has conducted a scoping exercise to test alternative search strings. The exercise resulted in the selection of the following search terms:

Subject: lake*, reservoir*, pond*, fresh$water
Intervention: *manipulat*, remov*, restor*, stock*, introduc*, reduc*, addition
Target: *planktivor*, *benthivor*, cyprinid*, piscivor*, "predatory fish*", *Rutilus*, *Abramis*, *Esox*, *Perca*, *Stizostedion*, *Micropterus*, *Dorosoma*, *Coregonus*, *Oncorhynchus*, *Salmo*, roach, bream, pike, muskellunge, perch, pike$perch, zander, sander, "*mouth bass", whitefish, cisco, minnow, "gizzard shad"

The terms within each of the categories 'subject', 'intervention' and 'target' will be combined using the Boolean operator 'OR'. The three categories will then be combined using the Boolean operator 'AND'. An asterisk (*) is a 'wildcard' that represents any group of characters, including no character, while a dollar sign ($) represents zero or one character.

Searches will also be made for Danish, Dutch and Swedish counterparts to the above terms. The following search strings will be used (although they in some cases will have to be simplified):

English: (lake* OR reservoir* OR pond* OR fresh$water) AND (*manipulat* OR remov* OR restor* OR stock* OR introduc* OR reduc* OR addition) AND (*planktivor* OR *benthivor* OR cyprinid* OR piscivor* OR "predatory fish*" OR *Rutilus* OR *Abramis* OR *Esox* OR *Perca* OR *Stizostedion* OR *Micropterus* OR *Dorosoma* OR *Coregonus* OR *Oncorhynchus* OR *Salmo* OR roach OR bream OR pike OR muskellunge OR perch OR pike$perch OR zander OR sander OR "*mouth bass" OR whitefish OR cisco OR minnow OR "gizzard shad")
Danish: (sø* OR dam OR mose* OR ferskvand*) AND (*manipulat* OR opfisk* OR restau* OR udsæt* OR introduk* OR reduk*) AND (*planktivor* OR *benthivor* OR cyprinid* OR piscivor* OR rovfisk* OR fredfisk* OR skidtfisk* OR *Rutilus* OR *Abramis* OR *Esox* OR *Perca* OR *Stizostedion* OR *Coregonus* OR *Oncorhynchus* OR *Salmo* OR skalle OR brasen OR gedde OR sandart OR aborre OR *ørred OR helt)
Dutch: (meer* OR plas* OR zoetwater*) AND (biomanipul* OR "actief biologisch beheer" OR afvissen OR restauratie* OR uitzetten*) AND (*planktivor* OR *benthivor* OR planktoneten* OR bodemomwoel* OR piscivor* OR visetende* OR roofvis* OR *Rutilus* OR *Abramis* OR *Esox* OR *Perca* OR *Stizostedion* OR brasem OR snoek OR ruisvoorn OR snoekbaars OR karper)
Swedish: (sjö* OR insjö* OR *magasin* OR *damm* OR sötvatten* OR färskvatten*) AND (biomanipul* OR utfisk* OR reduktionsfisk* OR reducer* OR *restaurer* OR inplanter* OR utplanter* OR utsättning*) AND (*planktivor* OR *planktonäta* OR bent$ivor* OR bottenäta* OR bottendjursäta* OR cyprinid* OR karpfisk* OR piscivor* OR rovfisk* OR *Rutilus* OR *Abramis* OR *Esox* OR *Perca* OR *Stizostedion* OR *Coregonus* OR *Oncorhynchus* OR *Salmo* OR mört OR brax* OR gädda OR abborre OR gös OR sik OR *lax OR *öring OR regnbåge)

No time, language or document type restrictions will be applied.
In addition to the main search described above, a complementary search will be made in a few of the sources mentioned below. The complementary search will focus on potential mechanisms and outcomes of biomanipulation, using the following set of search terms:

Subject: lake*, reservoir*, pond*, fresh$water
Target: fish*

Mechanisms: trophic, cascad*, foodweb, topdown, bottom$up, resuspen*, "stable state*", bistable, "regime shift*"
Outcomes: water$quality, transparency, clarity, turbid*, secchi, "suspended solids", phosph*, nitrogen, oxygen, chlorophyll, phytoplankton

Literature databases

The search aims to include the following online databases:

1) Academic Search Premier
2) Agricola
3) Aquatic Sciences and Fisheries Abstracts
4) Biological Abstracts
5) BioOne
6) COPAC
7) Directory of Open-Access Journals
8) GeoBase
9) IngentaConnect
10) ISI Web of Science
11) JSTOR
12) Libris
13) PiCarta
14) Scopus
15) SpringerLink
16) SwePub
17) Wiley Online Library

Search engines

An Internet search will also be performed using the following search engines:

Google (www.google.com)
Google Scholar (scholar.google.com)
Growyn (www.growyn.com)
Scirus (www.scirus.com)

In each case, the first 100 hits (based on relevance) will be examined for appropriate data. Google will primarily be used for searches in non-English languages.

Specialist websites

Websites of the specialist organisations listed below will be searched for links or references to relevant publications and data, including grey literature.

Broads Authority (www.broads-authority.gov.uk)
Danish Centre for Environment and Energy (dce.au.dk)
Environment Canada (www.ec.gc.ca)
European Commission Joint Research Centre (ec.europa.eu/dgs/jrc)
European Environment Agency (www.eea.europa.eu)

Finland's environmental administration (www.environment.fi)
International Union for Conservation of Nature (www.iucn.org)
IVL Swedish Environmental Research Institute (www.ivl.se)
Leibniz Institute of Freshwater Ecology and Inland Fisheries, IGB (www.igb-berlin.de)
National Institute for Public Health and the Environment (RIVM) (www.rivm.nl)
Netherlands Institute of Ecology (www.nioo.knaw.nl)
Norwegian Institute for Water Research (NIVA) (www.niva.no)
Swedish Agency for Marine and Water Management (www.havochvatten.se)
Swedish County Administrative Boards (www.lansstyrelsen.se)
Swedish Environmental Protection Agency (www.naturvardsverket.se)
Swedish River Basin District Authorities (www.vattenmyndigheterna.se)
UK Environment Agency (www.environment-agency.gov.uk)
United Nations Environment Programme (www.unep.org)
United States Environmental Protection Agency (www.epa.gov)

Other data sources

Relevant literature will also be searched for in bibliographies of literature reviews such as those mentioned in the background section.

In addition, unpublished data may be available from e.g. consultants or local authorities involved in biomanipulation projects. Stakeholders will be asked to suggest suitable contacts.

Study inclusion/exclusion criteria

Articles found by searches in databases will be evaluated for inclusion at three successive levels. First they will be assessed by title. In cases of uncertainty, the reviewer will tend towards inclusion. As a check of consistency, a subset of 100 articles will be assessed by all members of the review team.

Next, each article found to be potentially relevant on the basis of title will be judged for inclusion on the basis of abstract. The reviewer will tend towards inclusion in cases of uncertainty. A subset consisting of at least 10% of the articles will be assessed by at least two reviewers. A kappa statistic relating to the assessments will be calculated. If this statistic indicates that the reviewers are inconsistent in their assessment ($\kappa < 0.5$), discrepancies will be discussed and the inclusion criteria will be clarified or modified.

Finally, each article found to be potentially relevant on the basis of abstract will be judged for inclusion by reviewers studying the full text. Again, the reviewers will tend towards inclusion in cases of uncertainty.

Studies or datasets found by other means than database searches may be entered at any of the two latter stages of this screening process.

A list of studies rejected on the basis of full-text assessment will be provided in an appendix together with the reasons for exclusion.

Each study must pass each of the following criteria in order to be included, either by providing all the required data itself or by referring to other studies where supplementary information is presented.

Relevant subjects: Temperate lakes or reservoirs (with an area equal to or larger than 1 hectare) characterised by study authors as eutrophic (or hypertrophic) and/or having summer concentrations of total phosphorus exceeding 30 µg/l before biomanipulation.
Relevant types of intervention: Removal (mainly by fishing) of planktivorous or benthivorous fish, stocking of piscivorous fish and any combination of such interventions.
Relevant type of comparator: No intervention.
Relevant types of outcome: Change of Secchi depth, of concentrations of oxygen, nutrients, suspended solids and chlorophyll, and of phytoplankton abundance.
Relevant types of study: Any primary field study of water quality in lakes or reservoirs (or in artificially separated compartments with areas ≥ 1 ha in such water bodies) that have been subjected to large-scale biomanipulation of the kinds described above. The study should be based on before/after comparisons or site comparisons or both (see Study quality assessment below).

Potential effect modifiers and reasons for heterogeneity

To the extent that data are available, the following potential effect modifiers will be considered and recorded:

Geographical coordinates
Altitude
Lake area
Mean and maximum lake depth
Retention time
Lake connectivity (presence of tributaries and/or connections that allow fish migration into the lake)
Lake salinity and conductivity
Water colour or concentration of dissolved organic carbon (DOC)
Occurrence of stratification in the lake
Annual and monthly water temperature
Special weather conditions (e.g. droughts, heat waves, storms)

Land use in the surrounding area before, during and after biomanipulation (including attempts to reduce nutrient losses by modifying the use of fertilisers, establishing buffer zones with permanent vegetation between fields and watercourses etc.)
History of external supplies of nutrients (and other pollutants) from point sources and runoff, of internal nutrient loading and of any experimental nutrient additions to the lake. It may also be relevant to consider the removal of nutrients with fish that are caught in the lake.
History of fisheries and stocking
History of damming, lake lowering and other hydrological disturbances
Presence of introduced species
Presence of grazing or piscivorous birds
History of disturbances (algal blooms, fish kills etc.) caused by eutrophication
Earlier or contemporary attempts to mitigate eutrophication problems (using other approaches than biomanipulation) and to improve recruitment habitats for predatory fish
Dominating fish species before manipulation
Methods for fish removal
Study duration and seasonality
Intervention duration and seasonality

Further modifiers and causes of heterogeneity will be identified in an iterative process.

Study quality assessment

Most studies that may be relevant in the present context report on how the water quality of a lake (or a number of lakes) has responded to some kind of biomanipulation. Thus, they are usually 'BA' (Before/After) studies comparing data that have been collected prior to and following the intervention. Some of them present data from a single sampling occasion after the intervention, while others are based on repeated data collection over several years. Long-term studies are particularly valuable in this context, since they may clarify whether biomanipulation has lasting effects or not.

Alternatively, a study may be based on comparison between a manipulated lake and a similar lake where no such intervention has taken place (or between different parts of a single lake that has been artificially separated into two or more compartments, at least one of which has not been manipulated). These may be termed as 'CI' (Comparator/Intervention) studies, or 'BACI' (Before/After/Comparator/Intervention) if they present data collected both before and after the intervention.

The BACI study design is generally to be regarded as more reliable than the BA and CI designs. Similarly, studies that describe potential effect modifiers are more

valuable than studies that do not report on the local environment in detail.

The following factors will be assessed and used to categorise studies as having high, medium, or low susceptibility to bias:

Study design (BA/CI/BACI)
Temporal extent of study
Methodological detail
Accounting for potential effect modifiers
Use of statistics and statistical analysis

Detailed reasoning concerning these factors will be recorded in a transparent manner. In general, the quality of a study will be assessed by one reviewer. As a check of consistency, however, a subset of the studies will be appraised by all reviewers involved in the quality appraisal.

A list of studies rejected on the basis of quality assessment will be provided in an appendix together with the reasons for exclusion.

Data extraction strategy

Means and measures of variation (standard deviation, standard error, confidence intervals) will be extracted from tables and graphs, using image analysis software when necessary. If only raw data are provided, summary statistics will be calculated. Data on potential effect modifiers will also be extracted.

It may in some cases be useful to ask authors of relevant articles for access to unpublished primary data.

Data synthesis and presentation

A narrative synthesis of data from all studies included in the review will describe the quality of the results along with the findings of studies of sufficient quality. Tables will be produced to summarise these results. Where studies report similar outcomes, meta-analysis may be possible. In these cases effect sizes will be standardised (using standardised mean effect size) and weighted appropriately. Details of the quantitative analysis will only be known when full texts have been assessed for their contents and quality.

Meta-analysis of effect sizes will take the form of random-effects models, and meta-regression will be performed where effect modifiers cause significant heterogeneity between studies. Subgroup analysis of categories of studies will also be performed where sufficient studies report common sources of heterogeneity. Publication-bias and sensitivity analysis will also be carried out where possible. Overall effects of biomanipulation will be presented visually in plots of mean effect sizes and variance.

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