**Biomanipulation as a Fisheries Management Strategy in Lacustrine Ecosystems**

**Abstract**

Eutrophication resulting from high nutrient loading has been the paramount environmental problem for lakes world-wide for the past four decades. Around the world, efforts are being made to divert nutrient-rich inflows or improve wastewater treatment in order to lessen external nutrient loading. Under such circumstances, the economical biomanipulation approach may be regarded as one of the best ways to address the issue of eutrophication and restore the water quality in small, shallow estuaries. The original theory behind biomanipulation was that fewer planktivorous fish meant a higher density of giant cladoceran zooplankton, and that their summertime grazing may lower the quantity of particular planktonic algae species and lower the water's algal turbidity. More scientific studies are required to determine whether bio-manipulation of lake ecosystems can have long-term beneficial consequences. Finally, the potential of biomanipulation for enhancing lake water quality was assessed based on the existing empirical and theoretical evidence

**Keyword:** Eutrophication, Lake Ecosystem, Biomanipulation, environmental problem

**Introduction**

Lake ecosystems' aesthetic values and water quality are currently being significantly impacted by the eutrophication issue. In that case, the cost-effective bio-manipulation technique can be regarded as one of the best ways to deal with the issue. The full success of the bio-manipulation technique is still up for debate, though, and depends on the strategy used, such as whether the fish were removed completely or partially, if only predatory fish were stocked, the size (small lakes are easy to manipulate, Meijer 2000), and the depth of the lake. In general, biomanipulation is referred to as engineering technology. Lake and reservoir water quality can now be regularly improved through biomanipulation (Hansson *et al*., 1998; Drenner & Hambright, 1999). A third explanation of biomanipulation biology is that it is a human management technique used to restore deteriorated water bodies. According to Wysujack & Mehner (2002), Combining the introduction of piscivore, the manual removal of fish species, and its integration with nutrient management is the best bio-manipulation technique for fisheries management. More scientific studies are required to determine whether bio-manipulation of lake ecosystems can have long-term beneficial consequences. Even though there are still a number of scientific issues surrounding biomanipulation that need to be investigated further, the technology is sufficiently developed from a scientific and managerial perspective to make reliable forecasts about improvements in water quality in many situations. Almost all lentic freshwater ecosystems, with the exception of fishless lakes, exhibit the trophic interactions in pelagic communities described by the "bottom-up: top-down theory" (McQueen, Post & Mills, 1986) and the "trophic cascade model" (Carpenter, Kitchell & Hodgson, 1985). The precise structures and procedures involved, however, vary greatly. Because both are affected by top-down and bottom-up influences, it can occasionally be challenging to make quantitative predictions about the results of a biomanipulation experiment.

Here, the term "biomanipulation" refers to the intentional reduction of planktivory, which is followed by an increase in zooplankton size and abundance (mostly large Daphnia species). This causes increased grazing pressure on phytoplankton, which in turn leads to clearer lake water. Either manually eliminating zoo planktivorous fish or encouraging a large community of piscivorous fish through stocking and protection measures to increase predation pressure on the planktivorous fish would result in the desired reduction of planktivory.

Numerous studies concentrated on distinct trophic levels, like zooplankton and phytoplankton, and how they relate to the trophic levels that are nearby. Species and functional groupings that are indirectly impacted by biomanipulation received some in-depth investigation. Furthermore, the difficulties of using basic food-chain models to explain some of the responses seen in lakes were emphasized, as was the propensity of shallow lakes to flip between two stable states. Finally, the potential of biomanipulation for enhancing lake water quality was assessed based on the existing empirical and theoretical evidence

**Major components behind Bio-manipulation mechanisms**

**Fish:**

Fish is a crucial component of the bio manipulation process. There are two types of measures we might pursue in order to reduce the number of planktivorous fishes and to boost the zooplankton biomass. First technique to lower the biomass of planktivorous fish is by kill (using some pesticides like rotenone by following the recommended dose) and removal (catching the fish directly by nets) whereas secondly, we can go for the stocking of predatory (piscivorous) fishes. A reduction in the biomass of benthivores fish is also believed to have a favourable impact on the bio-manipulation process since the benthivores fish while feeding will stir-up the bottom causing increased turbidity, hindering the colonization & growth of macrophytes and their stability.

However, because they actively graze on the phytoplankton blooms, phyto-planktivorous fish play a significant role in the bio-manipulation process by improving the water quality. Silver carp (*Hypophthalmichthys molitrix*), a phyto-planktivorous fish species, can have a stronger effect on planktonic Cladocera than phytoplankton, according to Radke and Kahl's (2002) experiment on fish bio-manipulation. As a result, this fish species cannot be regarded as a candidate for bio-manipulation in mesotrophic lakes. According to research by Starling *et al*. (2002), the introduction of a few small-scale commercial fish species that are targeted against these fishes will not only enhance the reservoir's water quality but also supply high-quality protein to the local people. Since mussels are filter-feeders and lower the nutrient load, Roy *et al*. (2010) and Gulati *et al*. (2008) proposed that mussels might be used as an alternative to fish in order to filter water and produce pure water. Given its ability to decrease phytoplankton biomass through filter feeding, the zebra mussel (*Dreissena polymorpha*) **(Italic)** may be a good choice for the bio-manipulation strategy in this instance (Caraco *et al*. 1997 and Reeders *et al*. 1993).

**Zooplankton:**

As an essential part of lake ecosystems, zooplanktons play a significant part in the bio-manipulation process. According to Cooke (1986), larger zooplanktons are more effective than smaller ones at consuming a range of algal blooms. It is acknowledged that Daphnia is the most important genus that affects algal blooms and plays a key role in the effectiveness of bio-manipulation. Zooplankton cannot decrease phytoplankton biomass in the absence of huge Daphnia. According to Mehner *et al*. (2002), Daphnia's heavy grazing of phytoplankton improves water quality and makes macrophytes the major producers, which in turn reduces phytoplankton biomass. Therefore, reducing Daphnia mortality is the primary objective of the bio-manipulation technique in order to attain the intended outcomes.

**Macrophytes:**

“Aquatic macrophytes have been highlighted as a vital component for the long-term success of biomanipulation management. Macrophytes maintain the sediment avoiding re-suspension of nutrients as well as using nutrients for their own growth. The fundamental significance of the macrophytic communities of the lake is that they provide refuge to the zooplanktons and produce the zone of low-oxygen levels where planktivorous fishes cannot survive well which would result in the restricted admission of planktivorous fishes to zooplankton refuge” (Shapiro 1990). “Increased macrophyte population will lessen the algal blooms” ((Hosper 1990). Fugl and Myssen (2007) tried to restore Lake L. Rogbolle in Denmark by allowing submerged vegetation to naturally grow there, while Moore *et al*. (2010) tried to restore a freshwater tidal area in the United States by introducing Vallisneria americana shoots, seeds, and seed pods artificially or man-madely and providing protection from grazing.



Fig .1 Process of Biomanipulation (Khalasi *et al.,* 2024)

**The distinction between shallow and stratified lakes influences biomanipulation approaches**

From a management perspective, it is generally agreed that biomanipulation likely has a significantly higher success rate in shallow lakes as opposed to stratified deep lakes (Gulati *et al*., 1990; McQueen, 1998; Scheffer, 1998).

When Daphnia graze phytoplankton intensely, the water becomes clearer, allowing macrophytes to take over as the main primary producers while phytoplankton is repressed (Mehner *et al*., 2002). When nutrient loading is strong and dense populations of benthivores or planktivorous fish re-establish, the plankton-dominated condition may reappear, even though the macrophyte-dominated clear-water state of shallow lakes is usually regarded as stable. Repeated biomanipulation efforts, however, may reestablish the clear-water condition (Van de Bund & Van Donk 2002).

The primary benefit of modifying the food web in shallow lakes is the possibility of macrophytes (re)colonizing sizable bottom regions. These organisms support the clear-water condition of shallow lakes in a variety of ways, including: (1) According to Stansfield *et al*. (1997), macrophyte beds can protect zooplankton from fish predation; (2) predatory fish like perch (*Perca fluviatilis* L.) and pike (*Esox lucius* L.) **(Italic)** have a higher feeding efficiency in macrophyte beds than do planktivorous or benthivorous cyprinids like roach (*Rutilus rutilus* (L.)] or bream [*Abramis brama* (L.)]. (Winfield, 1986; Grimm & Backx, 1990); (3) observational and experimental findings that high densities of phytoplankton, particularly cyanobacteria, are uncommon in dense macrophyte beds imply that macrophytes effectively compete with phytoplankton for nutrients (Van Donk *et al*., 1990) and may release substances that are allelopathic to cyanobacteria (Declerck *et al*., 2000); (4) conditions within macrophyte beds may increase denitrification, which reduces the amount of nitrogen available for phytoplankton growth (Van Donk *et al*., 1993); and (5) resuspension of bottom material is typically lower in macrophyte beds (Barko & Smart, 1981). Together, these processes stabilize or even improve water clarity, which increases the depth of the water and the space at the bottom where macrophytes can grow. The notion of alternate stable states in shallow lakes, where there are quick transitions between a murky, plankton-dominated state and a clear, macrophyte-dominated state, has been developed as a result of the recognition of this positive feedback mechanism (Scheffer, 1998).

The situation appears to be different in stratified eutrophic lakes. Non-edible algae typically take over the phytoplankton population after the spring clear-water phase brought on by high Daphnia grazing rates, resulting in reduced water clarity in the summer. Therefore, the ability to inhibit the growth of inedible algae throughout the summer is one of the most important aspects for guaranteeing a long-term effectiveness of biomanipulation un stratified lakes.

**The role of nutrient supply and recycling in determining the success of biomanipulation**

Even in lakes that are heavily top-down modified, it has long been hypothesized that bottom-up impacts of nutrients on the organization of pelagic food webs are nevertheless effective (McQueen *et al*., 1986). Therefore, according to Benndorf (1987), lowering nutrient runoff from the catchment may be a crucial precondition for successful biomanipulation. Additionally, before biomanipulation can improve lake water quality, an annual loading threshold below 0.6–0.8 g of total P m)2 of lake surface area must be reached (Benndorf *et al*., 2002). According to Jeppesen *et al*. (1991), the crucial level below which biomanipulation's long-term impacts in shallow lakes can be anticipated is an in-lake P-concentration of roughly 100 l g L)1. The decrease in nutrient concentrations and, subsequently, the decrease in phytoplankton biomass in that lake may have been further influenced by rising phosphorus coprecipitation and calcite precipitation (Koschel, 1997).

Lakes' trophic status affects the length of their food chains, defining the possibility of biomanipulation through shifts in the top trophic levels. According to Persson *et al*. (1992), “mesotrophic lakes have four levels with large populations of predatory fish, primarily perch, that have a strong top-down influence on planktivorous roach populations, while oligotrophic and eutrophic lakes in Europe have three-level food chains devoid of piscivores (phytoplankton, zooplankton, and planktivorous fish). The lack of piscivorous perch in eutrophic lakes is attributed to the fact that, in these unfavorable feeding conditions, perch is competitively inferior to roach” (Persson *et al*., 1992).

Daphnia feeding on phytoplankton rose with phosphorus concentration, according to Sarnelle (1992), suggesting that the lakes most affected by nutrient inputs would react most strongly to a decrease in planktivory. According to the aforementioned theories, the trophic condition of lakes may have a systematic impact on how effective biomanipulation techniques are.

The improvement of nutrient recycling by aquatic species, such as fish, is a rediscovered consequence of biomanipulation. This has an indirect bottom-up effect on the organization of the pelagic food web. The indirect impacts of fish egestion and nutrient excretion can better explain many of the effects of fish on phytoplankton that were initially ascribed to fish feeding on zooplankton (Brabrand, Faafeng & Nilssen, 1990; Schindler *et al*., 1993; Attayde & Hansson, 2001).

According to Breukelaar *et al*. (1994), benthivorous fish species like bream and common carp (*Cyprinus carpio* L.) “agitate the lake bottom, increasing sediment re-suspension, water turbidity, and internal nutrient loading. Furthermore, it has been proposed that the removal of benthivorous fish has a stronger effect on the outcome of biomanipulation in shallow lakes than the removal of planktivorous fish” (Lammens *et al*., 1990; Drenner & Hambright, 1999). “Additionally, the feeding activity of these fishes may directly destroy or uproot macrophytes, suggesting that benthivorous fish may exert bottom-up effects on water quality” (Tatrai & Istvanovics, 1986).

**The significance of ontogenetic niche shifts and size-structured interactions**

Particularly in aquatic environments where size-structured fish populations predominate, an organism's body size has a significant role in influencing the form and intensity of trophic interactions (Werner & Gilliam, 1984). Analyzing such interactions requires treating distinct developmental phases independently because a single species may exhibit changes in nutrition or habitat use during ontogeny. Fish populations in North America (Werner, 1992) and Europe (Persson, 1994) provide evidence of ontogenetic niches. The diet shift of fish, such as perch and pikeperch*, Sander lucioperca* (L.), which begin their lives as planktivores but change to piscivory when they reach a specific length, is of special relevance for biomanipulation (Persson, Bystro¨m & Wahlstro¨m, 2000; Beeck *et al*., 2002). Therefore, increased planktivory by the young is necessary to establish a top trophic level of piscivores with these species (Mehner *et al*., 1996).

The relationship between piscivores and their prey is another mechanism that relates to the size-structure of fish groups. Because strong predation may shift the age structure of prey populations towards larger individuals (Bronmark *et al*., 1995), prey fish that can grow to a large enough size find refuge from predators (Hambright, 1994; Persson & Eklo¨v, 1995). This prevents piscivores from controlling large planktivores from the top down (Lammens, 1999). Therefore, it is only possible to prey on planktivorous animals like roaches or common bream when they are younger.

**The influence of temporal variability and spatial heterogeneity on food webs**

There hasn't been much focus on the many temporal or spatial scales that most trophic interactions in lakes take place on. In lakes, fish-zooplankton interactions can differ in strength along spatial gradients (George & Winfield, 2000). The spatial distribution of their prey fish determines the piscivores' possible growth rate (Mason & Brandt, 1996). Shallow lakes have been observed to have a structurally different trophic cascade inside and outside of submerged macrophyte stands, which results in a higher water transparency within macrophyte beds (Schriver *et al*., 1995). It is unclear, nevertheless, if processes that are very effective in a single habitat significantly affect the strength of interactions across the entire lake.

“A decrease in predatory losses in pelagic zooplankton may result from planktivorous fish seeking refuge in the deep hypolimnion or in littoral vegetation throughout the day against predation by piscivorous fish or birds” (Gliwicz & Dawidowicz, 2001). “Therefore, by prohibiting planktivores from feeding on daphnids in the open water during the day, stocking with visually oriented pelagic piscivores, like the highly day-active perch” (Jacobsen *et al*., 2002), “may have a behavior-mediated biomanipulation effect. Additionally, the presence of pelagic predators like pikeperch, which are active throughout the diurnal cycle, can further inhibit planktivory” (Brabrand & Faafeng, 1993; Ho¨lker *et al*., 2002).

“If fish feed in one part of a lake and excrete in another, this is an example of a similar spatial coupling. By feeding in nearshore locations and then migrating to the central open-water zone (littoral-pelagic coupling) or by feeding at the lake bottom and then moving higher into the water column (benthicpelagic coupling), fish can thereby reduce the pelagic nutrient pool. Pelagic phytoplankton receives fresh nutrients in both situations in a form that they can use right away. In certain instances, it was discovered that limiting this fish-mediated nutrient transfer was more crucial to the success of biomanipulation than the relief of feeding pressure on zooplankton after planktivorous fish were removed” (Horppila *et al*., 1998).

If a water body's physical or chemical features produce spatial refuges that influence the strength of trophic interactions, it is equally crucial to take habitat diversity into account. Because the production times of various pelagic food web members vary greatly, temporal scales must also be taken into account (Ramcharan *et al*., 1995). According to Yodzis (1988), time scales twice the sum of the trophic chain members' life spans—that is, at least 50 years in most lakes—must be taken into account when evaluating the long-term dynamics of whole-lake studies. The problem of trophic level regulation through resource limitation or predation is also related to time scale considerations. Only bottom-up control is mediated by time-dependent characteristics like population growth rate, reproduction rate, and individual growth rate, according to Gliwicz (2002). In contrast, top-down control affects state variables like population density, biomass, and individual body size regardless of how quickly these entities are produced.

**The importance of long-term maintenance for the success of biomanipulation measures**

It is necessary to continuously reduce planktivores since biomanipulation most likely does not result in stable food web structures (Kitchell, 1992; McQueen, 1998). “Either piscivores or periodic physical removal are necessary to regulate the enhanced recruitment success of planktivores after a period of planktivorous fish removals” (Romare & Bergman, 1999; Van de Bund & Van Donk, 2002). Additionally, biomanipulated lakes may be quickly overrun by planktivorous fish, especially if they are connected to other bodies of water. If the connections are used for navigation, preventing immigration may be particularly difficult (Perrow *et al*., 1997). Without manually removing the planktivores, even restocking piscivores might not be enough. Among a variety of methods assessed by Drenner & Hambright (1999), biomanipulation via piscivore stocking had the lowest success rate.

“The significant declines in planktivore fish stocks generally necessary for successful biomanipulation imply that press perturbations are required to shift a system into another state; the impact of pulsed perturbations appears to be too minor” (Persson *et al*., 1993).

**Importance of bio manipulation**

Biomanipulation is significant primarily because it can be used to solve ecological issues brought on by human activity. For example, eutrophication is a common problem caused by excessive nutrient inputs into aquatic bodies, usually from wastewater discharge or agricultural runoff. An overabundance of algae is caused by a higher nutrient load, which harms other organisms, reduces oxygen levels, and disturbs the ecosystem's natural balancing. In order to restore ecological equilibrium, biomanipulation techniques can be used to decrease algal biomass and promote the growth of beneficial species. Additionally, biomanipulation is essential for reducing harmful algal blooms (HABs). HABs are large and quick buildups of specific algae species that emit toxins, endangering aquatic life and posing health concerns to people. The detrimental effects of HABs can be reduced and water quality improved through biomanipulation, by either introducing particular predators or grazers which consume the toxic algae or by carefully adjusting the dynamics of the food web. Biomanipulation can help to improve ecosystem management and conservation in nature. Habitat restoration and biodiversity preservation become viable by focusing on certain species or ecological relationships. It also helps protect native species by limiting the spread of invasive or non-native species that interfere with the natural ecosystem.

**Advantages of Biomanipulation**

* Natural Process Introduced by Humans, It is a kind of natural/ biological process induced by humans to improve the water quality of the aquatic ecosystem.
* Reduces Turbidity
* No Requirement of Chemicals
* Improves Fisheries
* Maintain Nutrient Cycling
* Supports Biodiversity, the decreasing biodiversity due to algal blooms starts increasing as water quality gets better.

**Disadvantages of bio manipulation**

* **Management of Lakes:** When using the bio manipulation technology, lakes need to be managed continuously.
* **Poisoning of Water Bodies:** The water bodies are poisoned by Rotenone application and water is not suitable for human consumption.
* **Lack of Awareness:** The fishermen are often not aware of the side effects of dominant species. Awareness about the importance of predator species is important for Fishermen.
* **Expensive Treatment:** The cost of the bio manipulation method is high and it is totally dependent on the method which is being used.

**Challenges for bio-manipulation**

* Bio-manipulation can only be used for small, shallow and closed system which means lake system needs to be totally closed (no connection with other water bodies)
* It is must to remove some fish fauna prior to the introductions of new piscivorous fishes to the lakes to reduce the risk of competition for food, shelter and breeding ground
* The eutrophication of lakes is being caused by increased worldwide development activities and climate change, which are doing so through increased nutrient influx.
* Modifications to the lake ecosystems' structure
* Limited long-term effectiveness

**Conclusion**

A key component of biomanipulation is the interactions that occur between the various prey groups and piscivorous, planktivorous, and benthivorous fish. Designing suitable fish manipulation strategies for specific water bodies and optimizing ongoing biomanipulations are based on the scientific data and expertise gathered from biomanipulation studies in a variety of lake types. It is becoming more evident how nutrients can influence the likelihood of successful biomanipulations. The examination of scales is vital for understanding trophic interactions along the temporal (diel, seasonal, interannual), spatial (habitat coupling, lake and catchment linkages), and interorganismic (size structure, ontogeny) axes. In addition to scales, complex food webs' reactions to shifts in the strength of predation are governed by boundary conditions including lake depth, underwater light environment, temperature regime, mixing intensity, and trophic state. Therefore, while basic food-chain models can replicate significant food-web changes in response to press perturbations, it is unrealistic to expect them to capture the wide range of potential impacts of biomanipulations. One strategy for improving the quality of water is biomanipulation, which calls for both management and study. Most lake managers today learn by doing, employing biomanipulation as an adaptive management method. Regarding the objectives of biomanipulation and strategies for achieving them, there is some consensus between fisheries and water quality management. Therefore, benefits for certain lake users may result even if biomanipulation proves unsuccessful in some water bodies.

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