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Bio-manipulation: A restoration tool for eutrophied lakes

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Abstract
Eutrophication is a naturally occurring process of high loading of nutrients in aquatic system (particularly phosphorous) which is being accelerated by anthropogenic activities. Overuse of fertilizers, excessive feeding, untreated sewage discharge, industrial effluents, aquaculture waste are the main causative agents behind eutrophication. Eutrophication poses serious threats to aquatic flora and fauna, endangers fisheries, produces harmful algal blooms which have health impacts and deteriorates the aesthetic and recreational value of water resources. Hence, the techniques like bio-manipulation can be used as an effective tool to restore the pristine beauty of eutrophied lakes by increasing grazing pressure on phytoplankton and reducing grazing pressure on zooplankton that would leads to increase the water clarity.

Keywords: Eutrophication, lakes, planktons, fish, restoration

Introduction
Presently eutrophication is one of the utmost serious ecological problems of aquatic resources (lakes, oceans and reservoirs etc.), which is described by dense algal and plant growth due to the fortification by nutrients (phosphorus & nitrogen) needed for photosynthesis. These nutrients can come from different sources like animal wastes, fertilizers; industrial & sewage discharge and enter into the water bodies through surface run-off. Eutrophication can also take place naturally over thousands of years as the lakes grow old and get filled with sediments. Human activities top the list that speeds up the degree and rate of eutrophication through both point and non-point source discharges of the chemical nutrients (phosphates and nitrates) into water systems. The eutrophied lakes are characterized by decreased biomass of large-bodied zooplanktons (e.g. *Daphnia*), elevated biomass of planktivorous & benthivorous fish species in the lake, shift from submerged macrophyte dominance to phytoplankton dominance and increase in algal biomass (cyanobacterial blooms) that deteriorate the water quality of lake causing the health problems. Eutrophication has been strongly suppressing the aquatic life by deteriorating the water quality, threatening the survival of aquatic fauna, endangering the fishing, degrading the recreational opportunities, reducing the aesthetic values of the aquatic water bodies and ultimately affecting the livelihood of the users and their economical conditions.

Why bio-manipulation?
The problem of eutrophication nowadays is greatly affecting the water quality and aesthetic values of the lake ecosystems. In that case, bio-manipulation technique which is cost-effective technique can be considered as one of the most suitable solution to overcome the problem of eutrophication and to restore the quality of water in small and shallow eutrophied lakes. The chances for success of bio-manipulation technique depends on the approach adopted i.e. whether the removal of fish was partial or complete, if only predatory fish were stocked, size (small lakes are easy to manipulate, Meijer 2000) [14] and depth of the lake but the complete success through bio-manipulation is still debatable. After reviewing the literature, Wysujack & Mehner (2002) [25] suggested the best bio-manipulation strategy for the fisheries management is the combination of piscivore introduction, manual removal of fish species and its integration with the nutrient management. There is a need of more scientific research with respect to the potential bio-manipulation of lake ecosystems with the long-term positive effects.

Concept of Bio-manipulation

The use of bio-manipulation as tool for water management started in the 1970s in small lakes and because of its success it was also applied in large lakes in the 1990s. The term was first introduced by Shapiro *et al.* (1975) [22] to refer to a kind of '*biological engineering*' whereby lake food-webs are manipulated to reduce algal biomass. Bio-manipulation is the deliberate alteration of an ecosystem by adding or removing species, especially predators or it can also be defined more broadly as a removal or biomass reduction of any undesirable fish, irrespective of the impact on the zooplankton grazing, and then a reduction in phytoplankton biomass could be expected. Shapiro *et al.* (1975) [22], Shapiro & Wright (1984) [20] & Carpenter *et al.* (1985) [5] carried out their study on food web manipulation of freshwater pelagic ecosystems and reported that phytoplankton biomass can only be mediated by reducing the grazing pressure on zooplanktons by planktivorous fish species. Further Bartell & Kitchell (1978) [1] & Bartell (1981) [2] has suggested that nutrient recycling rates of zooplankton community can be increased by selecting the fish species for larger zooplanktons that would shift the dominance from large to small zooplanktons which are most likely to be faster recyclers. In general, it is considered to be a useful tool to fasten the recovery of culturally eutrophied lakes with the continuous maintenance (McQueen 1998, Benndorf *et al.* 2000) [12, 3]. For the long-term management of shallow eutrophied lakes, the bio-manipulation is probably to be the most successful tool and if we will do bio-manipulation repeatedly that may recreate the clarity of water **(**Van de Bund & Van Donk 2002) [24].

Bio-manipulation could be a water quality restoration option for the lakes depending on certain situations which include severity of the eutrophication problem, chances for the success of bio-manipulation, affects on the present users and their support. In general, the most important criterion is the level of eutrophication. If the lake has a high concentration of nutrients even after serious reductions in the load of nutrients, and high concentrations of algae, in particular cyanophytes, the lake is considered as a serious candidate for bio-manipulation. Now a days it is becoming a more popular technique for improving the water quality of lakes due to various factors which include its low-cost involvement, high effectiveness, non-use of toxic chemicals, absence of machinery and getting desired outcomes easily just by adjusting the biological communities in an aquatic ecosystem with the regular maintenance of water bodies (Benndorf *et al.* 2000) [3].

Major components behind Bio-manipulation mechanisms

1. **Fish:** Fish is an important component of the bio-manipulation process. There are two types of approaches we can follow in order to control the population of planktivorous fishes and to increase the zooplankton biomass. First approach to reduce the biomass of planktivorous fish is through kill (using some chemicals like rotenone by following the recommended dose) and removal (capturing the fish directly by netting) whereas secondly, we can go for the stocking of predatory (piscivorous) fishes. A reduction in the biomass of benthivorous fish is also suggested to have a favorable impact on the bio-manipulation process because the benthivorous fish while feeding will stir-up the bottom causing more turbidity, impairing the colonization & growth of macrophytes and their stability. Whereas the role of Phyto-planktivorous fish (e.g. silver carp, big head carp and others) in bio-manipulation process is important as they improve the water quality by actively grazing upon the phytoplankton blooms. Radke and Kahl (2002) [17] carried out an experiment of fish bio-manipulation and concluded that silver carp (*Hypophthalmichthys molitrix*), a Phyto-planktivorous fish species can more strongly impact the planktonic Cladocera's than phytoplankton, therefore, this fish cannot be considered as a candidate fish species for bio-manipulation in mesotrophic lakes. Starling *et al.* (2002) [23] carried out a study and suggested that introduction of some small-scale commercial fish species targeted against these fishes would not only improve the water quality of the reservoir but also provide the local population with good quality protein. As an alternative to the fish, Roy *et al.* (2010) [19] and Gulati *et al.* (2008) [8] suggested that the introduction of mussels can also create clear water through the filtration of water as they are the filter-feeders and by reducing the nutrient load. In this case, Zebra mussel (*Dreissena polymorpha*) could be considered as a suitable candidate for bio-manipulation technique as it can reduce the phytoplankton biomass through filter feeding (Caraco *et al.* 1997 and Reeders *et al.* 1993) [4, 18].
2. **Zooplankton:** Being a key component of lake ecosystems, zooplanktons have a very important role in the process of bio-manipulation. Cooke (1986) [6] stated that larger zooplanktons can consume a variety of algal blooms more efficiently as compared to smaller ones. Daphnia is recognized as the most significant genus to impact upon algae blooms and major contributor to the success of bio-manipulation. When large Daphnia are absent, zooplankton cannot reduce phytoplankton biomass. Mehner *et al.* (2002) [13] suggested that intensive grazing by Daphnia on phytoplankton leads to the better water quality and also macrophytes becomes the dominant primary producers which would ultimately suppress the phytoplankton biomass. So, the main goal of the bio-manipulation technique is to lower the mortality of Daphnia to achieve the desired results.
3. **Macrophytes:** Aquatic macrophytes have been identified as a key component for the long-term success of bio-manipulation management. Macrophytes stabilize the sediment preventing re-suspension of nutrients as well as utilizing nutrients for their own growth. The main role of the macrophytic communities of the lake is that they provide refuge to the zooplanktons and create the zone of low-oxygen levels where planktivorous fishes cannot survive well which would result in the prohibited entry of planktivorous fishes to zooplankton refuge (Shapiro 1990) [21]. Increased macrophytic population will reduce the algal blooms ((Hosper 1990) [9]. Fugl and Myssen (2007) [7] attempted the restoration of lake L. Rogbolle in Denmark with the natural establishment of submerged flora whereas Moore *et al.* (2010) [16] attempted the restoration of Freshwater tidal area in USA by following the artificial or man-made introduction of shoots, seeds and seed pods of *Vallisneria americana* and protection against grazing.

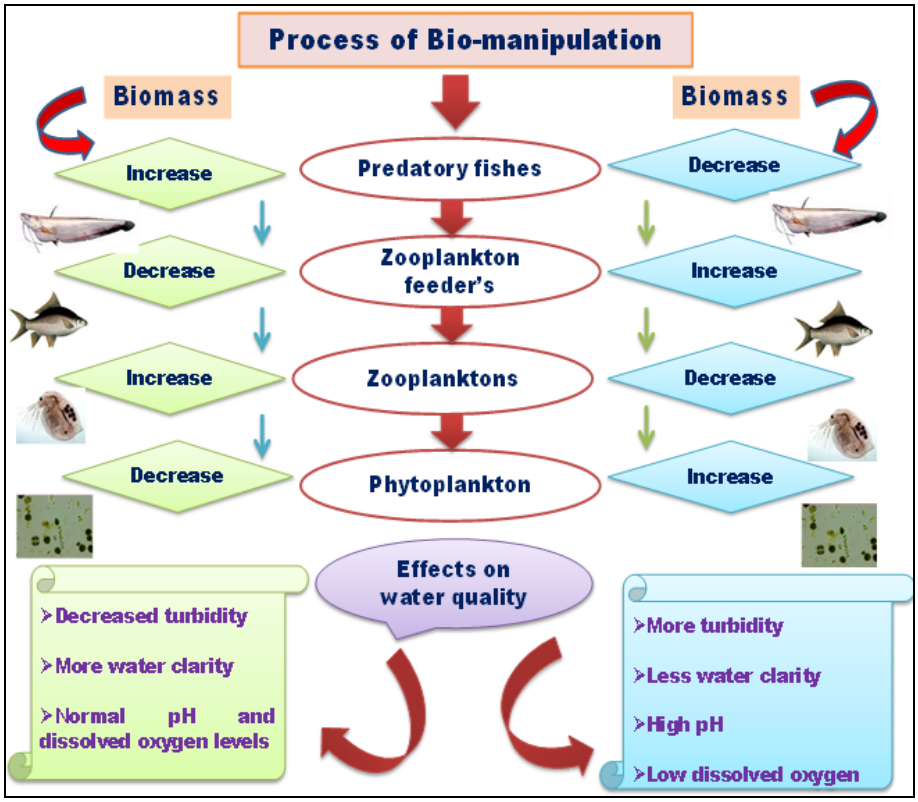


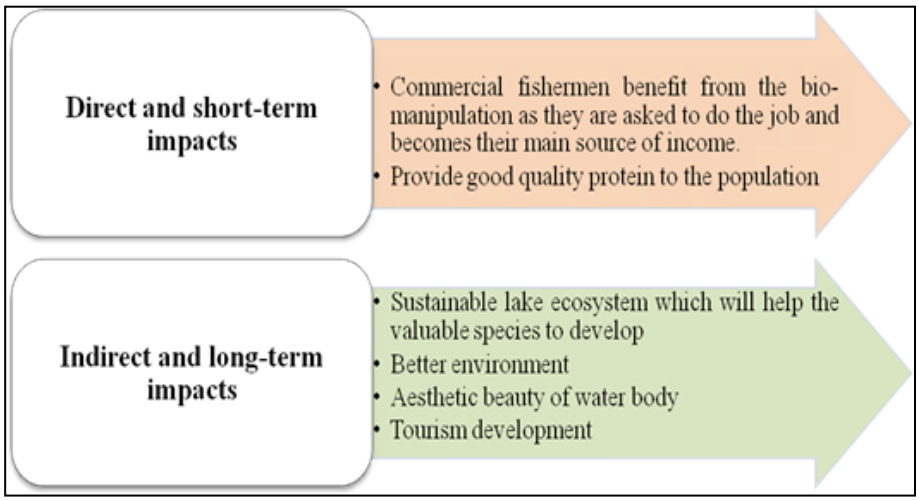
Diagram showing the components and process of bio-manipulation

Combined Bio-manipulation techniques

Combined with chemical treatment	Combined with hypolimnion oxygenation
Main aim to provide the more sorption sites on the sediment surface for phosphorous. It will reduce the phytoplankton growth by reducing the phosphorous loading through precipitation of the phosphorous. To promote phosphorous inactivation in the lake, aluminum sulfate or sodium aluminate can be used. Other than these, calcite ($CaCO_3$) and hydroxides of oxidized iron (Fe^{3+}), Lanthanum (La) and La-modified benthonite (Meis *et al.* 2011) [15] can also be used for this purpose.	Oxygenation of hypolimnion not only reduces the nutrient loading but also improves the overall conditions of the pelagic ecosystem. It enhances the water clarity by reducing the P-loading through improving the redox sorption of phosphate to iron in sediments. It is restricted to the Stratified (summer) lakes (Liboriussen *et al.* 2009) [10]. Alternatively, nitrate electron acceptors can also be used either by stirring the liquid nitrate solution in the upper sediment layer or by injecting it to the water just above the sediment layer.

Combined treatment = More synergistic effects + Reduced restoration cost

Impacts of bio-manipulation on fisheries



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 grounds

- Increasing global developmental activities and climate change strongly contributing to the eutrophication of lakes through enhanced allochthonus nutrient inflow
- Alterations in the structure of the lake ecosystems
- Limited long-term effectiveness

Conclusion

Eutrophication a nature-based tool is an efficient and cost-effective solution for the restoration of the degraded ecosystems. Lake Eutrophication is a big challenge all over the world and restoration of eutrophied lakes even a bigger challenge and biomanipulation is a simple way forward. While adopting Biomanipulation strategies care must be taken on any deleterious effects on the food web. Thus, Biomanipulation strategies should be region specific and be formulated depending upon the eutrophication status of the water body to be restored. While reducing the population of planktivore fish and increasing the concentration of piscivore fish, care must be taken on long term sustainability of the resource in terms of fauna and flora. To conclude it is beyond doubt that implementation of a biomanipulation strategy in combination with nutrient reduction can lead to restoration a limnetic environment, thus increasing its multiple uses and restoring its pristine beauty.

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