



Biomanipulation: Food Web Management of Lake Ecosystems

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Biomanipulation is a technique used to restore eutrophied lakes. Eutrophication is the accumulation of nutrients, particularly phosphorous, in aquatic systems. The process does occur naturally in all bodies of water but human activities accelerate the process. Intense nutrient influxes into lakes cause dramatic changes to lake dynamics. Planktivores become abundant and reduce zooplankton (Gophen 1990). Larger sized zooplankton species are diminished leading to dominance by smaller sized species. The ratio of planktivores to piscivores widens, reducing the ability of piscivores to control planktivore populations. Planktivores also recycle phosphorous in lakes through excretion that directly influences algae production (Hanazato 1990). High concentrations of phosphorous through external and internal nutrient loading promotes algae blooms. Blooms cause fish death, macrophyte decline, and a decrease in dissolved oxygen. Biomanipulation seeks to control blooms by increasing zooplankton populations to promote heavy grazing of algae (Gophen 1990).

Zooplankton are key ecosystem components of lakes. Larger sized zooplankton are the most desirable in terms of algal filtration. Larger zooplankton are able to consume a wider range of algae types compared to smaller zooplankton (Cooke 1986). Zooplankton feed in the epilimnion at night and descend deeper into the lake during the day. This adaptive strategy allows for zooplankton to escape predation of planktivores, which feed mostly by sight (Shapiro 1990). The macrophyte populations and dissolved oxygen levels deep in the lake provide refuges for zooplankton. Decreased macrophyte populations and lower dissolved oxygen levels occurring in eutrophied lakes causes a rapid decline of zooplankton (Shapiro 1990).

Biomanipulation is a relatively new technique. The concept was formally defined by Shapiro in 1975 (Kitchell 1992). Shapiro desired an alternative approach to lake restoration that relied less upon chemicals and engineering. However, the concept has been utilized earlier in history. Caird (1940) described a situation that occurred in a Connecticut pond; the pond suffered immense algal blooms and required copper sulfate treatments several times per year. The introduction of large-mouth bass into the lake eliminated the need for copper sulfate treatments. Caird observed the change in the pond, but it is unclear if he fully understood how the large-mouth bass controlled the algae blooms (Shapiro 1990).

Biomanipulation is typically used in lakes that are small, shallow, and closed systems. Biomanipulation tends to work well in shallow lakes since organisms are not spatially separated by depth. Also, nutrient levels are more static since losses to the hypolimnion are unlikely (Hanson 1994). Lakes need to be closed systems because organisms entering a lake through connections with other water bodies will inhibit the ability to control lake fauna.

The premise behind biomanipulation is the manipulation of biotic components of a lake as opposed to conventional nutrient management. The goal of water quality improvement is achieved through the manipulation of higher level consumers of a lake. Two general biomanipulation approaches are used to increase zooplankton populations.

One method to increase zooplankton populations is the removal of planktivores through a fish kill or removal. Rotenone, a powdered form of derris root in 5% formulation, is an effective piscicide used to restructure or eliminate certain fish communities. All fish are susceptible to its impacts but planktivores and benthivores are the main target. A dose of 1.0 mg l^{-1} will achieve a complete fish kill. The dose can be altered to fit the level of fish kill desired. Rotenone application is most effective in warm weather. Optimal water temperature is 20° Celsius or above. If rotenone is applied in cold weather it remains toxic in the lake for long periods of time (Cooke 1986). Fish removal can be accomplished by intense seining, the capture of fish by nets.

Rotenone may produce undesirable side effects. Other lake fauna are killed in addition to the intended target. Zooplankton are killed and may not rebound for several months, causing a decrease in algae grazing rates. Application prior to spawning of desired species will enhance the success of Rotenone use. For example, Rotenone should be applied in spring prior to large-mouth bass spawning (Cooke 1986).

Seining activities produce little success. Seining may only be performed in shallow lakes with smooth bottoms. Most lakes do not have smooth bottoms which leads to inefficient fish capture due to tearing of the net. The technique is costly since it is labor intensive (Cooke 1986).

The second method to increase zooplankton is the direct stocking of faunal components of a lake. Piscivore stocking increases predation of planktivores. A decrease of planktivores leads to reduced predation of zooplankton. The desired fish composition is 30-40% piscivores which corresponds to a biomass ratio of .28 to .66 piscivores to planktivores (Benndorf 1990). The average stocking rates of zooplankton are 4 million individuals (Theiss 1990).

The success of piscivore stocking is limited. When used as the sole technique, stocking does not appear to provide long term effectiveness (Shapiro 1990). One problem is the inability to stock the number of fish required to control abundant planktivore populations (Cooke 1986). Another problem is related to the nonexistence of spawning grounds and habitat requirements of piscivores in eutrophied lakes (Cooke 1986). A way to increase the success of stocking is to perform a fish kill or removal prior to stocking to decrease planktivores.

Limited research is available to determine if zooplankton stocking is successful. A concern is the ability for zooplankton to survive in a lake they are not present in prior to introduction (Theiss 1990). Two factors that may increase the success of zooplankton stocking is the presence of an abundant food supply and low predation rates. A potential result of zooplankton stocking is the sudden increase in zooplankton grazing might allow for the macrophyte community to rebound. An increase of macrophytes may induce a long term change from a lake dominated by phytoplankton to one dominated by macrophytes (Theiss 1990).

A recent modification to stabilize the effectiveness of biomanipulation is the enhancement or construction of refuges to provide defenses for zooplankton against predation. Construction of refuges in conjunction with fish kills, fish removal, or stocking will increase the survival rate of zooplankton. The refuges act as a buffer to control predation in case the intended biomanipulation technique begins to fail (Shapiro 1990).

One way to create a low dissolved oxygen refuge is through oxygenation of deeper waters by artificial circulation (Shapiro 1990). The zooplankton are able to inhabit the oxygen levels while planktivores cannot. If macrophytic communities are lacking, adding bundles of brush to a lake bottom may provide an adequate refuge for zooplankton (Shapiro 1990). Consideration of a species behavior when stocking will enhance the success of refuge utilization. For example, after a fish kill planktivores that are unlikely to enter the refuge of low dissolved oxygen should be stocked (Shapiro 1990).

The overall success of biomanipulation is debatable. Some sources proclaim the approach as successful while others question its reliability. The relative young age of the concept makes it difficult to study long term effectiveness. The experiments are typically less than five years and are not long enough in duration to determine dominant trends or causal relationships among the variables being manipulated (Hanson 1994).

For example, the loss of fish populations by a fish kill or removal will effectively increase macrophyte populations as well as zooplankton. Through nutrient competition, abundant macrophyte populations are able to reduce algae growth (Hosper 1990). Determination of whether phytoplankton are controlled by zooplankton or macrophytes is difficult to ascertain (Hanson 1994).

Biomanipulation may produce positive results early in the study but may not five or ten years later. In a case study of Round Lake in Minnesota, biomanipulation did produce the desired results for the first two years with improvement in each successive year but during the third year the lake began to digress to its previous denuded state (Shapiro 1984).

Lastly, an argument is raised concerning zooplankton grazing rates of blue-green algae. Blue-green algae are a major problem in eutrophied lakes and it is questionable whether zooplankton are able to use blue-green algae as a food source. Filtering of the algae may be impeded by its size and shape and may even clog the filtering apparatus of zooplankton (Bernardi 1990).

Biomanipulation was designed to be an alternative to nutrient management and may provide the long term effectiveness that nutrient management has failed to do in eutrophied lakes (Cooke 1986). Nutrient management techniques ignore the biological interactions occurring in a lake which may be the primary cause of algae blooms and internal nutrient release (Cooke 1986). Nutrient management approaches are ineffective in shallow lake environments due to internal nutrient loading and the impossibility to successfully reduce the external nutrient loads (Moss 1991). Phosphorous accumulates in sediments and is released through bioturbation, the churning of sediments by organisms, and by low oxygen levels (North American Lake Management Society 1988). Nutrient management techniques tend to work best in deep lake environments since nutrient loading is not a major factor (Moss 1991). Nutrient management techniques seek to control nutrient loading and nutrient levels.

Nutrient loading can be controlled by stormwater diversion. Methods to accomplish diversion are the construction of retention ponds, in conjunction with chemical treatment of the water, and diversion of stormwater to sewer lines (Cooke 1986).

Stormwater diversion does not have the capacity to restore shallow eutrophied lakes. Abundant phosphorous already accrued in the lake leads to high internal nutrient loading. The act of diverting phosphorous laden water does not effect the phosphorous already accumulated in the lake. The fraction of phosphorous removed produces negligible results. Results of diversion may not be noticeable until years later (Cooke 1986).

Nutrient levels may be controlled through chemicals or sediment removal. Aluminum sulfate or sodium aluminate may be added to a lake to promote phosphorous inactivation. The phosphorus reacts with the aluminum salts to form the precipitate aluminum phosphate (Cooke 1986). Nutrients are released in large quantities from sediment. Sediment dredging or removal of the top .3-.5 m of the sediment core will reduce internal loading of phosphorous (Cooke 1986).

Aluminum sulfate treatments are not successful in shallow lakes. To control algae repeated treatments are necessary. Bioaccumulation of aluminum may occur at toxic levels in fish due to the repeated applications (Cooke 1986). The success of sediment removal is limited in shallow lakes as well. Sediment removal leads to resuspension of phosphorous through agitation of the sediment during dredging activities. Resuspension moves phosphorous into the euphotic zone, leading to algal blooms (Cooke 1986).

Even though the arguments against biomanipulation are extensive, it is a relatively effective method of lake restoration in shallow lakes compared to nutrient management. Nutrient management techniques have to be repeatedly performed and are not final solutions to eutrophication problems in shallow lakes (Cooke 1986). Biomanipulation is advantageous because of its cost effectiveness and potential to be a long-term solution (Cooke 1986). Biomanipulation appears to produce desirable results in most instances (Shapiro 1990). Unfortunately, the success in some cases is short term. Further research is necessary to enhance the stability of biomanipulation (Shapiro 1990).

A current restoration trend that may improve the reliability of biomanipulation is its integration with nutrient management. Controlling nutrient levels along with food-web manipulation has the potential to create long lasting results because neither food-web interactions nor nutrients are the sole regulators of phytoplankton (Kitchell 1992). For example, controlling high phosphorous concentrations in shallow lakes will increase the success of piscivore stocking. In lakes with phosphorous levels above *ca.* 100 $\mu\text{g. p l}^{-1}$, it is nearly impossible to alter piscivore rates (Jeppesen 1990). A decrease in phosphorous levels through phosphorous inactivation or sediment removal prior to piscivore stocking will increase the survival of piscivores. Thus, combining the efforts of biomanipulation and nutrient management techniques may prove to be the future solution to eutrophication problems in shallow lakes.

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