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Project Summary

Experiments and Experiences in Biomanipulation: Studies of Biological Ways to Reduce Algal Abundance and Eliminate Blue-Greens

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Studies were made to find alternatives to restoring or managing lakes by controlling external sources of nutrients. The guiding principle was to understand and use biological interactions within lakes. This process is called biomanipulation and it is clear from the results that algal abundance and type can be varied substantially by one or more of the following procedures: elimination of benthivorous fish which recycle phosphorus from sediments; manipulations of algal populations by lowering pH, causing artificial circulation; increasing abundance of larger herbivorous zooplankters by reducing predation on them, by eliminating planktivores entirely or, by providing refuges from planktivores.

This Project Summary was developed by EPA's Environmental Research Laboratory, Corvallis, OR, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Lake restoration projects designed to reduce the abundance of undesirable algae usually are based on the premise that reduction of nutrient input from external sources or from anoxic sediments is the key to success. Rarely have biological interactions within lakes been exploited deliberately to reduce or help in the reduction of such algal populations. However, consideration of such an approach, termed *biomanipulation,* as opposed to nutrient manipulation, indicates that it has great potential alone or in combination with nutrient manipulation.

Figure 1 shows some of the possibilities. Note that although the end goal is reduction of algal biomass, none of the possible manipulations involve nutrients directly. Most manipulations listed deal with changing the quantitative and qualitative relationships among the biota so that the desired reduction is achieved. It should be evident that while some of the possible manipulations are more likely to succeed than are others, most are likely to be more feasible and less expensive than direct reduction of the nutrients. What is not known is the extent to which the manipulations might be successful, the duration of their effectiveness, or the unexpected consequences from their use. Figure 2 illustrates the aquatic food chain.

This report is a summary of work done on biomanipulations at the University of Minnesota Limnological Research Center, ending in 1980.

Among the possibilities for such manipulation are:

- Elimination of bottom-feeding fish which, by their feeding activities, increase the nutrient concentrations and thereby the abundance of algae in lakes.

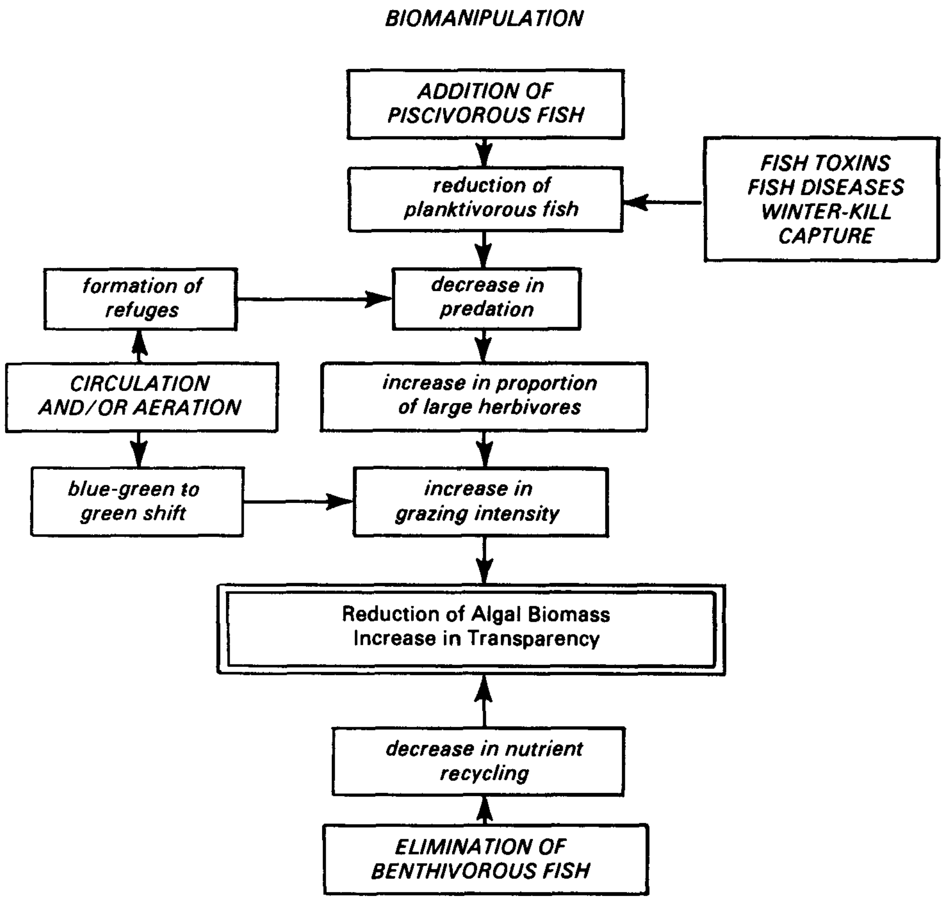

Figure 1. *Some aspects of biomanipulation. The central goals of reduction of algal biomass and increased transparency are achieved through a variety of manipulations such as those shown in capital letters; mechanisms are indicated in lower case type.*

- Manipulation of algal populations to change algae species' composition and/or reduce algae abundance by lowering pH, causing artificial circulation, stimulating activity of viruses that attack blue-green algae.
- Direct manipulations of zooplankton populations to increase abundance of herbivorous species and therefore grazing on the algae.
- Indirect manipulation of zooplankton herbivores by manipulating their predators—planktivorous fish—by experimental additions, elimination of planktivores by rotenone treatment, or elimination of planktivores by winter kill.
- Modifications in oxygen concentrations, possibly leading to large changes in algal populations via their effects on refuges for zooplankters.

Elimination of Bottom-Feeding Fish

The work of Lamarra (1975) showed that bottom-feeding fish excrete phosphorus and nitrogen compounds and that the rate of excretion depends on the fish size, the temperature, and the type of lake sediment present. Lamarra hypothesized that such input could make a significant contribution to the total nutrient loading of lakes. An opportunity to test this idea arose when the Minnesota Department of Natural Resources decided to restructure the fish population in Lake Marion, a shallow, large lake (mean depth 1.98 m, 172 ha area) in south central Minnesota. Estimates of the fish population and its characteristics were made before and after the rotenone treatment using mark-recapture methods and shore census of the dead fish, respectively. The latter method gave much higher values. Using these values, annual inputs for fish excretion were calculated at 88 mg/m^2 per year for phosphorus, and 270 mg/m^2 per year for nitrogen. The Minnesota Pollution Control Agency had previously calculated the total phosphorus loading rate to the lake from its primarily agricultural watershed as 84 mg P/m^2 per year. Therefore, fish excretion provides about half the phosphorus input to the lake. Based on two years' study of the lake before treatment, predictions have been made regarding reductions in algal biomass and productivity and increases in transparency expected from reduction in total phosphorus. Data to test these predictions have been collected and are being analyzed.

Manipulation of Algal Populations by pH Lowering

Preliminary studies had confirmed the hypothesis that green algae are favored over blue-greens at lower pH values. In these preliminary experiments, nutrients plus CO_2 or nutrients plus acid, added to the waters of Lake Emily caused green algae to become dominant, while adding nutrients alone caused the blue-greens to increase. A total of 70 experiments have now been done in the field and in the laboratory and the conclusions are as follows:

1. The phenomenon is reproducible. In every case (19) in Lake Emily where CO_2 was added with nitrogen and phosphorus, the blue-green to green shift occurred.
2. The phenomenon is not limited to Lake Emily. Ten other lake waters have been tested, and the shift took place in all of them.
3. Additions of HCl generally had the same effect as additions of CO_2, but some exceptions did occur.
4. The shift occurred whether field experiments were begun in June or in late September.
5. Field experiments with pH-controlled enclosures showed that the shift from blue-greens to greens occurred at pH values of 5.5 to 8.5, when CO_2 was used, and at pH values of 5.5 to 7.5 when HCl was used.
6. In most of the experiments, the green algae resulting from the shift were *Scenedesmus* and *Chlorella;* in one experiment, there were 22 species and subspecies of *Scenedesmus.*
7. The shift from blue-greens to greens seemed to be more rapid in spring and fall than in summer. This may be related to the size of the inoculum of greens: experiments with different sizes of inoculum showed the rate increased with a higher initial proportion of greens.
8. The shift often seemed to occur precipitously, and it involved almost all species of blue-greens in the lakes

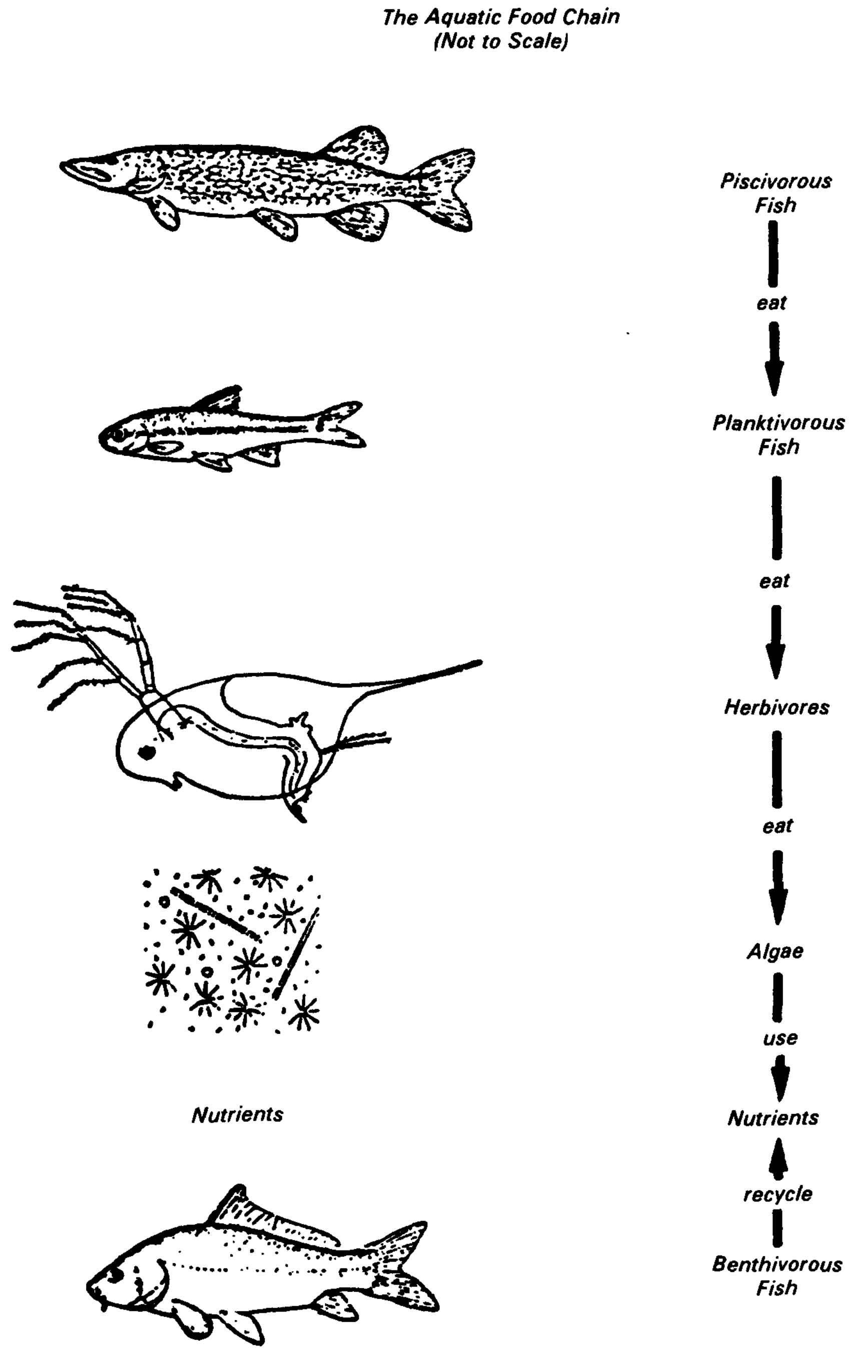

Figure 2. *The aquatic food chain (not to scale).*

tested. However, some blue-greens remained, for if the pH was raised, they again began to regain dominance.

9. The reason for the shift is obscure. It may involve competition between the two types of algae, but the *increase of the greens occurs after* the decrease of the blue-greens. Thus, the two phenomena are distinct. As the blue-greens disappear, phosphate and ammonia are found in the water but disappear as the greens grow.

10. One possibility is that the blue-greens are affected by algal viruses at lowered pH. This is suggested by the *manner in which the filaments break* up. The role of nutrients appears to be important to the greens. If arsenate, which reduces phosphate uptake by the greens, is added the shift is delayed or prevented. Chlorine additions at high pH also cause the shift, presumably by a different mechanism.

Manipulation of Algal Populations by Artificial Circulation of Lakes

Artificial circulation, frequently termed aeration, has been a lake restoration technique of limited value probably because of the lack of a proper theoretical framework for its use. To remedy this situation, two such frameworks were constructed: one to explain the shift from blue-green algae to greens that is often observed, and the other to explain the diminution in algal biomass that sometimes occurs. The hypotheses were tested in two lakes in a series of eight experiments utilizing a total of 76 enclosures one meter in diameter, which extended from the surface through the thermocline to a depth of eight meters. Some of the "bags" were open at the bottom, while others were sealed and filled with surface water only, so that following temperature stratification in them by conduction, the chemistry of their bottom waters could be adjusted. The enclosures were circulated by air to different depth and with different intensities.

Species Composition

Response of the phytoplankton at the species level appeared to depend primarily on changes in water chemistry in the euphotic zone during mixing. In the eutrophic lake with lower alkalinity, deep rapid mixing which increased nitrogen, phosphorus, and CO_2 levels in the euphotic zone led to a shift from blue-green algae to greens and diatoms. Deep slow mixing, which also increased nitrogen, phosphorus, and CO_2 levels in the euphotic zone resulted in increases in blue-greens. However, in the case of rapid mixing, carbon dioxide was introduced into the euphotic zone rapidly enough to lower pH values, while in the slow-mix enclosures pH remained high. This result agrees with results of the previous sections.

Not only did the green algae benefit from rapid circulation, but diatoms also increased. As this occurred during shallow mixing as well, without the increase in nutrients and CO_2, the mechanism must be different—possibly related to turbulence preventing the diatoms from sinking out of the euphotic zone.

Circulation in the higher alkalinity eutrophic lake was not as successful in shifting algal species composition. Not only was the water more buffered against pH change, but the concentration of CO_2 in the hypolimnion was lower. Consequently, pH values did not decrease significantly during circulation. Furthermore, the lake contained a metalimnetic population of *Oscillatoria rubescens* which generally increased in abundance in proportion to the total phosphorus increases in the euphotic zone resulting from mixing, and probably also as a result of increased light and temperature.

Community Response

Data from the circulation experiments were also used to construct and test a mathematical model describing response of the total algal community. The most important variables in the model were found to be Zm, the mixed depth, and TP, total phosphorus, which have opposite effects on the maximum concentration of chlorophyll in the mixed layer during circulation. An increase in Zm causes a decrease in chlorophyll and an increase in TP causes an increase in chlorophyll. The relative magnitude of these changes therefore determines whether the chlorophyll concentration will increase or decrease. Furthermore, the size of the chlorophyll change will be a function of such other factors as the N/P ratio, as at higher ratios the yield of chlorophyll/P is greater; the loss rate as a result of depth, sinking, and grazing—factors also affected by circulation; and the extinction coefficient, Ew, of the water as it is determined by non-algal substances dissolved or suspended in the water.

These results demonstrate why, without an adequate theoretical framework, it has been difficult to predict and/or understand the qualitative and quantitative changes that have occurred in lakes during circulation. The results obtained here will be useful in designing future attempts.

Manipulation of Algal Populations Through the Use of Specific Viruses

Attempts have been made without success to control blue-green algae in lakes by utilizing the known capacity of several viruses to lyse them. As part of an investigation into the mechanism of the shift from blue-greens to greens at lower pH, laboratory studies were used to explore the relationship between algal viruses and their hosts. The blue-green *Plectonema boryanum* and the Cyanophage LPP-1 were used. Among the factors studied were: 1) the effect of pH alterations, 2) the effect of algal host age and density, 3) the effect of nutrient concentration, and 4) the effect of other algal species. The most relevant observation was that the alga thrives at both high (>10.5) and low (<7.5) pH values in the absence of the virus, but it is lysed at the lower values in the presence of the virus. The implication is that lowering pH by artificial circulation of a lake may result in lysis of the blue-greens by viruses present in the system. However, more work needs to be done to determine whether this is what actually occurs.

Direct Manipulation of Zooplankton Populations

Decreases of algal abundance could result from increases in herbivore abundance. Therefore, experiments were conducted on the feasibility of using pantothenic acid, previously reported to be effective, to increase *Daphnia* abundance. Results were negative, and it is concluded that such manipulations, including attempts to add herbivores directly to lakes, would be ineffectual. Certain pesticides may be exceedingly effective in eliminating *Daphnia*, however.

Indirect Manipulation of Zooplankton Populations via Planktivorous Fish

Experiments in which different densities of planktivorous fish were studied for their effects on zooplankton and algal populations were carried out in enclosures, divided ponds, and whole ponds.

Enclosure Experiments

In an enclosure measuring one meter in diameter and one meter deep additions of bluegill sunfish eliminated such herbivores as *Daphnia pulex* and *Daphnia galeata* while allowing the smaller species, *Daphnia ambigua* and *Daphnia parvula*, to develop. Effects on the algae were dramatic with algal biomass in the enclosures with fish averaging, in one series, 16-fold than in the enclosures without fish. In some of the experiments, as fish predation intensity increased, filamentous blue-greens became relatively more abundant. In the absence of fish predation the predominant algae were greens. The effects on algal biomass were the result of fish predation on the zooplankton, rather than fertilization of the enclosures by fish excreta. This result was achieved by experiments in which nutrients were added intentionally to the enclosures.

Divided-Pond Experiments

These experiments were done by dividing a small pond (0.5 ha) with polyethylene sheeting. One half contained numerous fathead minnows and the other half contained a few larger fish. As in the enclosures, *Daphnia pulex* was eliminated in the half containing the minnows and *Daphnia ambigua* and *Daphnia parvula* appeared. Consequently, the algal biomass in this half of the pond averaged five times as high as that in the other half during July. This was not a result of greater phosphorus availability since the phytoplankton/P ratio was an average of 3.4 times as high in the "minnow" half.

Whole-Pond Experiments

In these experiments, two ponds side by side, which normally winter-killed, were used. One was stocked with mature perch and bluegill sunfish. One year later the ponds differed greatly in their zooplankton communities. In the stocked lake, *Daphnia pulex* was absent, chlorophyll concentrations were high and transparency was low. The pond not stocked had large populations of *Daphnia pulex*, generally low chlorophyll concentrations, and high levels of transparency.

During these investigations it was discovered that under certain circumstances the presence of *Daphnia pulex* appears to result in an abundance of *Aphanizomenon flos-aquae* in the form of large flakes not grazeable by the *Daphnia*. This has been noted in other studies, as described later.

Manipulation of Planktivore Populations with Fish Toxins

Previous Experiences in Minnesota

Examination of the files of the Minnesota Department of Natural Resources revealed 13 lakes which had been treated in previous years with fish toxicants; for all 13, pre- and post-treatment transparency data were available. Seven had higher transparencies after treatment, two probably increased in transparency and four showed no change.

Effect of Rotenone in Wirth Lake

This (16 ha, 4.3 m mean depth) lake is eutrophic from storm drainage input. Over a period of several years, the lake was treated by a variety of ameliorative techniques: nutrient export, artificial circulation, and piscivore stocking. However, beneficial effects were minimal (circulation actually increased nutrients and algal concentrations) until the lake was treated with rotenone in fall, 1977. In 1978, *Daphnia pulex* became abundant and, despite the circulation-caused high nutrient levels, it kept algal concentrations very low and transparency high until August. In August, *Aphanizomenon flos-aquae* became abundant in the flake form, disappearing only in September when *Daphnia pulex* were also absent. Evidence suggests that had the lake not been treated with rotenone, the piscivores would have controlled the planktivore populations and *Daphnia pulex* might have become abundant for this reason.

Effect of Rotenone in Clear Lake

This small lake divided by a roadway was treated with rotenone after one year of study. The half which had not previously winter-killed was affected most by the rotenone treatment. *Daphnia pulex* became abundant and algal biomass declined sharply.

Manipulation of Planktivores by Winter-Kill

Lakes Affected in 1978-79

Many Minnesota lakes winter-killed in 1978-79. Nineteen lakes including those with no winter-kill controls were sampled four times during spring and summer of 1979 to determine the effects. Of eight lakes suspected of hard winter-kill, four had *Daphnia pulex* in them, and in three it was the dominant crustacean, averaging 19-33/l. *Daphnia pulex* also appeared in two lakes suspected of partial winter-kill and in one lake known to be low in panfish.

Chlorophyll/TP ratios in the four lakes with abundant *D. pulex* averaged less than .132 ± .046. Among the remaining fifteen lakes, chlorophyll/TP averaged .362 ± .136.

Transparencies of the four *D. pulex* lakes averaged greater than 2.07 ± .57 m and that of the remaining fifteen lakes 1.63 ± .68 m. For three control lakes, for which pre- and post-winter-kill transparency data were available, no transparency changes were noted following winter-kill; but for three partial winter-kill lakes, transparency doubled after the winter-kill.

With regard to the algal population, three of the four lakes in which *D. pulex* were abundant were characterized by an abundance of *Aphanizomenon flos-aquae* in its flake form.

Effect of Winter-Kill in Lake of the Isles

In 1976-77, Lake of the Isles in Minneapolis suffered a severe winter-kill. This storm drainage-fed eutrophic lake had perennially developed large crops of blue-green algae and low transparency during summer. In 1977, transparencies were so high that macrophyte problems prevailed, requiring mechanical harvesting. The high transparencies were probably caused by grazing by *Daphnia pulex* which became abundant in the lake following the demise of the planktivores. At the same time as *D. pulex* appeared, *D. magna* was found in the lake, and *D. galeata* increased in size over previous years. Although some of the increase in transparency resulted from the decrease in chlorophyll, part of the increase rests on the fact that much of the remaining chlorophyll was present in *Ceratium*. Not only do these organisms not attenuate light effectively, but they were most abundant at some distance below the lake surface.

Effects of Physical-Chemical Conditions on Algal Populations

Lake Harriet (143 ha; 8.8 m mean depth) in Minneapolis perennially produces lower algal concentrations than expected from its nutrient concentrations. This discrepancy has been attributed to grazing by the abundant *Daphnia galeata*, and indeed low chlorophyll concentrations have been correlated with a high proportion of phaeophytin—evidence of such grazing. In 1974, summer chlorophyll concentrations in the lake suddenly increased from the usual 5 μg/l to as high as 47 μg/l. Algal volumes increased in proportion and transparencies decreased. The situation ameliorated in 1975, and by 1976 was "normal." In recent years, the same phenomenon appears to be recurring.

The explanation for the high chlorophyll in 1974 appears to lie in the reduced numbers of *Daphnia* present that year. The decreased numbers of *Daphnia* may have resulted indirectly from the somewhat higher concentration of phosphorus in the lake in 1974. That is, the hypothesis was made that the increased phosphorus levels, too low to raise algal abundance by more than 20 or 30 percent, nonetheless allowed primary production in the euphotic zone (not measured) to increase to the extent that dissolved oxygen concentrations in the upper part of the hypolimnion (measured) became too low to allow the *Daphnia* to retain the zone as a refuge from fish predation. Consequently, the *Daphnia* were forced to inhabit the waters above, where predation depleted their numbers and released the algal population from their herbivory. Hence the algal increase. If this hypothesis is correct, it will represent the first true threshold effect of nutrients in stimulating algal biomass in a lake. It also opens the possibility that, if the upper portion of the hypolimnion of such a lake were to be oxygenated artifically, *Daphnia* could find a refuge from the fish and remain abundant enough to limit the size of the algal population.

Reference

Lamarra, V. A. Experimental studies of the effect of carp (*Cyprinus carpio*) on the chemistry and biology of lakes. Ph.D. Thesis. University of Minnesota, Minneapolis. 1975.

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The complete report, entitled "Experiments and Experiences in Biomanipulation: Studies of Biological Ways to Reduce Algal Abundance and Eliminate Blue-Greens," (Order No. PB 83-148 098; Cost: $22.00, subject to change) will be available only from:

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