Macrophyte Control By Harvesting And Herbicides: Implications For Phosphorus Cycling In Lake Wingra, Wisconsin

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ABSTRACT

Harvesting of Eurasian water milfoil would remove an amount of phosphorus equal to about 37% of the annual net load in Lake Wingra. Phosphorus removal would be the equivalent of 100% of the available phosphorus and 22% of the total inorganic phosphorus in the upper 12 cm of littoral sediment. Repeated harvests year after year would be necessary to deplete available phosphorus in the sediments because (a) shoots obtain an unknown fraction of their phosphorus from the water, (b) available phosphorus in the sediments is continually replenished by equilibration with insoluble forms and (c) phosphorus is continually added to the sediments by sedimentation. Harvesting alone cannot counteract the tremendous loading of nutrients to the lake in urban runoff. Chemical poisoning of macrophytes would release at least 165 kg of phosphorus into the lake water within a few days. This nutrient pulse, equal to about a tenth of the lake's annual net phosphorus load, would include a large proportion of phosphate that could be readily assimilated by algae.

INTRODUCTION

Mechanical harvesting has been an attractive approach to the management of nuisance growth of aquatic macrophytes for a variety of ecological and practical reasons. Harvesting is target-specific, removes the nuisance immediately, removes nutrients from the ecosystem, and generates a resource which is potentially useful as mulch, fertilizer, or fodder (12, 16). Nutrient removal is one of the most frequently cited advantages of harvesting, yet little information exists on the magnitude of potential nutrient removal by harvesting and the implications of this removal for the ecology of lakes.

We have investigated potential removal of nutrients from eutrophic hardwater Lake Wingra in suburban Madison, Wisconsin. The lake is shallow (mean depth = 2.4 m) and at the peak of the growing season has dense growths of Eurasian watermilfoil (*Myriophyllum spicatum* L.) over 30% to 35% of its surface (11). This paper reports potential removal of 15 minerals, including 10 essential plant nutrients, from the lake. Implications of potential phosphorus removal from the lake ecosystem are discussed and compared with the probable consequences of widespread herbicide use in the lake.

METHODS

Methods of shoot sampling for tissue chemistry analysis and analytical procedures were described previously (7). Eurasian watermilfoil shoot biomass was measured both by analysis of aerial photographs (11) and conventional quadrat sampling techniques (1).

Studies of decomposition were carried out in the laboratory using freeze-dried shoots of Eurasian watermilfoil. Shoots were incubated in 750 ml of glass fiber-filtered lake water in aerated one l bottles. Volume of the water phase was maintained at 500 ml or more by periodic additions of distilled water to replace water lost by evaporation. At the end of incubations, coarse particulate material was isolated by filtration through 0.33 mm mesh plankton net. The material was dried (70 C for 24 hr), weighed, and subsampled for determination of phosphorus content by a vanadomolybdate procedure (13). Final phosphorus content was compared to initial phosphorus content determined by the same method on parallel subsamples of undecomposed freeze-dried tissue.

The plankton net filtrate was subsampled for total phosphorus determination, and then passed through 0.7 μ glass fiber filters and subsampled for dissolved total phosphorus and dissolved inorganic phosphorus measurements. Dissolved phosphorus was determined by a phosphomolybdate procedure (22) with the strength of the reagents increased 37%. Total phosphorus was determined by the same method after persulfate digestion (17).

Plants cultured in radiophosphate were lyophilized and allowed to decompose. The molecular weight distributions of dissolved phosphorus compounds in the leachates were determined by gel filtration (Sephadex G-25) followed by measurement of P^{32} activity by Cerenkov counting on the tritium channel of a Packard Tri-Carb liquid scintillation counter.

RESULTS AND DISCUSSION

Potential removal of 15 minerals from Lake Wingra by thorough harvesting of Eurasian watermilfoil in late August is illustrated in Figure 1. Most of the minerals studied were essential nutrients for plants, with the exceptions of sodium, aluminum, barium, strontium, and chromium (9). The time of maximum potential removal varies from mineral to mineral (7). Most studies have indicated that phosphorus is the most critical process-limiting nutrient in Lake Wingra (7, 20, 23). Therefore, a harvesting program designed to alleviate symptoms of eutrophication should maximize phosphorus removal. Maximum phosphorus removal would occur with a late August harvest (7).

What significance does mineral nutrient removal have for the lake ecosystem? One approach to this question is to examine the role of macrophytes in the nutrient budgets of the lake. In a previous publication, nitrogen and phosphorus budgets for Lake Wingra were calculated and compared with potential nutrient removal by harvesting (7). The results for phosphorus are shown schematically in Figure 2. Precipitation, dryfall, urban runoff, and springs contribute a gross annual load of 1740 kg to the lake. Downstream losses through the lake's outlet are 150 kg•yr^{-1}, so the net annual phosphorus load is 1590 kg. Thorough harvesting of Eurasian watermilfoil in late August would remove 580 kg of phosphorus, or about 37% of the lake's annual net load. Potential removal of nitrogen by harvesting in late August was about 17% of the annual net nitrogen load.

Rooted macrophytes such as Eurasian watermilfoil probably derive a significant fraction of their shoot nutrients from the sediments (24). Therefore, harvesting could result in the removal of substantial amounts of phosphorus from

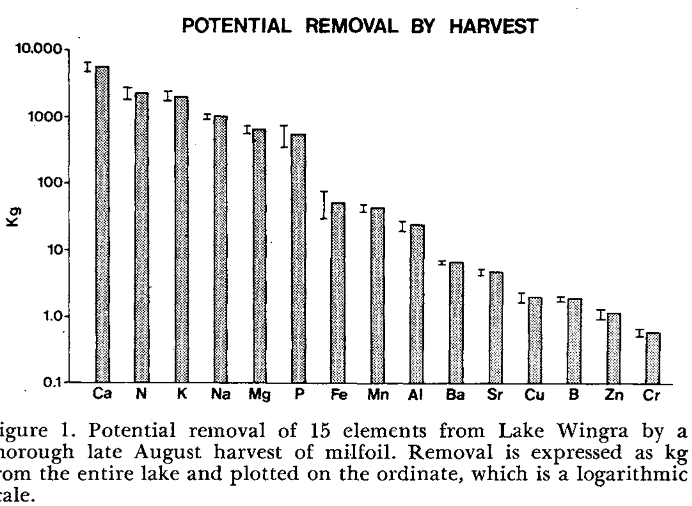

Figure 1. Potential removal of 15 elements from Lake Wingra by a thorough late August harvest of milfoil. Removal is expressed as kg from the entire lake and plotted on the ordinate, which is a logarithmic scale.

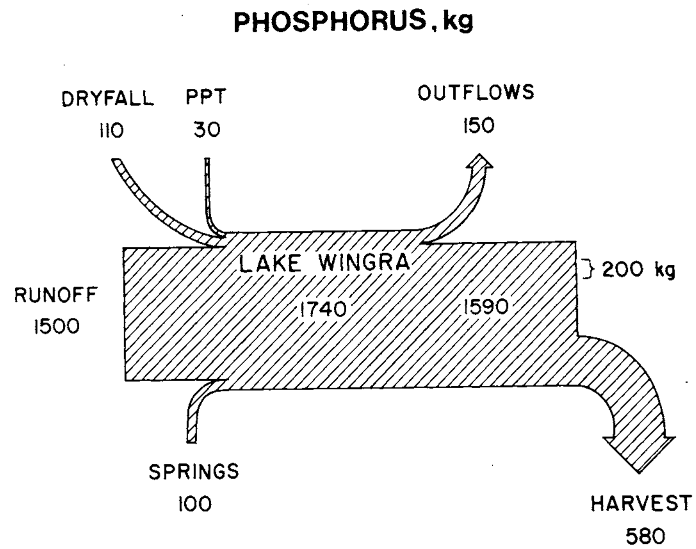

Figure 2. Annual phosphorus budget of Lake Wingra.

the surface sediments. The upper 12 cm of littoral sediment in Lake Wingra contains 6.4 g inorganic phosphorus•m^{-2} (3). About 22% of this phosphorus is available to plants (15), or about 1.4 g•m^{-2}. A late August macrophyte harvest could remove about 1.4 g P•yr^{-1}•m^{-2} of littoral zone.

Potentially harvestable phosphorus is equivalent to available phosphorus in the upper 12 cm of littoral sediments. However, years of repeated harvesting would be necessary to deplete sediment phosphorus. Between 0.5 and 1.0 g•m^{-2} of phosphorus is added to littoral sediments each year by sedimentation.[1] Available phosphorus is replenished by equilibration with the insoluble inorganic phosphorus pool, which is about 4 times larger. This indicates that 10 to 15 years of annual harvests would be necessary to deplete sediment phosphorus. This is a minimal estimate because it is likely that some macrophyte shoot phosphorus is taken up from the water rather than the sediments.

The potential benefits of nutrient removal by harvesting are clear. To aid in management decisions, it was desirable to compare the potential effects of harvesting and macrophyte control by herbicides. Previous studies in Wisconsin have shown harvesting and herbicides to be comparable in cost and effectiveness.[2] Effects of herbicides, including release of nutrients, oxygen depletion, and toxicity to nontarget organisms have been reviewed recently (6, 18). Because of its apparently critical role in Lake Wingra, phosphorus was emphasized in this investigation of potential effects of herbicides.

Phosphorus is lost rapidly from decaying Eurasian watermilfoil. During the first 2 days of decomposition, coarse particulate phosphorus is broken down to fine particulate and dissolved forms more rapidly than coarse particulate organic carbon. Presumably, this is because a greater proportion of the phosphorus is found as soluble, readily metabolized forms within the plant cells. In situ, loss rates of phosphorus from decaying Eurasian watermilfoil are probably higher

[1]Carpenter, unpublished estimates.

[2]Nichols, S. A. 1974. Mechanical and habitats manipulation for aquatic plant management: A review of techniques. Tech. Bull. No. 77, Dept. Nat. Resour., Madison, Wisconsin. 34 pp.

than those we measured, because fresh tissues lose phosphorus at a slightly greater ratè than freeze-dried tissues.[3]

Initial losses of phosphorus from decaying shoots were linearly related to the initial phosphorus content of the tissue (Figure 3). Within 2 days, the phosphorus content of decaying coarse particulates stabilized at about 0.05% to 0.1%. After an initial period of leaching and stabilization of about 2 days, breakdown of coarse particulate phosphorus paralleled the breakdown of organic carbon.

Filtration and chemical analysis of phosphorus decomposition products indicated that they comprised approximately equal fractions of fine particulate phosphorus and dissolved inorganic phosphorus. Dissolved organic phosphorus was a relatively unimportant component of the breakdown products. Apparently, formation and maintenance of a dissolved organic phosphorus pool depended on the activities of microbes.

The results obtained by chemical methods were corroborated by the results of gel filtration (Figure 4). The largest peaks of the elution curves (ca. fractions 18-22) probably represent phosphate, since elution points of a given compound typically vary by a few fractions from filtration to filtration. In the elution curve produced by the intact microbial community, two organic phosphorus peaks appear, one in fractions 10 and 11 and one in fraction 16. Organic phosphorus peaks are absent in the elution curve from the incubation in which microbes were poisoned with mercury.

Literature reports of nutrient release following macrophyte control by herbicides are inconsistent. Several studies have documented phosphorus release into the water, corroborating the results presented here (8, 14, 19). However, several cases have been reported in which macrophyte de-

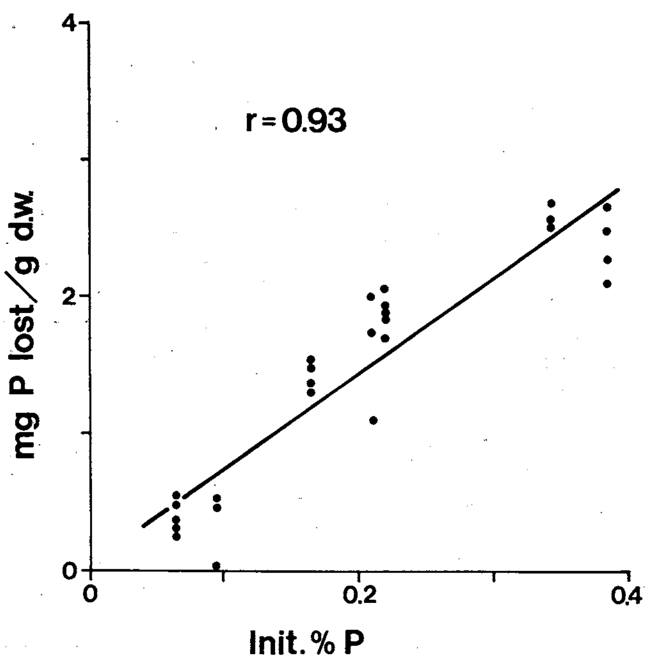

Figure 3. Phosphorus release during the first 10 days of macrophyte decay as a function of the initial tissue phosphorus concentration.

[3]Carpenter and Adams, unpublished data.

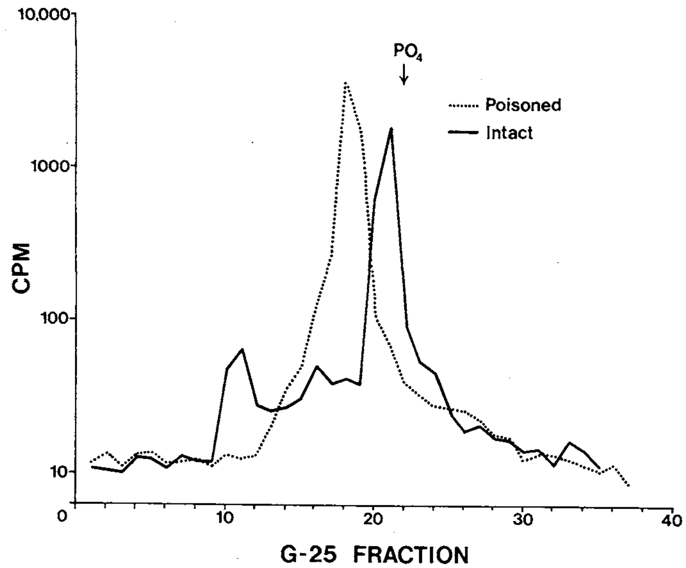

Figure 4. Counts per minute (CPM) of P^{32} in gel filtration fractions of dissolved macrophyte decomposition products from intact incubations and incubations poisoned with 5 mg $Hg \cdot l^{-1}$. On the abscissa, molecular weight decreases from left to right.

composition following herbicide use had little effect on the phosphorus content of the water (4, 5, 10, 21).

In some cases, nutrient release may be masked by rapid uptake and incorporation into algal biomass (5). However, Strange (21) reported no increases in algal biomass or nutrient concentrations in the water. It is possible that nutrients were tied up in microbial biomass since herbicide use increased microbial metabolism. A second possibility is that the plants had low initial concentrations of phosphorus, and little was available for release to the water.

Data presented here indicate that release or uptake of phosphorus by macrophyte detritus was dependent on the initial phosphorus concentration of the senescent tissue. Little or no phosphorus was released by tissues with low phosphorus concentrations of 0.05% to 0.1%. However, most of the macrophyte shoot tissue in Lake Wingra contained sufficient phosphorus to release a great deal of the nutrient into the water.

During the growing season, concentrations of phosphorus in milfoil shoots in Lake Wingra ranged from 0.15% to 0.45% (7). In late June, when the macrophyte biomass usually first reaches nuisance levels, tissue concentrations of phosphorus were about 0.2%. At that tissue concentration, release of phosphorus during the initial stages of decomposition would be about 1.5 mg P per g dry weight of tissue (Figure 3). Typically, the total biomass of milfoil in the lake in late June is about 1100 metric tons dry weight (1, 11). Therefore, total phosphorus release by thorough poisoning of macrophyte shoots at that time would be about 165 kg. This pulse would equal about 10.4% of the lake's annual net loading. About half the pulse would be phosphate, which could be rapidly taken up by the algae. Poisoning earlier in the season when biomass was lower would not ameliorate the nutrient release because tissue concentrations of phosphorus are higher earlier in the growing season (7). Tissue phosphorus concentrations decrease while biomass increases during the middle of the summer. Later in the summer, biomass and tissue phosphorus concentrations increase, and the severity of the consequences of herbicide use would increase accordingly.

We conclude that herbicide use would increase phosphorus availability and could thereby accelerate the eutrophication of Lake Wingra. Harvesting, on the other hand, would remove nutrients from the lake.

Harvesting alone cannot counteract the tremendous loading of nutrients to the lake in urban runoff. Lake Wingra was eutrophic when Europeans first settled Wisconsin (2) and it is probably unrealistic to try to make it oligotrophic today. However, the rate of eutrophication has accelerated over the years because of human activities. Harvesting can partially counteract the effects of increased nutrient loading, and thereby help to return the lake to its pristine state. Greater reductions in the rate of eutrophication would require further steps such as decreases in point-source nutrient loads.

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