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The Effect of Harvesting on Macrophyte Regrowth and Water Quality in LaDue Reservoir, Ohio

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Two experiments in a bay of LaDue Reservoir (Geauga Co., northeastern Ohio) during summer, 1985 demonstrated that removal of Eurasian watermilfoil (*Myriophyllum spicatum* L.) root crowns with an aquatic weed harvester retarded plant regrowth to quantities well below nuisance levels for 28 days. Nearly summer-long control was achieved following a "touch-up" harvest on day 42. In contrast, the harvester was used in this bay in 1982 to "mow" milfoil, leaving intact "stumps." The mowed plants regrew to preharvest and control area biomass levels within 23 days. The difference in plant regrowth between these two methods strongly suggests that user dissatisfaction with harvesting could be reduced by using the root crown removal technique. Root crown removal was associated with elevated levels of total phosphorus, chlorophyll, blue-green algae, and seston. The implications of milfoil control with root crown removal, and the associated water quality change, are discussed in relation to recreational and water supply uses of lakes and reservoirs.
INDEX DESCRIPTORS: *Myriophyllum* sp., lake management, aquatic weed harvesting, water supplies, trihalomethanes.

Submersed and floating macrophytes, often called "weeds," can grow prolifically in shallow, well-lighted ponds, reservoirs, and lakes, and in shallow embayments of deeper water bodies. These plants form a habitat for many organisms and are a major source of nutrients and energy to pelagic food webs in some lakes (Wetzel, 1983).

Dense growths of macrophytes are nuisances to swimming, boating, and fishing. Macrophyte-infested water bodies used as potable water supplies can provide poor tasting raw drinking water which may be high in trihalomethane precursors. As well, decomposition of plants can produce a high oxygen-demand in deep water leading to releases of iron, manganese, and nutrients from sediments, thereby indirectly affecting drinking water quality (Cooke and Carlson, 1989).

Management of macrophyte infestations has always been difficult. Many techniques, none without drawbacks of cost, toxicity, and/or limited longevity of effect, have been employed (Cooke et al., 1986). Two of these, stocking with grass carp (*Ctenopharyngodon idella* Val.) and harvesting, have been frequently used in midwestern lakes because of their effectiveness and comparatively low environmental impacts (Cooke and Kennedy, 1989).

Harvesting has been a popular choice for aquatic plant management. No toxic substances are introduced, plant material and a source of nutrients and oxygen demand are removed, and selected areas of the lake can be treated, leaving the remainder of the littoral zone in an unmanaged condition.

A harvester is a machine which is used to lower a horizontal and two vertical cutter blades, mounted on the fore-end of a conveyer, into the water column. The depth of the cutter blades can be increased by the operator, usually to a maximum of 1.5-1.8 meters. As the harvester moves forward, plants are cut, fall onto the conveyer, and are transported into the hold. In water deeper than the reach of the cutter bar, only the tops of the plants can be cut. Harvesters vary in size. The largest hold up to 22 m^3 of cut plants, the smallest about 3 m^3. Loads of plants are dumped at the shore into trucks and removed. Further details are found in Cooke et al. (1986), Cooke and Kennedy (1989) and Cooke and Carlson (1989).

A major problem with harvesting is the rate of regrowth. For example, Anderson (1984) found that the biomass of macrophytes in a bay of LaDue Reservoir (Ohio) returned to preharvest quantities, and to the amount of biomass in an unharvested control bay, within 23 days of harvesting during a 1982 experiment. In this case, as in most harvesting experiences, the harvester was used to "mow" the plants, and stumps which allow quick regrowth were left intact. When plants regrow at this rate, up to three full harvests per summer season would be needed to keep the weeds at non-nuisance levels, at a cost of $300 per hectare or more for each reharvest (see Cooke and Kennedy (1989) and Cooke and Carlson (1989) for cost comparisons of lake management techniques).

An alternative to the "mowing" technique was suggested by Conyers and Cooke (1983). They lowered the cutter blade into the sediment-water interface. Root crowns were removed and macrophyte regrowth in a small test plot in East Twin Lake (Ohio) was compared to control plot and preharvest biomass. Even after a seven week regrowth period the biomass in the harvested plot was only 69% of the preharvest biomass and 12% of the control plot biomass. Their results suggested a far more effective means of using a harvester.

The purpose of the present study was to determine the relationship between harvesting frequency, using the root crown removal technique, and the regrowth of the exotic nuisance macrophyte, Eurasian watermilfoil (*Myriophyllum spicatum* L.), in test plots in a bay of LaDue Reservoir (Ohio). The experimental design was suggested by the report of Nichols and Cottam (1972), who compared milfoil regrowth in plots harvested with a diving knife.

The root crown removal harvesting technique has the potential to impair water quality by disturbing littoral sediments, thereby increasing the concentration of suspended and dissolved materials in the water column. To study this potential impact, a large section of the Auburn Road bay was harvested, using root crown removal rather than mowing, and its water quality and macrophyte biomass compared to an adjacent and unharvested upstream section of the bay.

LOCATION

LaDue Reservoir (Geauga Co., Ohio) is a water supply impoundment located on Bridge Creek, Black Brook Ditch, and Black Brook, which were direct tributaries to the Cuyahoga River prior to dam construction. Figure 1 illustrates its location and Figure 2 is a morphometric map of the reservoir showing the location of the Auburn Road bay where the study took place during summer, 1985. Table 1 is a list of the morphometric features of the reservoir. As suggested by the high ratio of drainage basin to reservoir surface area, LaDue Reservoir receives substantial runoff from the well-drained soils of its forested and mainly agricultural watershed.

LaDue Reservoir is eutrophic. The deep open water supports heavy blue-green algal blooms during summer (mean chlorophyll A of 43.0 $\mu g l^{-1}$) and is nutrient-rich (mean total phosphorus $= 42.0 \mu g P l^{-1}$). Auburn Road bay receives the flow of Bridge Creek, the reservoir's principal tributary, and is shallow (mean depth of about 1.0 m), turbid (Secchi Disc transparency < 30 cm), nutrient-rich (mean summer total phosphorus $= 66.0\ \mu g\ P\ l^{-1}$), alkaline (total alkalinity $= 110$ mg $CaCO_3\ l^{-1}$), and choked with macrophytes. The dominant plant is *Myriophyllum spicatum* (Eurasian watermilfoil), with

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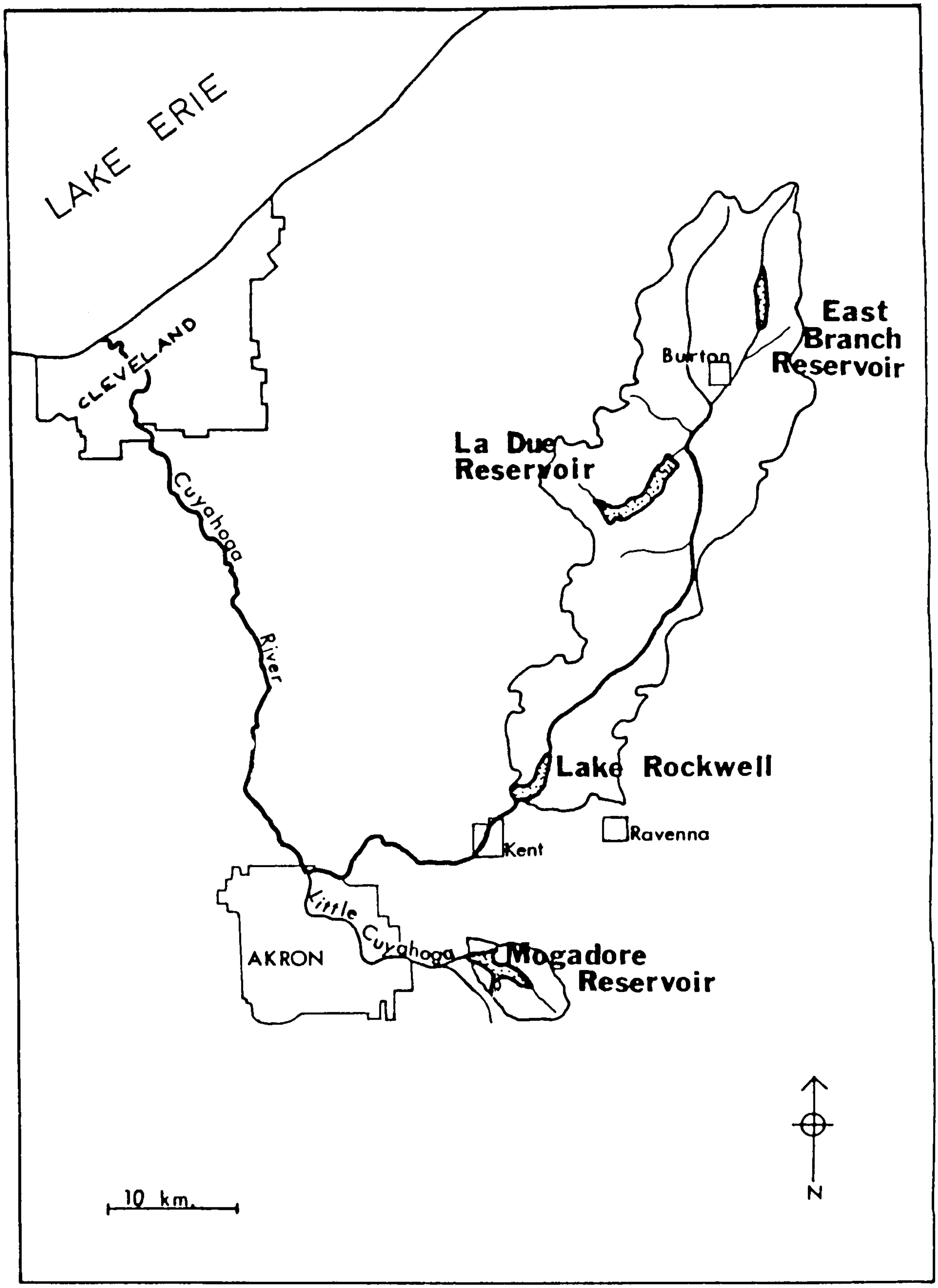

Fig. 1. The location of LaDue Reservoir and other Akron, Ohio water supply reservoirs on the Cuyahoga River (from Cooke and Carlson, 1986).

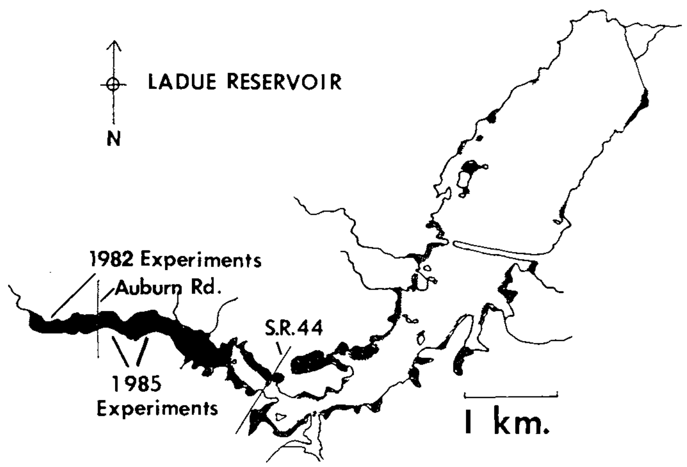

Fig. 2. LaDue Reservoir, Bridge Creek, and the Auburn Road bays. Shaded areas have 100% coverage by macrophytes.

lesser populations of *Nymphaea* sp. and *Potamogeton* sp. The Auburn Road bay is actually divided into a series of smaller bays which are partially separated from each other, allowing some areas to be harvested and some to serve as controls. It should be noted that the first part of the bay, where Bridge Creek enters, is the location harvested by Anderson (1984) in 1982 (Figs. 2 and 3).

METHODS

Four 9 × 16 m plots were established, side by side, with 3 m gaps between them, along the north shore, in the bay just east of Auburn Rd. (Fig. 3). Depth in the plots was 0.25-1.0 m. Weekly plant biomass samples (nearly 100% Eurasian watermilfoil) were taken from each plot, and from areas directly adjacent to the open water end of the plot (controls), for 10 weeks, beginning 10 June 1985.

Macrophyte biomass was obtained by removing all plants, including roots, from three randomly chosen 0.25 m^2 quadrats in each test plot. SCUBA was used as needed. The plants were gently washed of silt and oven dried until constant weight was reached.

All plots were initially harvested with an Aquamarine H-650 harvester on 8 July 1985, week four of the experiment, by placing the cutter bar 1-2 cm into the sediments to remove root crowns. To determine the relation between harvest frequency and regrowth, one plot was then reharvested weekly, a second every other week, a third plot every third week, and the last plot every fourth week (Fig. 4).

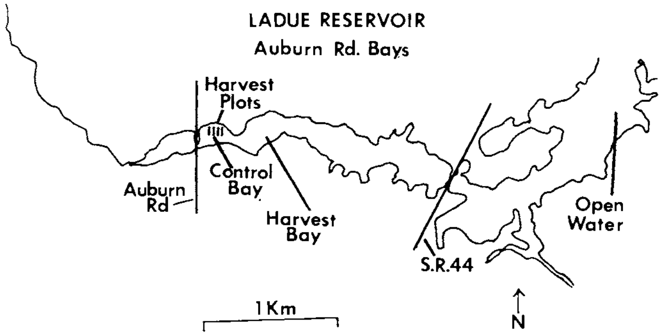

Fig. 3. Locations of the harvest frequency test plots and the harvest and control bays in LaDue Reservoir near Auburn Road.

Table 1. **Morphometric Features of LaDue Reservoir (Ohio) and Its Watershed.**

Watershed Area (WA)	84.48 km^2
Reservoir Area (RA)	5.91 km^2
WA/RA	14.3
Mean Depth	3.77 m
Maximum Depth	7.0 m
Water Residence Time	1.22 yr

The effect of the root crown removal technique on water quality was assessed by comparing the two sections of the bay just downstream from Auburn Road (Figs. 2 and 3). The bay section where the harvesting-frequency plots were located (16 ha) remained otherwise uncut, and served as a control for the experiment. It was assumed that harvesting in the small test plots along its north shore would not affect water quality of the entire 16 ha bay area. This bay was also the control bay for Anderson's (1984) 1982 harvesting experiment. The slightly larger bay (20 ha) just downstream, separated by a narrow neck from the control bay, was harvested completely on 8 July 1985 (day 14) with the root crown removal technique. A second "touch-up" harvest took place on 19 August (day 42). Both bays are shallow (0.25-2.0 m), with most of the water less than 1.5 m deep, have organic-rich soft hydrosoils, and support a dense infestation of *M. spicatum*. Plant biomass in the control bay was sufficient to eliminate recreational uses.

Weekly sub-surface (0.1-0.2 m) samples were taken from each bay, in a central location, for chlorophyll, algae, seston, and total phosphorus. Chlorophyll was determined following Long and Cooke (1971). Seston was determined by filtering known water volumes through tared, preignited glass fiber filters, followed by oven drying and reweighing. Total phosphorus was determined with the USEPA (1971) method, modified to include digestion in a pressure cooker for 45 mins at 121° C and 15 psi. Five randomly chosen sites in each bay were sampled for macrophyte biomass determinations using procedures described earlier.

RESULTS AND DISCUSSION

Sampling variance was sometimes high, as is common in aquatic macrophyte biomass studies. For this reason, biomass data are expressed in a unit equal to the sampler size (0.25 m^2) rather than extrapolated to some larger area such as a square meter. The plants had patchy distributions, producing some of the variance. However the harvester occasionally pushed over some plants without cutting them, and also small areas were missed. When these sites were among those randomly chosen for sampling, for example in the two week frequency plot at week 6 (Fig. 4), the data gave the appearance of plant regrowth. Another important source of biomass variance when sampling *M. spicatum* comes from the formation of a canopy by this plant so that as much as 70% of its biomass is located in the upper 0.5 m of water (Grace and Wetzel, 1978). In deeper water, where the canopy tended to drift or lean over open spaces, it was difficult to drop the sampler over the plant stems. The effect of this problem was an underestimate of actual biomass. Neverthless, the data clearly illustrate the visually observed effects of the harvester on macrophyte biomass.

HARVEST FREQUENCY EXPERIMENT

Initial biomass in the plots on 10 June 1985 ranged from 5-20 gms. dry weight 0.25 m^{-2}. By 8 July, the date of the first harvest, biomass had increased in three of the plots and remained unchanged in one of them (Fig. 4). The root crown removal technique controlled

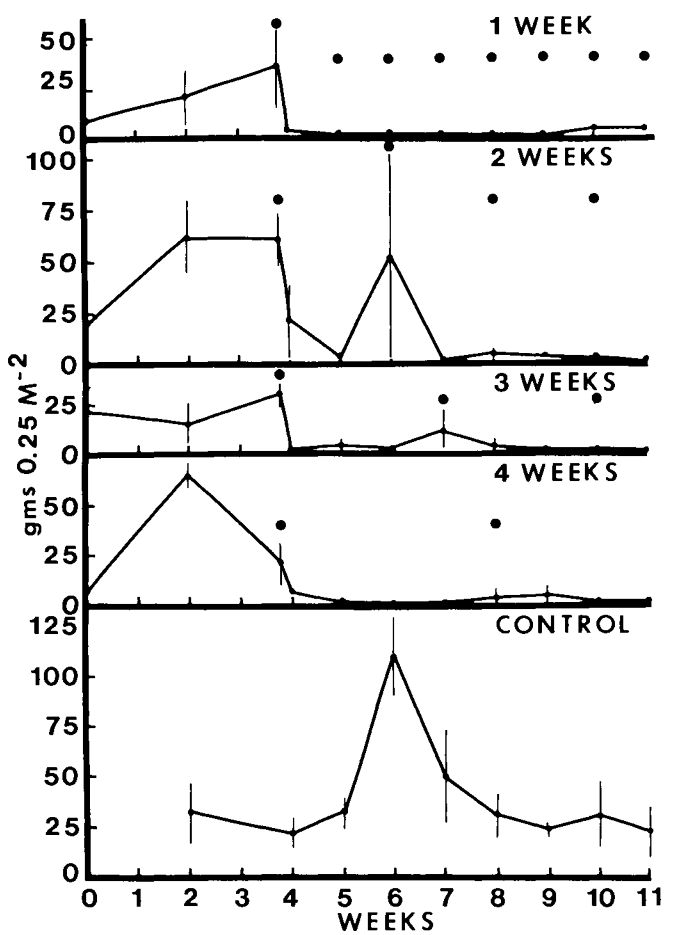

Fig. 4. The effect of harvest frequency on regrowth of aquatic macrophytes in LaDue Reservoir. Dots indicate times of harvest. Data are gms. dry wt. 0.25 m^{-2}. Bars are +/− one standard error (redrawn from Cooke and Carlson, 1986).

milfoil biomass to very low levels (< 5 gm. dry weight 0.25 m^{-2}), whether the plots were harvested weekly, or up to a harvest interval as long as one month. The control area had an average biomass level of at least 25 gms dry weight 0.25 m^{-2} throughout the experiment, and increased to a midsummer peak of more than 100 gms. dry weight 0.25 m^{-2}. The "mowing" technique, used in an adjacent bay in 1982 (Anderson, 1984), in contrast, left "stumps", and plants rapidly regrew to initial biomass levels and to the biomass level of the control bay within 23 days (Table 2).

Longevity of effect is important when using harvesting to improve recreational areas or to protect raw drinking water quality. Harvesting with root crown removal took place in early July, near the time when intense milfoil growth would take place and recreational use is approaching its maximum. If plant biomass can be kept low until early August in lakes of these latitudes, with perhaps a "touch-up" harvest, then biomass will begin to decline naturally as the days become shorter, water becomes cooler, and the shading effect of late summer algal blooms occurs. For water supplies, this effect could mean a reduction in the concentration of trihalomethane precursors which normally increase in late summer (Cooke et al., 1988), and for the lake users, this effect could mean a non-nuisance level of macrophytes from the beginning to the end of the heavy recreation season. It is presently unknown whether the harvesting process itself will add trihalomethane precursors to the water column by disturbing sediments.

EFEFCTS OF LARGE-SCALE HARVESTING ON BIOMASS AND WATER QUALITY

Eurasian watermilfoil develops greater biomass in deeper (1-3 m) water (Grace and Wetzel, 1978). This appeared to be the case in LaDue Reservoir, as shown by comparing biomass data in Figures 4 and 5. Initial biomass on 24 June 1985, prior to harvesting, averaged about 30 gms. dry weight 0.25 m^{-2} in the deeper water of both bays, and increased to over 60 gms. dry weight 0.25 m^{-2} in the control bay by day 35 (29 July) (Fig. 5).

Root crown removal was effective in maintaining sharply reduced milfoil biomass for 28 days (day 14-42), and a small-scale "touch-up" harvest at day 42 essentially eliminated the macrophyte problem through day 60 (23 August). The control bay developed a large biomass of milfoil, plus some *Potamogeton* sp. and *Nymphaea* sp., which reached a peak on day 35 (29 July). Recreational use of this bay stopped in early July just prior to the initial harvest because macrophyte density prohibited boat traffic and fishing. As with the small test plots, a single harvest, in which root crowns were removed by lowering the cutter blade into the top 1-2 cm of sediment, was sufficient to maintain milfoil biomass at non-nuisance levels (less than 5 gms dry weight 0.25 m^{-2}) for about one month. The "touch-up" harvest kept the bay open until about the end of the primary recreation (fishing, boating) season in early September (Fig. 5). These results are in direct contrast to the results of Anderson (1984), shown in Table 2, wherein biomass of harvested plants in an upstream bay in the Auburn Road area returned to preharvest levels and to the level of the control bay within 23 days.

The root crown removal technique produced obvious changes in water quality (Fig. 5). Total phosphorus, an algal nutrient often in growth limiting concentrations in some lakes, was higher in the harvested bay than in the control. Seston was always higher in the harvested bay, especially in late summer when there were more windy days and the erosion-damping effects of rooted plants were low. The harvested bay, but not the control, had a series of algal blooms (*Anabaena* sp., followed by two blooms of *Aphanizomenon* sp.). Each bloom was larger than the previous one (up to 60 μg Chl A l^{-1}). The seston data also reflect the algal blooms.

It is unknown whether the increased phosphorus concentration in the harvested bay was responsible for the algal blooms. No determination of the limiting factors to phytoplankton growth was made. While the concentrations of other potentially limiting nutrients such as nitrogen are unknown, the very high levels of phosphorus at the beginning as well as during the experiment strongly suggest that if nutrient stimulation of algal growth in the harvested bay was involved, the growth-limiting nutrient probably was not phosphorus. This conclusion is also supported by the observation that no algal blooms occurred in the control bay despite fairly high levels of total phosphorus (about 50 mg m^{-3}).

Table 2. Mean macrophyte biomass and standard error in gms. dry weight m^{-2}, after harvesting in a LaDue Reservoir bay near Auburn Road. Harvesting occurred on 17 July 1982 (from Anderson, 1984).

Date	Control Bay	Harvest Bay
	Pre-Harvest	
6-22-82	147.9 ± 29.4	123.4 ± 10.4
7-8-82	140.7 ± 36.5	228.3 ± 73.7
	Post-Harvest	
7-21-82	117.6 ± 9.9	26.6 ± 5.2
8-9-82	189.4 ± 24.8	216.9 ± 26.9

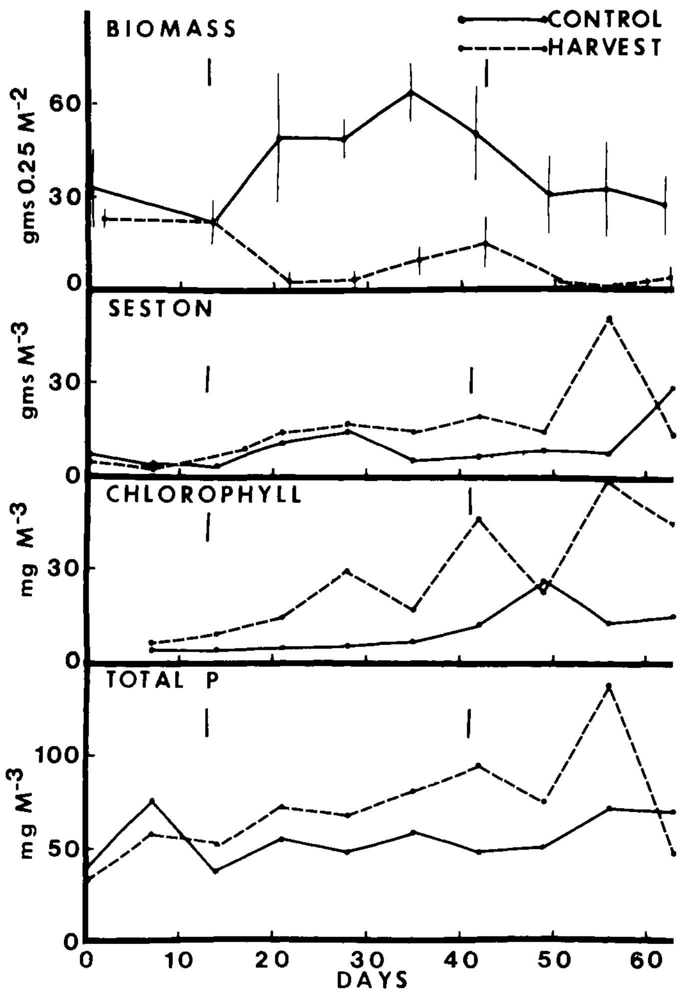

Fig. 5. Changes in aquatic plant biomass and water quality in harvest and control bays of LaDue Reservoir. Vertical bars indicate harvest dates. Bars on the plant biomass data points are +/− one standard error.

Some investigators have reported algal blooms following macrophyte removal by grass carp or harvesting (e.g. Neel et al., 1973; Richard et al., 1984) while others have not (e.g. Canfield et al., 1983; Wile et al., 1979), and several explanations are possible.

It has been suggested (summarized by Canfield et al., 1983), that there is an antagonistic relationship between phytoplankton and submersed macrophytes, and/or their epiphytes, that could offer a hypothesis to explain the algal blooms. For example, Planas et al. (1981) found that phenolic compounds (allelochemics) released by *M. spicatum* were inhibitory to *Anacystis nidulans* and three species of Chlorophyta. In other experiments however, *M. spicatum* stimulated phytoplankton productivity, though not biomass, in enclosures (Godmaire and Planas, 1986). Greater intensity of zooplankton grazing of algae in the control bay is also a possible explanation for the absence of algal blooms in it. Timms and Moss (1984) have provided evidence to support the hypothesis that macrophytes provide refuge to zooplankton from fish predation. Areas without a significant biomass of weeds, such as the harvested bay, might therefore have far less herbivory of algae.

The roles which macrophytes could have in affecting plankton community metabolism is an area which should receive much greater attention. Management of macrophytes so that only some areas of the littoral zone have plant removal could permit continued biological control of algae through allelochemics released by the remaining macrophytes, or through grazing of phytoplankton. Weed eradication could eliminate these controls, allowing problems with algae to replace those with weeds.

Part of the increase in chlorophyll in the harvested bay could be associated with sediment disturbance by the harvester and later by the wind. Epipelic algae were mixed into the water column, along with nonliving plant matter and its associated chlorophyll. No attempt was made to distinguish phaeophytin from total chlorophyll A. Nevertheless, the primary source of chlorophyll appeared to be the obvious algal blooms.

The switch from macrophytes to blue-green algal blooms, as occurred in this study, is a trade which can pose problems for lake users. Lakes with algal blooms are usually acceptable for boaters, and may be lakes with substantial fisheries. But swimming and the production of finished drinking water could be impaired. There are few instances, however, where prudent lake management would include harvesting of the entire littoral zone of a lake, and it is therefore unlikely that this lake and reservoir management procedure would normally be used to an extent that could stimulate a lake-wide algal bloom. This problem is far more likely when the goal of lake management is to produce macrophyte eradication, as is common when herbicides are employed or grass carp are overstocked (Cooke and Kennedy, 1989).

Macrophyte harvesting is a symptomatic treatment of a problem caused by the successful invasion of lakes and reservoirs by exotic plants, and by conditions such as excessive shallowness, good water clarity, and high external loading of particulate and dissolved materials which allow native plants to have prolific growth. While there can be problems associated with harvesting, the results presented here suggest that when the littoral zone is shallow enough that root crown removal can be practiced (depths out to 1.5 to 1.8 m, or 5-6 feet), the harvested area can remain open for recreational use for most of the summer in northern latitudes. It remains to be determined whether the use of this or other root crown removal procedures (see review by Newroth and Soar (1986)) can have a carry-over effect to subsequent years. A major drawback to this method of using a harvester is the slower rate of harvesting. Compared to "mowing," root crown removal is thus likely to be more expensive but longer lasting.

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