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Water Quality Impacts of Mechanical Shredding of Aquatic Macrophytes

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ABSTRACT

We examined the impacts of mechanical shredding (i.e., shredding plants and leaving biomass in the system) of the water chestnut (*Trapa natans*) on water quality and nutrient mobilization in a control and experimental site in Lake Champlain (Vermont-New York). A 1-ha plot was mechanically shredded within 1 h on 26 July, 1999. Broken plant material was initially concentrated on the lake surface of the experimental station after shredding, and was noticeable on the lake surface for 19 d. Over a two week period after shredding, concentrations of total nitrogen (N) and phosphorus (P), and soluble reactive P increased in the lower water column of the experimental station, coinciding with decomposition of water chestnut. Sediments in the control and experimental stations exhibited very low rates of N and P release and could not account for increases in nutrient concentrations in the water column after mechanical shredding. Shredded plant material deployed in mesh bags at the experimental station lost ~ 70% of their total mass, and 42% N and 70% P within 14 d, indicating substantial nutrient mobilization via autolysis and decomposition. Chlorophyll *a* concentrations increased to 35 g/L at the experimental station on day 7 after shredding, compared to a concentration of 4 g/L at the control station, suggesting uptake of mobilized nutrients by phytoplankton. Disruption of the surface canopy of water chestnut by shredding was associated with marked increases in turbidity and dissolved oxygen, suggesting increased mixing at the experimental site.

Key words: Nutrient recycling, Plant decomposition, Sediment flux, *Trapa natans*, Water Chestnut.

INTRODUCTION

Harvesting and land disposal of large expanses of aquatic macrophytes is often impractical and/or cost prohibitive. One alternative control measure for these cases is mechanical shredding of macrophytes without harvesting and disposal (i.e., clipping or shredding plants and leaving biomass in the system; Sabol 1987). In particular, mechanical shredding may be very promising for control of monospecific stands of nonnative macrophytes like the water chestnut, which has invaded large regions of Lake Champlain.

Dense macrophyte stands can mobilize nutrients such as N and P directly by root uptake and senescence (Barko and Smart 1980, Carpenter 1980, Smith and Adams 1986). Mechanical shredding of macrophytes without removal from the system may enhance nutrient recycling directly via leaching from tissues during autolysis and decomposition (Nichols and Keeney 1973) and indirectly via enhancing dissolved oxygen depletion (Jewell 1971, Sabol 1987) and shifts in redox which favors nutrient release from sediments (Nürnberg 1987). These processes can potentially impact the nutrient economy and productivity of aquatic systems and, thus, need to be examined with respect to macrophyte management.

The objectives of this study were to examine changes in various *in situ* (i.e., dissolved oxygen, turbidity) and chemical constituents (i.e., N and P) in the water column, contributions of nutrients from decomposing macrophytes, and rates of N and P exchange at the sediment-water interface in mechanically-shredded versus untreated stands of water chestnut in Lake Champlain.

MATERIALS AND METHODS

Water chestnut is an exotic annual aquatic macrophyte that has been a management problem in Lake Champlain for many years and currently occupies ~ 125 ha of the southern portion of the lake. Control and experimental stations were established within 1-ha plots established in Pickerel and Peters Bay of the lake, respectively, for examination of water quality characteristics and changes as a result of mechanical shredding. Each plot was located in an embayment separated from the main-stem of the lake by an island. Thus, flow was reduced in the embayments relative to the main-stem. The embayments were protected from wind-exposure from the east and west by hilly terrain. Water depths in each plot ranged between <0.5 m and 2.2 m. The water column depth at each station was 0.75 m. Prior to mechanical shredding, water chestnut populations densely covered both plots, ranging in fresh weight between 6 and 7 kg m^{-2}. Mechanical shredding (Penny System) of water chestnut in the experimental site occurred on 26 July, 1999.

Water Column Profiling. Water samples for nutrient analyses were collected at each station two days prior to mechanical shredding (i.e., 24 July) and on day 1, 4, 7, and 15 after mechanical shredding. Vertical profiles of total P, soluble reactive P (SRP), total N, and ammonium-N (NH_4-N) were collected on these days at 0.125-m intervals using a pneumatically-driven close-interval syringe sampler as described by James and Barko (1991). Water for analysis of soluble constituents was filtered *in situ* by attaching 0.45 m membrane filters to syringes. N and P were analyzed using automated

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analytical techniques (Zellwger Analytics, Lachat Division, Milwaukee, WI; Method detection limits, mg L^{-1}, were total N = 0.077; total P = 0.009; NH_4-N = 0.011; SRP = 0.004). Total N and P samples were digested using alkaline persulfate (Ameel et al. 1993) prior to analysis.

Water samples for viable chlorophyll *a* analyses were collected at each station two days prior to mechanical shredding and on day 7 after mechanical harvesting. Samples integrated over the upper 0.6-m water column were collected using an integrated sampler (Barko et al. 1984), which consisted of a 1.5 inch PVC pipe with a one-way check valve attached to the base of the pipe. When the pipe was lowered into the water column down to the 0.6-m depth, the check valve remained open allowing water to pass freely through the pipe. When the sampler was raised from the water column, the check valve closed, trapping a water sample integrated over the upper 0.6-m depth. Samples were poured into an amber bottle and immediately cooled on ice before shipment to the laboratory. They were filtered within 24 h, extracted in a 50:50 solution of acetone and dimethyl-sulfoxide, and analyzed for viable chlorophyll *a* using fluorometric procedures (Welschmeyer 1994).

YSI (Yellow Springs Instruments, Yellow Springs, OH) 6000 recording data sondes were deployed ~ 0.3 m above the sediment surface in control and experimental sites within 1-2 h after mechanical shredding to monitor changes in turbidity and dissolved oxygen. Probes were calibrated using known standards and Winkler titrations (APHA 1992). The data sondes recorded measurements at 0.5-h intervals for 1-2 weeks. After retrieval, turbidity remained within 5% of reference standards while dissolved oxygen concentrations had declined by 25% with respect to reference Winkler concentrations. The sonde deployed in the control station malfunctioned 1 week after deployment; thus, data were not collected during the second week at this station.

Interstitial Water Analysis. SRP and NH_4-N gradients in the sediment porewater were determined *in situ* at the control and experimental stations using sediment peepers (dialysis techniques). The acrylic peepers consisted of 12 chambers spaced at 2-cm intervals that were covered by a 0.2-m pore size dialysis membrane (Nucleopore Corp.) The procedures of Carignan (1984) and Shaw and Prepas (1989) were followed for the preparation, deployment, and retrieval of the peepers. Chambers were filled with nitrogen-purged distilled water and placed in a nitrogen-purged water bath prior to deployment to maintain anoxic conditions during transport to the stations. The peepers were gently pushed into the sediments so that up to 3 chambers (i.e., 6 cm into the sediment) were exposed to sediment pore water. Six replicate peepers were deployed in the control and experimental station ~ 18 h after mechanical shredding. The peepers were allowed to equilibrate with the pore water for 14 d. Upon retrieval, samples were rapidly extracted from each chamber using syringes, immediately filtered though a 0.45 m membrane filter, and sealed in an air tight vial until analysis of SRP and NH_4-N.

Rates of Nutrient Release from the Sediments. Replicate (12) intact, sediment cores were collected (Wildco Wildlife KB Sediment Sampler; 6.5-cm ID core liners) at the control and experimental stations 2 d prior to mechanical shredding for laboratory determination of rates of N and P release from the sediments. The upper 10 cm of each sediment core was carefully extruded into a core liner (6.5-cm ID and 25-cm height). Lake water (300 mLs), collected from the sampling stations and filtered through a glass fiber filter (Gelman A/E), was siphoned onto the sediments. The sediment systems were sealed with rubber stoppers and incubated in a darkened environmental chamber at 20C for one week (the approximate temperature at the sampling stations). Six replicate sediment systems were subjected to an oxic environment while another set of six replicate systems were subjected to an anoxic environment by gently bubbling the water column of each system with air or nitrogen, respectively. Water samples were collected daily from each system, filtered through a 0.45 µm filter, and analyzed for SRP and NH_4-N using automated analytical techniques (see above). Rates SRP and NH_4-N from the sediments were calculated as the linear change in mass in the overlying water divided by time and the area of the sediment incubation system.

Macrophyte Decomposition. Within hours of mechanical shredding, broken plant material was collected for determination of nutrient leaching and decomposition in mesh bags due to plant senescence. Excess water was drained from the shredded macrophytes (exclusively water chestnut) and 100 g fresh mass aliquots were placed in mesh bags (3 mm hole size). Macrophyte seeds were assumed to be resistant to decomposition and not included in the bags. Extra macrophyte material was used to determine dry mass conversion factors. The bags containing plant material were deployed on racks at middepth in the water column (~0.3 m) of the experimental station 1 d after mechanical shredding. At intervals of 3, 6, 14, 27, and 55 d after initial deployment, 5 replicate bags were removed from the rack. The contents were dried at 70 C for determination of tissue dry mass remaining. The dried material was then ground in a Wiley Mill, digested in a sulfuric acid-hydrogen peroxide matrix (Allen et al. 1974), and analyzed for tissue N and P using automated techniques (APHA 1992, Zellwger Analytics, Lachat Division, Milwaukee, WI).

RESULTS AND DISCUSSION

Nutrient gradients in the sediment and water column. Before mechanical shredding (i.e., 24 July), total P concentrations were nearly homogeneous throughout the water column (range = 0.03-0.08 mg/L) and similar between the control and experimental station (Figure 1). On 30 July (4 d after mechanical shredding), total P increased markedly in the lower third of the water column to >0.70 mg/L at the experimental station. In contrast, concentrations of total P were < 0.1 mg/l near the bottom of the water column at the control station. In the experimental station, total P reached a maximum of 1.81 mg/L near the bottom on 2 August (7 d after mechanical shredding), then declined to 0.60 mg/L on 10 August (15 d after mechanical shredding). Total P was >0.50 mg/L at the 0.5-m depth in the experimental station on 10 August. In contrast, concentrations of total P were <0.33 mg/L in the bottom waters of the control station between 27 July and 10 August.

At the experimental station, SRP was near detection limits throughout the water column before mechanical shredding (24 July; not shown). The control station exhibited slightly

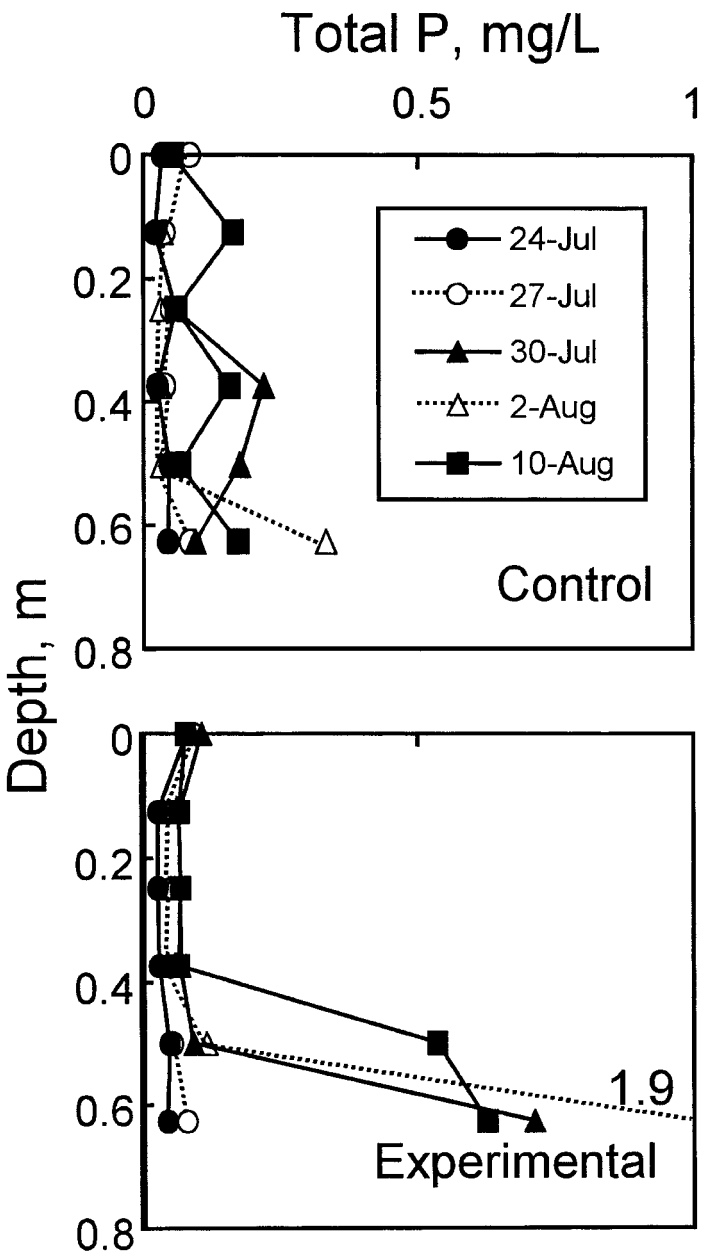

Figure 1. Variations in total phosphorus (P) in the water column at the control and experimental stations. Mechanical shredding occurred at the experimental site on 26 July, 1999.

greater SRP concentrations near the surface than the experimental station on 24 July. However, concentrations were <0.005 mg/L below the 0.2-m depth in the control station on this date, similar to concentrations observed for the experimental station before mechanical shredding. Four days after mechanical shredding, the experimental station exhibited a water-column-wide increase in SRP. Greatest concentrations (0.015 mg/L) occurred near the bottom at the experimental station, similar to patterns observed for total P at the experimental station. Concentrations remained high relative to pretreatment SRP at the experimental station on 2 and 10 August. At the control station, SRP was nearly homogeneous and <0.01 mg/L throughout the water column during the study period. An exception to this pattern occurred on 10 August, as concentrations of SRP exceeded 0.01 mg/L near the bottom.

Total N concentrations exhibited a response similar to that of total P in the experimental station as a result of mechanical shredding. Total N was uniform throughout the water column at this station before mechanical shredding (Figure 2). Between 30 July and 10 August, concentrations of total N declined in the upper 0.5 m and increased substantially near the bottom, with concentrations exceeding 3.0 mg/L on 2 and 10 August. The control station exhibited a similar decline in total N near the surface between 24 and 30 July. However, total N concentrations were much lower in the

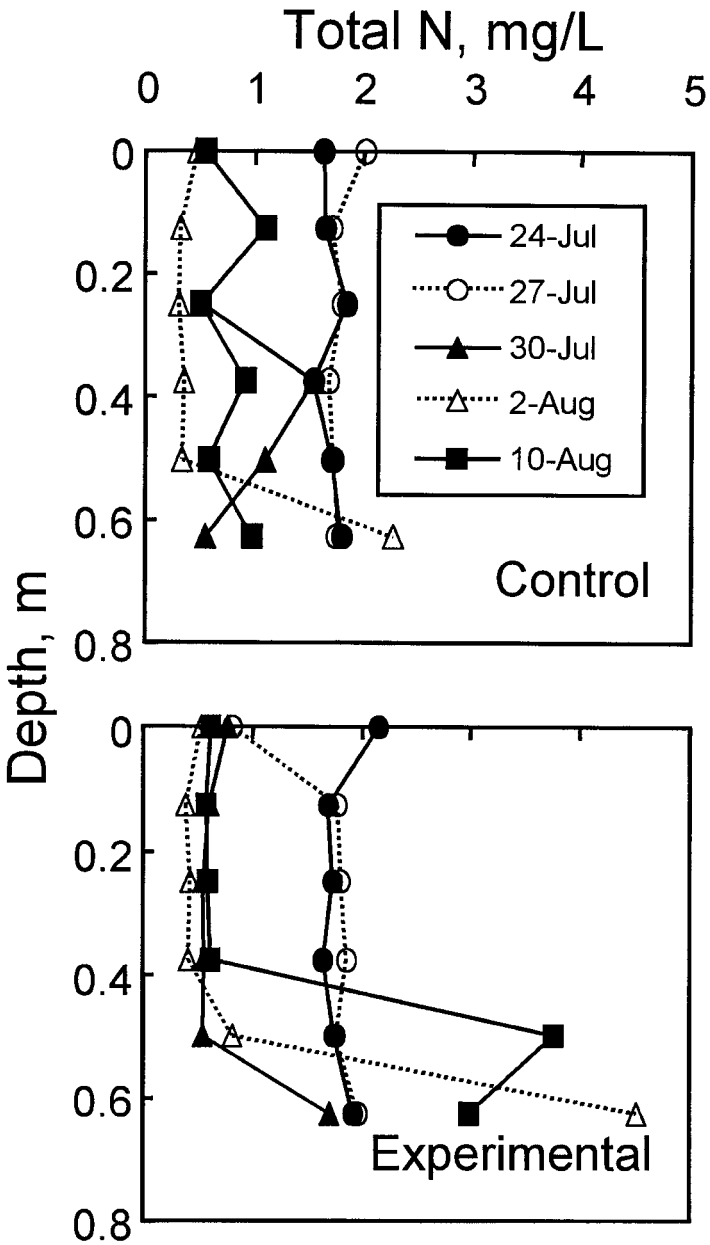

Figure 2. Variations in total nitrogen (N) in the water column at the control and experimental stations. Mechanical shredding occurred at the experimental site on 26 July, 1999.

bottom waters of the control station on 2 and 10 August, compared to concentrations in the experimental station on these dates. NH_4-N exhibited minor increases in concentration near the bottom in the experimental station on 2 and 10 August, relative to both pretreatment patterns on 24 July and control levels on 2 and 10 August (not shown).

Below the sediment-water interface, porewater SRP concentrations increased sharply to >1.5 mg/L between the 1 and 5 cm depth in both control and experimental stations (Figure 3; peepers represent an integrated porewater concentration between 27 July and 10 August). Above the sediment-water interface, porewater SRP was significantly greater in the experimental station verus the control station. These patterns of high SRP in the experimental station above the sediment-water interface reflected those patterns observed for total P and SRP in the water column.

Like SRP, marked gradients of increasing NH_4-N concentrations were observed below the sediment-water interface. NH_4-N was significantly greater in the experimental station than in the control station in the water column immediately above the sediment interface (Figure 3). Within the upper 5 cm of the sediment, porewater NH_4-N concentrations were similar between the experimental and control station.

Chlorophyll a. Before mechanical shredding, chlorophyll *a* concentrations were 3 times higher at the experimental (15.7 mg/m^3) versus the control station (5.0 mg/m^3) on 24 July. Seven days after mechanical shredding, chlorophyll *a* concentrations increased dramatically at the experimental station to 36.3 mg/m^3. In the control station, concentrations remained low (2.8 mg/m^3) and similar to those observed on 24 July.

Turbidity and dissolved oxygen. Immediately after mechanical shredding at the experimental station, turbidity exhibited a peak of >50 NTU due to sediment resuspension as an apparent result of the shredding machine (Figure 4). Between 26 July and 10 August, the experimental station exhibited markedly higher turbidity than the control station, coincident with disruption of the macrophyte canopy via shredding. Periodic peaks in turbidity in the experimental station throughout the study period may be attributed to wind-generated resuspension. In contrast, turbidity was near zero in the control station between 26 July and 2 August.

At the control station, dissolved oxygen was near zero during most of the study period (Figure 4). Minor peaks in the late afternoon were most likely due to net productivity by water chestnut. At the experimental station, dissolved oxygen was near zero between 26 July and 1 August. However, concentrations increased to >2 mg/L at this station during 2 through 10 August, coincident with sedimentation of shredded material and exposure of the lake surface to wind-generated mixing and reaeration. Unfortunately, dissolved oxygen measurements were not collected at the control station during that period due to instrument malfunction. High chlorophyll *a* concentrations and presumably high algal productivity also likely contributed to dissolved oxygen increases in the experimental station between 26 July and 2 August.

Nutrient recycling from sediments and decomposing macrophytes. Laboratory-based mean rates of N and P release from sediments collected at the control and experimental stations were low relative to other eutrophic aquatic systems (Nürnberg et al. 1986; James et al. 1995, 1996). In particular, mean rates of N and P release from sediments were negligible under oxic conditions for both stations. Under anoxic conditions, modest mean rates of N (control = 1.9 mg m^{-2} d^{-1};

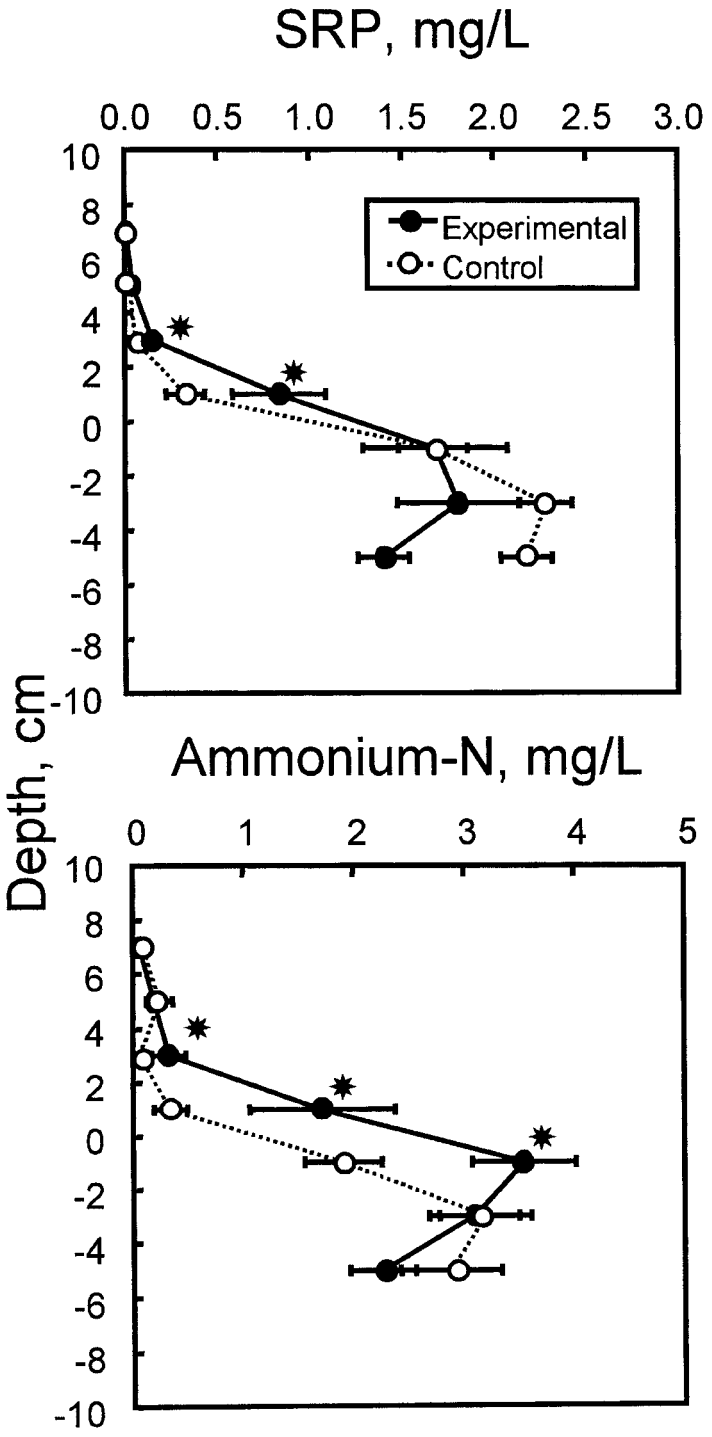

Figure 3. Variations in mean (n = 6) soluble reactive phosphorus (SRP) and ammonium-nitrogen (N) above and below the sediment interface at the control and experimental station. Concentrations represent the period 27 July through 2 August, 1999. Mechanical shredding occurred at the experimental site on 26 July, 1999. Asterisk indicates significant differences at $p < 0.05$ (t-test, SAS 1989). Horizontal lines represent two standard errors.

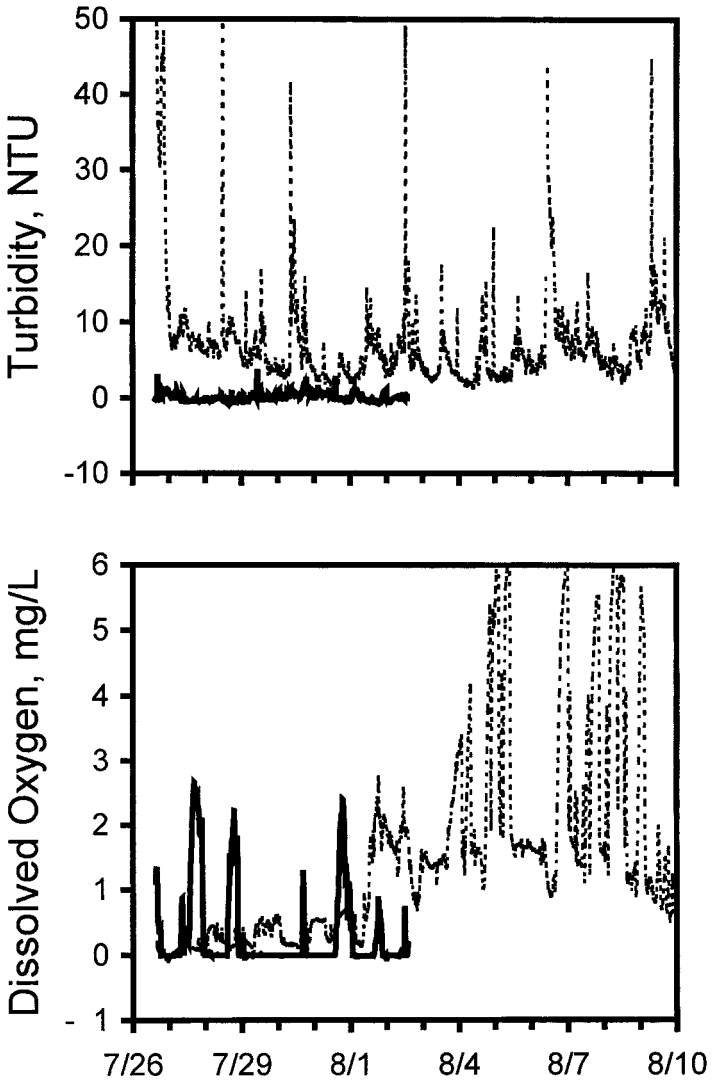

Figure 4. Variations in *in situ* turbidity and dissolved oxygen at the control (dashed line) and experimental (solid line) station after mechanical shredding at the experimental site on 26 July, 1999.

experimental = 2.4 mg m^{-2} d^{-1}) and P (control = 0.8 mg m^{-2} d^{-1}; experimental = 0.3 mg m^{-2} d^{-1}) release from sediments were observed at both stations. Rates of P release from sediments under anoxic conditions were significantly higher for sediments from the control station than from the experimental station (t-test; SAS 1990). However, statistical differences between stations were not observed for rates of N release under anoxic conditions (t-test; SAS 1990).

At the experimental station, large quantities of shredded water chestnut material were visible on the surface of the lake shortly after the shredding process, due to the buoyant nature of its plant morphology. Some shredded plant material was also observed on the lake surface by day 19 of treatment (Ann Bove, Vermont Department of Environmental Conservation, personal communication). However, within 3 weeks all plant material had completely settled from the surface.

Shredded water chestnut broke down rapidly in mesh bags, as nearly 70% of the initial dry mass was lost after only 14 d (Figure 5). Between 14 and 55 days of decomposition, dry mass in mesh bags remained low and approximately constant, indicating that only refractory organic material remained in the bags after 14 days of decomposition. Loss of N mass from decomposing water chestnut was partially offset by tissue concentration increases during the decomposition process (Figure 5). This pattern may be attributed to some N accumulation on the material as microbial biomass (Triska et al., 1975). Nevertheless, only 58% of the initial N remained after 14 d of breakdown. P loss from decomposing water chestnut was very rapid as 70% of the initial P mass was lost within 14 d (Figure 5).

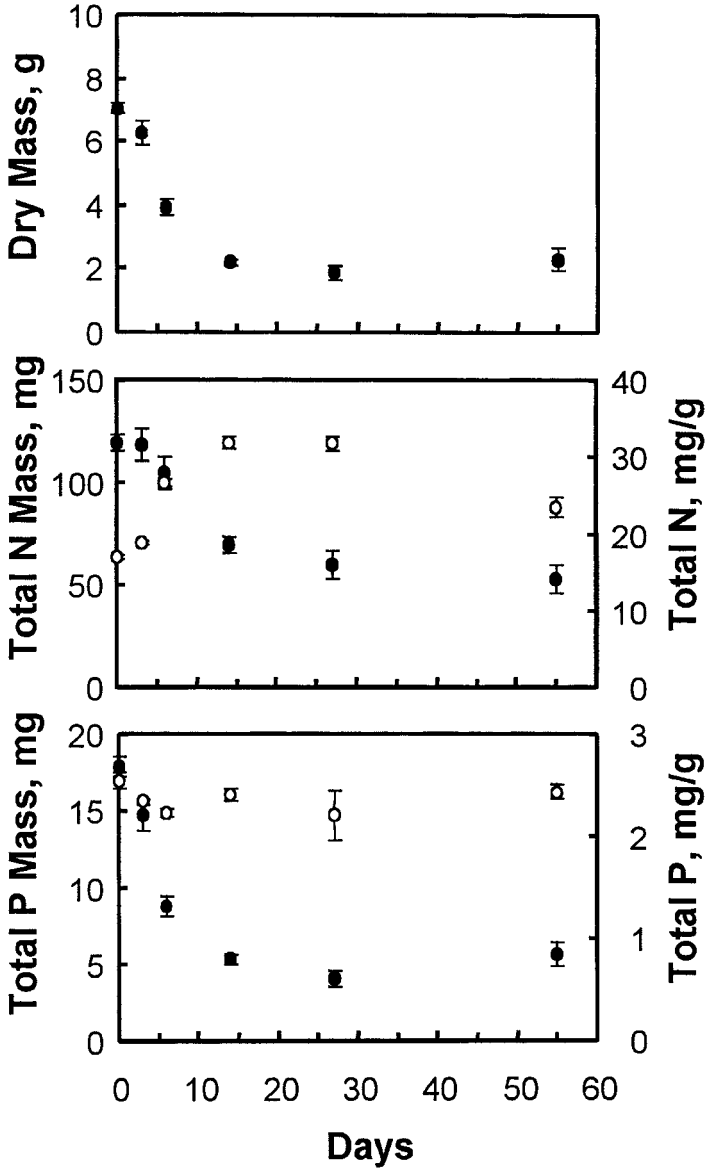

Figure 5. Variations in mean (n = 5) dry mass (upper), nitrogen (N) mass and concentration (middle), and phosphorus (P) mass and concentration (lower) as a function of time for decomposing water chestnut contained in mesh bags. Mesh bags were deployed at the experimental station ~ 1 d after mechanical shredding. Vertical bars represent 2 standard errors.

Analysis of nitrogen and phosphorus sources. We estimated the mass of N and P that was potentially mobilized in the experimental station via sediment-water interactions and macrophyte decomposition over the 14-d period after mechanical shredding. To estimate sediment nutrient sources, we assumed that the bottom waters at the experimental station were anoxic (i.e., < 2 mg/L dissolved oxygen) for the first ~ 7 d after shredding and oxic thereafter (Figure 4). Using rates of N and P release from sediments under oxic and anoxic conditions and an area of 1 ha (i.e., area that was mechanically shredded), approximately 200 g N and 20 g P were mobilized from the sediments over a 14-d period. In contrast, decomposition of water chestnut after mechanical shredding resulted in mobilization of 40,000 g N and 10,000 g P at the experimental station over the same time period.

As an apparent result of dense surface canopies in water chestnut beds, dissolved oxygen concentrations were near zero in the bottom waters on a diel time scale during the study period at the control station. Factors potentially contributing to low dissolved oxygen included suppression of reaeration from the atmosphere (i.e., mixing) by the surface canopy, the development of light-limiting conditions below the canopy for photosynthesis and production of oxygen by other plant and algal species, and dissolved oxygen demand via respiration of water chestnut and benthic microbial organisms. Others (James and Barko 1991, James et al. 1996) have observed low dissolved oxygen conditions in dense macrophyte beds.

Mechanical shredding of water chestnut coincided with improved dissolved oxygen conditions in the bottom waters of the experimental station, as dissolved oxygen concentrations increased to greater than 2 mg/L 7 d after shredding. This observation was unusual since macrophyte biomass was high (6-7 kg FW/m^2; R. Michael Stewart, U.S. Army Engineering Research and Development Center, Vicksburg, MS, personal communication) at the time of mechanical shredding and, thus, decomposition of this material represented a potentially large demand on oxygen stores at the experimental station, relative to the control station. However, increases in dissolved oxygen at the experimental station were associated with disruption of the surface canopy and a large increase in chlorophyll *a* concentration. These patterns suggested that oxygen demands created by decomposing macrophytes were offset by enhanced productivity by the algal community and reaeration from the atmosphere via wave activity and mixing processes.

Turbidity levels increased dramatically over a 14-d period in the experimental station after mechanical shredding, relative to the control station, suggesting some sediment resuspension due to increased wave activity. In particular, macrophytes can reduce sediment resuspension in shallow systems by dampening wave activity and redirecting water currents (Dieter 1990, Losee and Wetzel 1993, James and Barko 1994). Mechanical shredding of the canopy probably exposed the lake surface directly to wind effects, which promoted more frequent sediment resuspension in the experimental station. In contrast, high surface canopy biomass in the control station inhibited sediment resuspension and promoted sedimentation of particles, thereby resulting in negligible turbidity.

Mechanical shredding of water chestnut was accompanied by the buildup of N and P in the water column of the experimental station. Concentration increases were most pronounced in the lower half of the water column of the experimental station after shredding. Clearly, the source of these nutrient increases in the water column was decomposing macrophyte material, based on a comparison of nutrient mobilization via decomposing macrophytes and the sediments. Gradients of high total N and P in the bottom waters of the experimental station after shredding perhaps reflected some settling of fragmented macrophyte material.

Based on decomposition of water chestnut in mesh bags, loss of P from tissue was rapid during the first 6 d and could represent a substantial source of P to the water column. Although SRP increased in concentration in the experimental station, compared to the control station over this period, we did not observe the occurrence of a pulse of high SRP shortly after shredding. However, the chlorophyll *a* concentration increased markedly in the experimental station after mechanical shredding, suggesting uptake of SRP by algae for growth. Flushing and transport of SRP and other nutrients down stream may have also occurred, thus, diluting concentrations via water exchange in the experimental station.

Our results suggest that mechanical shredding resulted in both positive and negative effects on water quality. Disruption of the surface canopy of water chestnut was associated with an increase in dissolved oxygen concentrations. However, decomposition of water chestnut resulted in nutrient mobilization and an increase in algal biomass as indicated by high levels of chlorophyll *a*. The results of this study have implications for the management of aquatic plants in other water bodies via mechanical shredding. In particular, smaller lakes and isolated embayments exhibiting high residence times may be very susceptible to high nutrient levels and the occurrence of algal blooms as a result of allowing shredding plant material to decompose in the managed area. Although we did not see an impact on dissolved oxygen stores at the study site in Lake Champlain, oxygen demands from decomposing material could severely deplete concentrations in other applications under certain conditions (i.e., wind-protected, high residence times shallow lakes and embayments) exacerbating nutrient recycling pathways and aquatic habitat value (Sabol 1987). These water quality effects need to be considered in the development of macrophyte management plans for controlling water chestnut via mechanical shredding.

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