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EFFECTS OF VASCULAR AND NONVASCULAR MACROPHYTES ON SEDIMENT REDOX AND SOLUTE DYNAMICS¹

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Abstract. Oxygen release from the roots of submersed vascular plants influences redox (oxidation-reduction)-related solute dynamics in lake sediments. In a northern Michigan lake we found significant differences in pH, redox potential (Eh), and phosphorus and iron fractions among sediments, depending on whether they supported no vegetation, the vascular macrophytes *Isoetes braunii* and *Myriophyllum tenellum*, or the moss *Drepanocladus exannulatus*. Eh and total P were significantly higher, and filterable P was significantly lower, at vascular plant sites than at bare or moss-covered sites. An in situ transplant experiment of the three macrophyte species into three different sediment types showed that the vascular plants raised sediment Eh, lowered pH and filterable Fe and P percentages, and enhanced sediment P retention. Sediments with moss transplants remained reduced and high in filterable Fe and P, and released more P to overlying water than sediments with vascular transplants. Vegetation changes from tracheophytes to bryophytes, such as occur during lake acidification, could lower Eh and increase Fe and P mobility in sediments.

Key words: *Drepanocladus exannulatus*; iron; *Isoetes braunii*; macrophyte-sediment interactions; Michigan; *Myriophyllum tenellum*; phosphorus; redox potential; rhizosphere oxidation; sediment phosphorus cycling.

INTRODUCTION

In clear, unproductive lakes, submersed macrophyte communities contain both vascular and nonvascular species (Spence 1982). Typically, vascular and nonvascular macrophytes are heterogeneously distributed, with vascular plants dominating the shallow littoral zone, and nonvascular mosses becoming more abundant with depth (Spence 1982). Distribution patterns of vascular and nonvascular macrophytes imply major differences in ways these plants interact with their environments.

Many researchers have shown that submersed vascular plants characteristic of oligotrophic communities release oxygen to sediment interstitial spaces through their roots (Oremland and Taylor 1977, Tessenow and Baynes 1978, Sand-Jensen et al. 1982, Sand-Jensen and Prahl 1982, Smith et al. 1984). Nonvascular plants such as aquatic mosses lack the root and lacunar systems of vascular macrophytes, which facilitate oxygen release to sediment pore water. We therefore hypothesized that these nonvascular plants are unable to significantly oxidize their surface sediments.

Rhizosphere oxidation by vascular macrophytes could decrease phosphorus mobilization from sediment by establishing an oxidized barrier to diffusion. Oxygen release raises sediment redox potential (Eh),

causing precipitation of ferric and manganic oxyhydroxides on or around plant roots (Wium-Andersen and Andersen 1972, Tessenow and Baynes 1975, Mendelsohn and Postek 1982, Taylor et al. 1984). Under oxidized conditions, ferric and manganic oxyhydroxide complexes adsorb phosphorus and other mineral elements (Mortimer 1941, 1942, Ponnampuruma 1972, Tipping et al. 1981), making them less available for diffusion to the overlying water.

Based on these principles we would expect significant shifts in sediment solute mobility to accompany macrophyte community transitions from vascular to nonvascular forms. These transitions have been observed along littoral zone depth gradients in oligotrophic lakes, as previously noted. Such vegetation changes also occur over time in acidifying lakes (Grahm et al. 1974, Grahm 1977, Roelofs 1983).

The objectives of this research were to compare sediment oxidizing activity by submersed vascular and nonvascular plants, and to document the effect of changes in rhizosphere Eh on Fe and P dynamics. We sampled sediments from sites with vascular or nonvascular macrophytes to assess vegetation-related differences in redox potential under field conditions and investigated the effects of redox variations on sediment P and Fe fractions. To determine how submersed plants alter sediment chemistry, we performed an in situ transplant experiment. Our objectives were to quantify shifts in sediment chemistry over the growing season and to assess the relative growth of three macrophyte species (two vascular, one nonvascular) on different types of sediment.

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METHODS

Study site

Roach Lake, an oligotrophic, softwater seepage lake, is located in Vilas County, Wisconsin (Section 7, Township 43N, Range 8E), and Gogebic County, Michigan (Section 10, Township 44N, Range 42W), in the University of Notre Dame Environmental Research Center. Jaynes (1985) describes the morphometry and chemistry of Roach Lake. Detailed information on the composition and spatial pattern of submersed vegetation in Roach Lake is provided in Carpenter and McCreary (1985).

Comparisons of surface sediments

To investigate the influence of macrophytes on surficial sediment Eh, P, and Fe, we chose three sampling sites with distinct vegetative cover. Sediment at one site supported no macrophytes. Another site was colonized by the aquatic moss *Drepanocladus exannulatus* (BSG) Warnst (Darlington 1964). The third site supported a mixture of two vascular species, *Isoetes braunii* Dur. and *Myriophyllum tenellum* Bigel (Fassett 1957). All sampling sites were located between the 3.4 and 3.9 m depth contours, along a shoreline of uniform exposure. The three sites and their respective sediments are referred to hereafter as: B = bare sediment; M = moss-colonized sediment; and V = sediment supporting the two vascular plant species.

Samples of surface sediment (<8 cm deep) were taken at sites B, M, and V. Scuba divers filled plastic coring cylinders with sediment and immediately sealed the ends with plastic sheets to minimize mixing of sediments with overlying water and to prohibit sediment contact with air during transport. Samples were transported to the field laboratory and analyzed under nitrogen in a glove bag. Eh, pH, and temperature were measured for all core samples. Total P, total Fe, percent organic matter, and percent dry matter were determined for eight core samples from each site. Remaining cores were squeezed under nitrogen at 40 kPa (Robbins and Gustinis 1976) through Whatman GF/C glass fiber filters. Pore-water samples were sealed and remained frozen until analyzed for P and Fe. Chemical procedures are outlined in Sediment Analyses. Preliminary sampling indicated that sediment V was more variable than B and M sediments. For that reason, 12 cores from site V and 6 cores from each of the other two sites were squeezed for pore-water analyses.

Transplant experiment

To ascertain whether these submersed vascular species simply preferred sediment with particular chemical characteristics or if they actively altered sediment that supported them, we designed an in situ transplant experiment. The experiment followed a 3 × 4 factorial design, so that effects and interactions of

three sediment treatments and four vegetation treatments could be examined.

Sediment was collected from a bare area and from areas supporting vascular or nonvascular hydrophytes, and all plants were removed. Plant samples were collected from nearby areas. Subsamples of each sediment type and plant species were reserved for initial analyses. Pots used in the experiment are described in detail by Jaynes (1985). Each experimental pot received a 5-cm layer of one type of sediment and one of four vegetation treatments: transplants of *Isoetes*, *Myriophyllum*, or *Drepanocladus*, or no plants. Vascular transplant treatments consisted of six *Isoetes* rosettes or six three-shoot segments of *Myriophyllum* rhizome. These plants were inserted with their roots beneath the sediment surface. To obtain reasonably consistent *Drepanocladus* treatments, individual filaments were measured lengthwise into lots, each lot with a total (lineal) length of 300 cm of shoot. This method was chosen because *Drepanocladus* fragments vary greatly in size, and individual plants are difficult to define. One end of every *Drepanocladus* filament was pushed beneath the sediment surface to secure the transplant. Initial biomass of each transplant treatment was measured prior to planting. Each of the 12 resulting sediment-plant combinations was replicated six times. Pots were placed on the bottom of Roach Lake by a Scuba diver at a water depth of 2.1 m on 4–5 June 1984.

On 19–26 August 1984, a diver sealed the pots with airtight lids and then removed them from the lake bottom. Lids prevented sediment contact with air during transport to the field laboratory, where pots remained sealed until placed under nitrogen in a glove bag. Water overlying the top of the sediment was pipetted off. Sediment Eh, pH, and temperature were measured. If present, plants were removed for tissue P analysis. Sediment subsamples were squeezed for pore-water analyses. Additional subsamples were reserved for percent organic matter, percent dry matter, and total P and Fe determinations.

Sediment analyses

Eh was measured with a combination platinum-calomel redox electrode equilibrated in the center of each pot for 10 min. Redox electrodes were standardized against two solutions of potassium ferrocyanide and potassium ferricyanide (Orion Research 1980). Electrodes were lightly sanded to remove contaminants, and were rinsed with distilled water between samples. A glass electrode was used for pH measurements.

Total P was extracted from fresh sediment by Truog's method (Allen 1974). Extracts were frozen until analyzed at the Notre Dame campus by persulfate digestion (Menzel and Corwin 1965) followed by an ascorbic acid colorimetric procedure (Murphy and Riley 1962).

Percent dry matter was determined by drying 100 mL of fresh sediment at 105°C in a forced-air circu-

TABLE 1. Mean plant dry biomass (\pm SE, $n = 8$) at sites V (vascular plant) and M (moss) in Roach Lake, 29 July 1983. Percent species contribution to total biomass at each site is also indicated.

| Species | Site | | | |
|----------------------------------|---------------------|-----|---------------------|-----|
| | V | | M | |
| | (g/m ²) | (%) | (g/m ²) | (%) |
| <i>Isoetes braunii</i> | 17.4 \pm 4.6 | 70 | 1.8 \pm 1.7 | 3 |
| <i>Myriophyllum tenellum</i> | 5.8 \pm 2.6 | 23 | 2.4 \pm 2.2 | 4 |
| <i>Drepanocladus exannulatus</i> | 1.7 \pm 0.9 | 7 | 55.2 \pm 13.5 | 93 |

lation oven to constant mass. Percent organic matter was determined for duplicate subsamples by mass loss on ignition (450°, 5 h).

Oven-dried sediment was crushed with a porcelain mortar and pestle and sifted through a 625- μ m mesh sieve. Subsamples were extracted for total Fe estimates using hydrosulfite reduction and analyzed colorimetrically by a sulphonated bathophenanthroline method (Allen 1974).

Initial subsamples of the three sediment types used in the in situ transplant were analyzed for particle size distribution. Wet sediment was gently heated with 20 mL of 30% hydrogen peroxide in order to oxidize organic matter that would have interfered with particle settling (Allen 1974). Grain size distribution analysis followed the standard procedure adopted by the American Association of State Highway Officials (1966).

Pore-water samples were digested by the persulfate method (Menzel and Corwin 1965). Aliquots of each sample were removed for Fe analysis by a sulphonated bathophenanthroline procedure (Allen 1974) and P analysis by an ascorbic acid method (Murphy and Riley 1962).

Plant analyses

Samples of *Isoetes*, *Myriophyllum*, and *Drepanocladus* were taken in Roach Lake on 29 July 1983, to estimate midsummer plant biomass. A diver took eight samples at both sites V and M with a cylindrical Plexiglas sampler (surface area = 69.4 cm²). Whole plants were sorted by species, weighed, then dried for 24 h at 105° and reweighed.

Transplants used in the 1984 in situ experiment were weighed to determine initial biomass placed in each pot. At the end of the experiment, plants were removed from the pots, weighed, dried at 70°, weighed again to determine biomass change over the growing season, then combusted for 5 h at 450° to determine organic content.

Dried plants were ground in a Wiley mill and sifted through a 625- μ m mesh screen. Magnesium nitrate was added to weighed subsamples to stabilize the phosphorus (Jackson 1958). These treated samples were redried, combusted at 500° for 4 h, dissolved in 1 mol/L H₂SO₄, filtered, and analyzed for P by ascorbic acid colorimetry (Murphy and Riley 1962).

Statistical procedures

Data from the surface sediment comparison were analyzed statistically by one-way analysis of variance (ANOVA) to determine variations in sediment chemistry between sites. In situ transplant data were analyzed by two-way ANOVA to examine effects of sediment type, plant treatment, and their interaction on sediment chemistry. Where necessary, data were transformed to normalize the residuals from ANOVA. Statistically significant differences were defined as those for which $P < .05$. Complete ANOVA tables are provided in Jaynes (1985).

RESULTS

Surface sediment comparison

All three species were present at both vegetated sites, but each site was dominated by either vascular or non-vascular vegetation (Table 1). *Isoetes* and *Myriophyllum* together comprised 93% of the vegetation dry mass at site V, but only 7% of the plant mass at site M. *Drepanocladus* made up 93% of the vegetation at site M and 7% at site V. Site M had twice as much total plant biomass as site V, due to the dense mats formed by *Drepanocladus*.

Sediment B contained significantly more dry matter than M and V sediments (Fig. 1A). Sediments B and M were statistically similar for all remaining sediment characteristics (Fig. 1B–H).

The vascular macrophytes *Isoetes* and *Myriophyllum*, however, were associated with many sediment conditions that differed from those of sediments B and M. Sediment V had significantly less organic content (Fig. 1B) and significantly higher Eh values (Fig. 1C) than B and M sediments. Eh of sediment V averaged +186 mV, indicating relatively oxidized conditions. Redox values for B and M sediments were -99 and -47 mV, respectively, indicating reduced conditions. Sediment V had a significantly lower mean pH than sediment supporting *Drepanocladus* or sediment lacking plants (Fig. 1D). The range in pH from 5.43 in V sediment to 6.09 in M sediment represents a 4.5-fold difference in H⁺ concentration, and potentially strong effects on mineral speciation.

Sediment V had a mean total phosphorus concentration greater than sediments B and M (Fig. 1E). Pore-

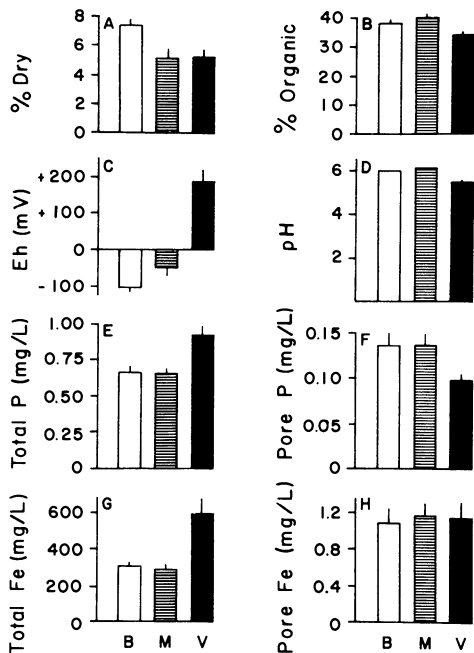


FIG. 1. Means of lake sediment characteristics in three sampling sites (B = bare, M = moss-colonized, and V = supporting vascular vegetation), July 1983. Standard errors are indicated where larger than bar outlines. (A) % dry matter = (dry mass/fresh mass) \times 100; number of replicates (n_i) for each sediment type: $n_B = 8$, $n_M = 7$, $n_V = 8$. (B) % organic matter = % dry mass lost on ignition; $n_B = 8$, $n_M = 7$, $n_V = 8$. (C) Eh, corrected to normal hydrogen electrode and neutral pH (7); $n_B = 14$, $n_M = 13$, $n_V = 20$. (D) pH; $n_B = 14$, $n_M = 13$, $n_V = 20$. (E) Total P concentration; $n_B = 7$, $n_M = 7$, $n_V = 8$. (F) Pore-water P; $n_B = 6$, $n_M = 6$, $n_V = 10$. (G) Total Fe; $n_B = 8$, $n_M = 7$, $n_V = 8$. (H) Pore-water Fe; $n_B = 6$, $n_M = 6$, $n_V = 12$.

water phosphorus levels also varied significantly from site to site (Fig. 1F). The proportion of the total P found in the pore water was lower in V (11.3%) than in B (20.1%) or M (20.3%) sediments.

V sediment had significantly more total iron than B and M sediments (Fig. 1G), but pore-water Fe levels (Fig. 1H) did not vary among sites. The percentage of total iron found in the pore water, however, was lower in V (0.187%) than in B (0.331%) or M (0.394%) sediments.

In situ transplant experiment

Initial sand, silt, and clay fractions for the three sediment types (Table 2) showed that clay content was highest in B, intermediate in M, and lowest in V sediments.

Sediment Eh values at the end of the experiment were generally higher than initial values (Fig. 2A). Initial Eh of all sediments was relatively low because deep, reduced sediment layers were included when collecting samples. Sediment in pots with vascular transplants

had high, or oxidized, final Eh values, while sediment in pots with moss transplants and in pots lacking plants had low, or reduced, redox values. Pots with *Isoetes* and *Myriophyllum* had significantly lower pH values than pots without these vascular species (Fig. 2B). The range in pH (5.73 to 6.27) indicates a 3.5-fold variation in H^+ concentration among treatments, and potentially strong effects on mineral speciation. Sediment type had no effect on final Eh or pH.

Total Fe, pore water Fe, and their ratio did not vary with sediment type (Fig. 3). Pots with *Isoetes* and *Myriophyllum* had significantly more sediment total Fe (Fig. 3A) and significantly less pore-water Fe (Fig. 3B) than pots with *Drepanocladus*. Pore-water Fe percentages for vascular plant treatments were maintained at consistently low levels across all three sediment types (Fig. 3C). There was much more variation in sediments treated with moss transplants or no plants. Moreover, sediments supporting *Drepanocladus* or no plants always had higher percentages of Fe dissolved in the pore water.

Sediment origin did not significantly affect total sediment P (Fig. 4A). All sediments treated with transplants of *Myriophyllum*, however, had final total P levels significantly greater than sediments that received the moss or no plants. This finding agreed with results from the surface sediment comparison, where greater total P concentrations were found in sediment supporting vascular macrophyte species (Fig. 1E). Although total P levels were higher in *Isoetes* pots than in *Drepanocladus* pots, this difference was not significant by Tukey's paired comparison test (Box et al. 1978:204).

Pore-water P (Fig. 4B) did not vary in relation to plant or sediment treatments. The percentage of total P in pore water did not vary with sediment type, but sediments associated with *Drepanocladus* had significantly greater pore-water P percentages than sediments planted with *Myriophyllum* (Fig. 4C).

Overall, total P concentrations fell from initial levels in 11 of the 12 experimental cells (Fig. 4A). Using mass data and changes in P concentrations, we calculated net sediment P losses (as absolute mass of P) from pots over the experiment's duration. Both sediment type and transplant species significantly affected phos-

TABLE 2. Initial grain size (diameter) distribution of the three sediment types. One sample of each sediment type was analyzed.

| Sediment* | % sand (0.02–2.0 mm) | % silt (0.002–0.02 mm) | % clay (<0.002 mm) |
|-----------|----------------------------|------------------------------|-----------------------|
| B | 31.4 | 36.6 | 32.0 |
| M | 53.9 | 25.4 | 20.8 |
| V | 61.8 | 19.7 | 18.5 |

* B = bare sediment, M = moss-colonized sediment, V = sediment supporting vascular plants.

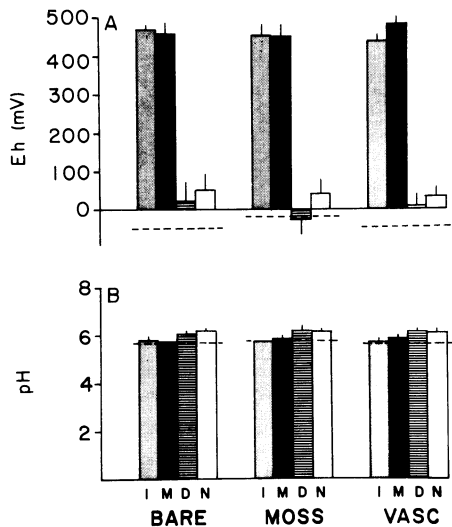


FIG. 2. Means for (A) Eh and (B) pH of lake sediment at the end of the transplant experiment. Each group of four bars represents one sediment type (bare, moss-colonized, and supporting vascular plants). Each bar in a group represents final sediment conditions in one plant treatment (I = *Isoetes*, M = *Myriophyllum*, D = *Drepanocladus*, N = no plants). Standard errors ($n = 5$ or 6) are indicated where larger than bar outlines. Dashed horizontal lines represent initial conditions in each type of sediment.

phorus loss from pots (Fig. 5A). Pots containing *Myriophyllum* lost significantly less P than pots with *Drepanocladus* and pots without plants. Although mean P losses were generally lower from sediments supporting *Isoetes* than from sediments with *Drepanocladus* or no plants, these differences were not statistically significant. Pots containing sediment V lost significantly less P than pots treated with B and M sediments, perhaps because of this sediment's initially low total P concentration.

Two-way analysis of variance showed significantly heterogeneous rates of growth among species, but no significant sediment type effect on growth (Fig. 6A). *Drepanocladus* biomass declined during the experiment because some shoots were washed out of the pots.

Tissue P concentration varied among plant species (Fig. 6B). Tissue P concentrations increased over initial levels in the two vascular species, but decreased slightly in *Drepanocladus* tissue. *Myriophyllum* P concentrations were significantly lower in pots with B sediment than in pots with M or V sediments.

Initial and final tissue P concentrations were converted to absolute mass of plant P using plant biomass data for each pot. Net P gain by plants, calculated as (final mass of P - initial mass of P), was independent of sediment treatment, but varied significantly among plant species (Fig. 5B). *Isoetes* and *Myriophyllum* gained similar amounts of P over the experiment's duration, while *Drepanocladus* experienced a net loss of P.

DISCUSSION

In Roach Lake, sediments colonized by the moss *Drepanocladus* and sediments lacking plants were reduced and contained relatively high concentrations of Fe and P in the pore water. The vascular macrophytes *Isoetes* and *Myriophyllum*, however, grew in sediments that were oxidized and contained more total Fe and P but less pore-water P than bare and moss-colonized sediments.

The transplant experiment demonstrated that macrophytes promoted these differences in sediment chemistry. All sediments with *Drepanocladus* transplants were more reduced and higher in dissolved P and Fe than vascular-colonized sediments, regardless of sediment origin. Nonvascular transplants, tended to bring sediment Eh and P and Fe fractions to levels resembling those in naturally bare or moss-colonized sediments. The *Drepanocladus* treatment, however, cannot be equated with the no-plant treatment in mechanistic terms. Even though *Drepanocladus* did not grow in this experiment, its presence in the pots served as a structural barrier to water mixing with sediments, a barrier absent from pots without plants. Moreover, *Drepanocladus* released oxygen to surrounding water during light-bottle incubations (M. Jaynes, personal observation), yet failed to oxidize sediments in the pots.

Isoetes and *Myriophyllum* transplants brought Eh,

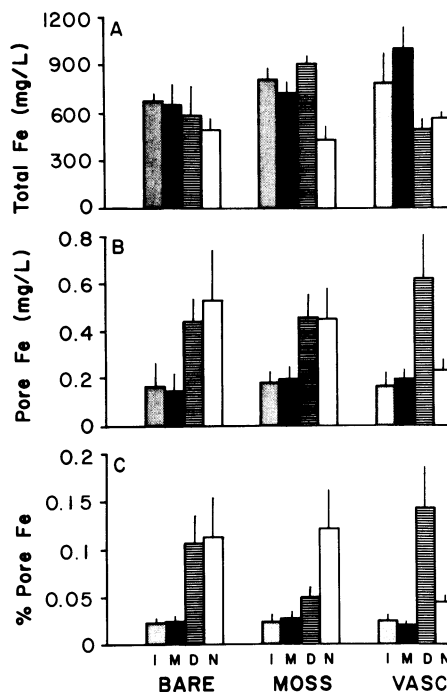


FIG. 3. Means + SE ($n = 5$ or 6) for (A) total Fe, (B) pore-water Fe and (C) % of Fe in the pore water, for lake sediment at the end of the transplant experiment. Histogram arrangement, labels, and all symbols follow Fig. 2.

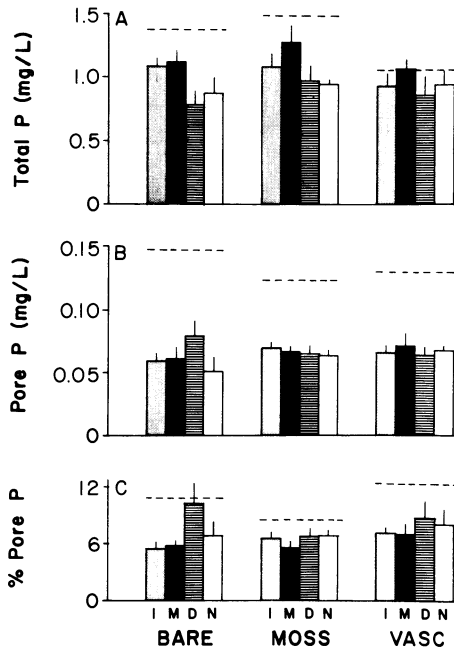


FIG. 4. Means + SE ($n = 5$ or 6) for (A) total P, (B) Pore-water P, and (C) % of P in the pore-water, for lake sediment at the end of the transplant experiment. Histogram arrangement, labels, and all symbols follow Fig. 2.

pH, P, and Fe fractions of all sediments to conditions resembling those in natural sediment colonized by vascular macrophytes. *Isoetes* and *Myriophyllum* raised initially reduced sediments to oxidized conditions during the 11-wk experiment. Vascular transplants maintained lower percentages of Fe and P in the pore water, and higher concentrations of total sediment Fe and P. Since total Fe and P levels were higher, it appeared that sediments with vascular plants retained more Fe and P over time than sediments with *Drepanocladus* or sediments lacking plants.

Sediment in all pots, however, experienced a net loss of total P over the growing season. Values for net plant gain of P by the two vascular species were comparable to P loss estimates for associated sediments, suggesting that accumulation of P in plant tissues could account for the P lost from those sediments (Fig. 5). The vascular macrophytes significantly decreased pore-water P concentrations by a combination of uptake and rhizosphere oxidation. Plant uptake could not explain elevated P loss from sediments lacking vascular transplants. Phosphorus lost from sediments with *Drepanocladus* and sediments lacking plants was apparently released into the overlying water.

Differences appear to exist in the mechanisms and amounts of Fe and P cycling through sediments with vascular vs. nonvascular vegetation. Depending on the type of macrophyte cover, different vegetation zones within a lake may release different amounts of P and

Fe to the overlying water. Our experiments suggest that rhizosphere-oxidizing macrophytes slow internal P and Fe release, and enhance sediment P retention over the summer growing season. It is during summer that P flux from the sediment could have the greatest effect on ecosystem metabolism. Evergreen vascular macrophytes typical of oligotrophic lakes are conservative of nutrients and may have significant under-ice photosynthesis. Hence, rhizosphere oxidation and P retention could be maintained throughout much of the year.

In oligotrophic lakes like Roach Lake, small, slowly growing plants characterize the submersed vascular macrophyte community. The slow turnover rates and sediment oxidizing capabilities of these plants may work together to decrease internal P recycling from littoral sediments to overlying waters. In eutrophic systems, large, robust species dominate the submersed macrophyte community. Oxygen release by these macrophytes is unable to overcome the supply of reductants to lake sediments, which remain reduced even in vascular plant beds (Carpenter et al. 1983). In addition, rapid turnover and decay of macrophyte biomass increase internal loading of P and the supply of organic matter to sediments (Carpenter 1980). Therefore, lake-wide effects of rhizosphere oxidation on P recycling should be less pronounced under eutrophic conditions.

Community transitions from vascular to nonvascular macrophytes, such as *Sphagnum* and other mosses, have been reported for acidifying lakes (Roelofs 1983). Several species of *Sphagnum* and *Drepanocladus* have been shown to lower water pH, Ca^{++} con-

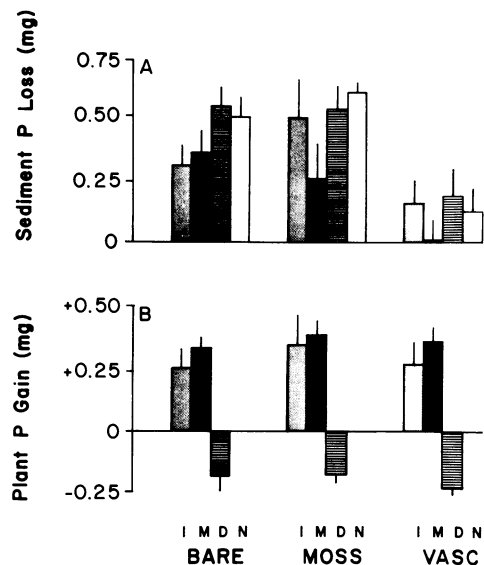


FIG. 5. Transplant experiment means + SE ($n = 5$ or 6) of (A) net P loss from sediments and (B) net P gain by plants for pots that received transplants. Histogram arrangement, labels, and all symbols follow Fig. 2.

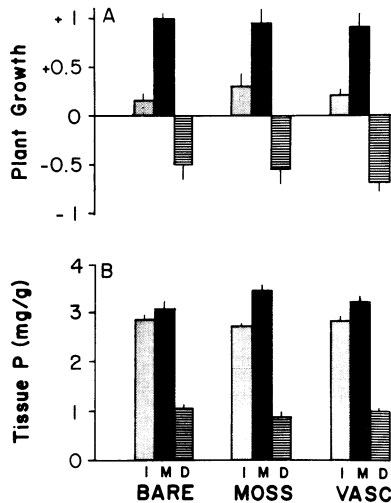


FIG. 6. Means + SE ($n = 4$ to 6) of (A) plant growth, relativized as $\log(\text{final biomass}/\text{initial biomass})$, and (B) plant tissue P (mg/g dry tissue), in the transplant experiment. Histogram grouping follows Fig. 2. Each histogram in a group represents final plant conditions in one plant treatment ($I = \textit{Isoetes}$, $M = \textit{Myriophyllum}$, and $D = \textit{Drepanocladus}$). Initial tissue P concentrations: $I = 2.64$, $M = 2.52$, and $D = 1.11$ mg/g dry tissue.

centration, and specific conductivity via cation exchange processes, with *Sphagnum* being a better acidifier than other mosses (Glime et al. 1982). Decomposition rates decline in acidified lakes, resulting in organic matter accumulation in the sediment (Grahn et al. 1974, Hendrey et al. 1976). Sediment organic matter accretion increases sediment reducing capacity and anaerobiosis, which are unfavorable for many rooted plants. These sediment-macrophyte interactions might accelerate community shifts toward non-vascular macrophyte dominance in acidifying lakes.

Our research indicates that vegetation shifts between vascular and nonvascular macrophyte assemblages in oligotrophic lakes might lead to ecologically significant shifts in sediment chemistry. Transitions to moss-dominated communities could enhance sediment reduction and mobilization of solutes from particulate to pore-water phases. These solutes would be readily exchangeable with the overlying water (Mortimer 1941, 1942; Bostrom et al. 1982, Twinch and Peters 1984). Since solutes regulated by redox and pH include potentially toxic forms of aluminum, manganese, zinc, iron, and sulfur, and nutrients like P, continuing study of the differential effects of vascular and nonvascular vegetation on sediment solute dynamics is warranted.

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