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Harvest as a Control for Sago Pondweed (*Potamogeton pectinatus* L.) in Badfish Creek, Wisconsin: Frequency, Efficiency and its Impact on the Stream Community Oxygen Metabolism

JOHN D. MADSEN[1], MICHAEL S. ADAMS[2], AND PETER RUFFIER[3]

ABSTRACT

Harvesting as a macrophyte control technique was investigated in two experiments. In the first experiment, the efficiency of harvesting and macrophyte regrowth under three harvest frequencies (every other month, every month and bimonthly) were examined. Harvest efficiencies in this experiment averaged 79%, and effective control was maintained under both the monthly and bimonthly harvest regimes. In the second experiment, the oxygen balance of a large river stretch was examined before and after harvesting. Although harvest efficiency in this second experiment was only 50%, harvesting significantly reduced diel oxygen variation by reducing both macrophyte respiration and photosynthesis, but average daily oxygen concentrations were unchanged. Suggestions to improve stream harvest efficiencies included harvesting early, and reharvesting before regrowth of biomass exceeded 200 to 250 g dw m^{-2}.

Key words: Cutting, harvest, oxygen mass balance, community photosynthesis, community respiration, stream, river, submersed aquatic macrophytes.

INTRODUCTION

Harvesting or cutting of submersed macrophytes is perhaps both the oldest and most common control technique used for both streams (Westlake and Dawson 1982) and lakes (Nichols 1974; Dunst *et al.* 1974; Andrews 1986). Several studies have examined the efficiency as well as the biological and limnological impacts of harvesting on lakes (Dunst *et al.* 1974), but such studies that examine northern temperate stream ecosystems are much less common.

Badfish Creek receives sewage effluent from the city of Madison, and has a substantial summer biomass of submersed macrophytes which aggravate flooding during storm runoff events and cause unacceptably low (<2 mg O_2 l^{-1}) night-time dissolved oxygen minima (Madsen 1986). The relationship between macrophyte biomass and oxygen concentrations depends upon the proportion of biomass that is photosynthesizing. In dense beds where light does not penetrate past the upper 10 to 20 cm, increased biomass could cause an increase in respiration without increased photosynthesis, depressing daytime dissolved oxygen concentrations. In addition, the entire biomass respires at night, consuming water column oxygen. Therefore, harvesting could potentially decrease respiration without lowering the total photosynthetic activity, thus increasing average oxygen concentrations in the stream.

In this paper, two topics will be discussed: 1.) The effect of different harvest frequencies on macrophyte biomass and regrowth, as well as the efficiency of harvesting; and 2.) The impact of macrophyte harvesting on stream oxygen metabolism demonstrates the applicability of this control technique to altering the ambient oxygen concentrations of the stream.

METHODS

Site description. Badfish Creek is located in southern Wisconsin, and receives treated sewage effluent from the Madison Metropolitan area (Figure 1). At the time of this study, total water column nitrogen concentrations averaged 14 mg l^{-1} and total water column phosphorus concentrations averaged 6 mg l^{-1}. Mean annual water temperature averaged 12.5 °C, with a summer maximum of 22 °C. Average annual dissolved oxygen was 4.2 mg O_2 l^{-1}. Badfish Creek is a calcareous stream, with an average alkalinity of 340 mg $CaCO_3$ l^{-1} and a specific conductance averaging 1300 umhos cm^{-1}. Treated sewage effluent comprises 90% of the baseflow at the study sites (Madsen 1986).

Harvest frequency. The harvest frequency experiment was set up in three contiguous 100 m long plots upstream but contiguous to biomass site 4 (Figure 1). All treatments began in week 27 of 1984 (June 25), with the last harvest date during the week 35 of 1984 (August 20). The three treatments were harvest frequencies of once every eight weeks (Treatment 1), every four weeks (Treatment 2), and every two weeks (Treatment 3). The data for the control plot used a three point (date) moving mean, treatment data are single date means. For each plot, five total shoot biomass samples were taken at each sample date. Samples

[1]Postdoctoral Research Asssociate, Fresh Water Institute, Science Center 1W14, Rensselaer Polytechnic Institute, Troy, NY 12180-3590.

[2]Professor of Botany and Director of the Center for Biotic Systems, Department of Botany and Institute for Environmental Studies, Birge Hall, University of Wisconsin-Madison, Madison, WI 53706.

[3]Research Biologist, Madison Metropolitan Sewerage District, 1610 Moorland Road, Madison, WI 53713-3398.

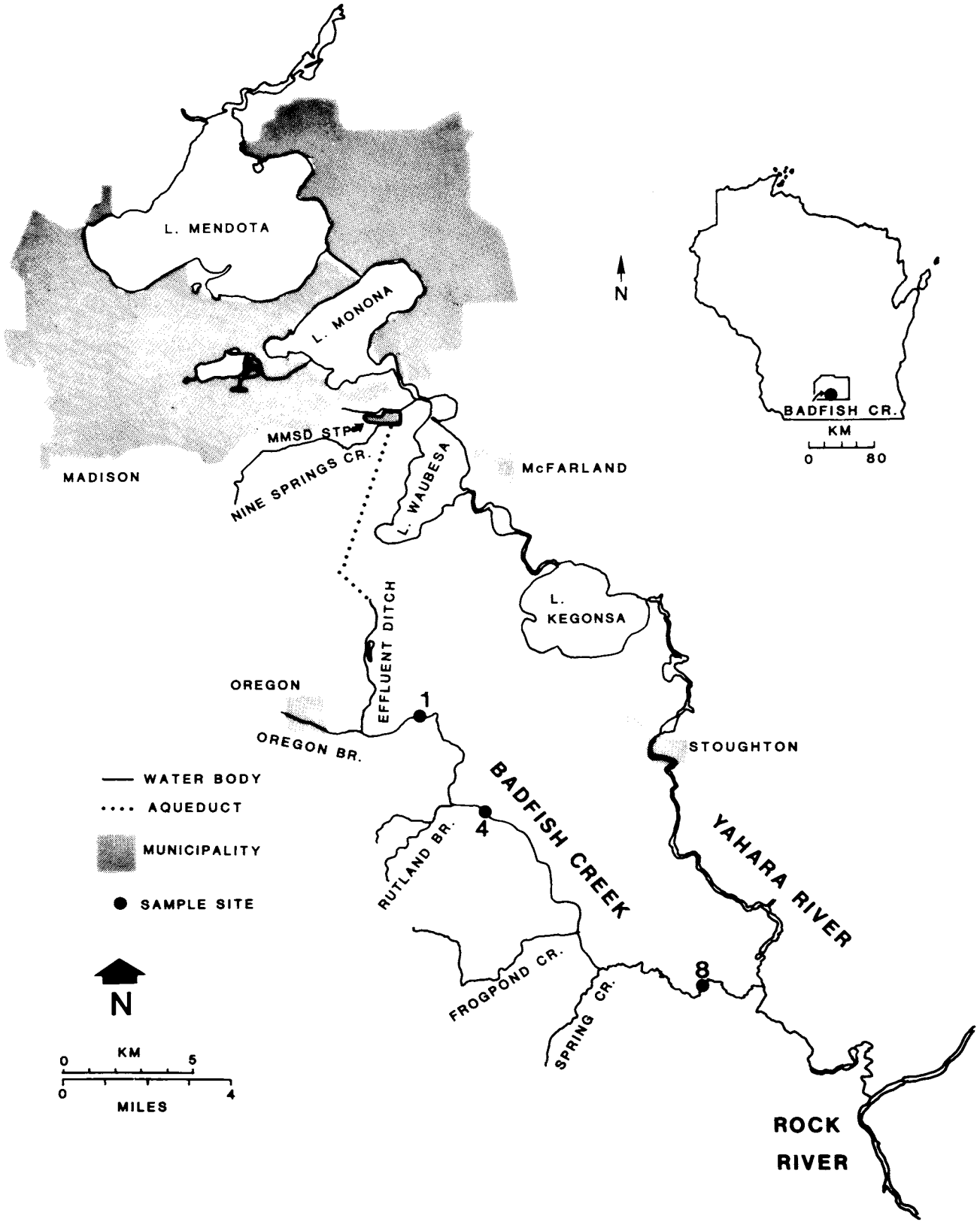

Figure 1. Location of sample sites on Badfish Creek.

were dried at 70 C to determine dry weight. Harvest treatments for each plot consisted of mechanical cutting by a sickle bar attached to a boat, as is used for harvesting throughout the entire stream. The crew attempted to harvest the entire plot, consistent with procedures used in management harvesting. Biomass samples were taken before and after each harvest event, with biweekly samples collected to measure regrowth. Biomass of the treatment plots were also measured for four weeks (two sample dates) after the last harvest treatment in mid-August. Regrowth was calculated by both biomass increment:

$$(1) \qquad GR = (B_n - B_{n-1})(t_n - t_{n-1})^{-1}$$

and by relative growth rate (Evans 1972):

$$(2) \qquad RGR = (\ln B_n - \ln B_{n-1})(t_n - t_{n-1})^{-1}$$

where: B_n = biomass at time n, in g dw m^{-2}
t_n = time n in days

Harvest data for week 33 (August 6) was excluded due to harvest operator error in harvesting the incorrect plot.

Oxygen mass-balance. In this experiment, the oxygen balance of a large stretch (0.6 km) was compared for one 24-hour day before and after harvesting. The entire stretch was harvested; there was no control, unharvested stretch. Initially, continuous-recording dissolved oxygen meters were utilized for one week before and after harvesting, but fouling of probes by weed fragments and other technical problems rendered the continuous data unuseable. Ambient oxygen conditions were measured by Winkler titrations at two-hour (June 20) and hourly intervals (June 27) at the upstream and downstream ends of the experimental reach located upstream of site 1 (Figure 1) on the Wednesday of the pre- and posttreatment week (June 20 and 27 1984, respectively). The study reach was 0.6 km in length, and averaged 8.5 m in width. Channel cross-sectional morphometry and flow were measured on four transects, with depth and velocity profiles measured at 0.67 m intervals along the cross-sectional transect. Current velocity was measured with a Marsh-McBirney electromagnetic current meter. Average depth before harvesting (June 20) was 0.89 m and average current velocity (using current velocity at 0.6 times the depth, as per Chow 1959) was 0.18 m s^{-1}. Postharvest averages (June 27) were 0.74 m depth and 0.18 m s^{-1} current velocity. Average flowrates for the two two dates were similar (1.8 m^3 s^{-1} on both June 20 and June 27). Twenty randomly placed biomass samples were taken before and after harvesting. The equation for determining community photosynthesis and respiration was from Gulliver *et al.* (1980):

$$(3) \qquad Q = P - R + J_s + A$$

where: Q = rate of dissolved oxygen change per unit surface area
P = Total community photosynthesis or gross primary productivity (GPP)
R = Total community respiration (R)
J_s = surface exchange per unit surface area
A = drainage accrual of oxygen from inflowing and outflowing streams

Microbial P and R in the water column (e.g., bacterial, phytoplankton and periphyton drift) were evaluated before and after treatment using an eight hour incubation of light and dark bottles with six replicates. Oxygen concentrations of ambient and incubated samples were determined by Winkler method titrations, and calculations followed Wetzel and Likens (1979):

$$(4) \qquad R = (1 - D)\, t^{-1}$$

$$(5) \qquad NPP = (L - I)\, t^{-1}$$

$$(6) \qquad GPP = (L - D)\, t^{-1}$$

$$(7) \qquad GPP = NPP + R$$

where: I = initial oxygen concentrations (ambient)
L = light bottle oxygen concentration
D = dark bottle oxygen concentrations
t = time in hours
R = respiration
NPP = net primary productivity
GPP = gross primary productivity

The community photosynthetic and respiratory rates were then corrected by the water-column rates to derive the rates by sediment, benthos, and the combined macrophyte and epiphyte activity, which we will simplify to macrophyte activity since sediment respiration should be constant, and epiphyte activity change proportional to macrophyte surface area. Solar radiation data for June 20 and June 27 is from tbe U. S. Meteorological Service (U. S. Department of Commerce) site at Truax Field, Madison, Wisconsin.

RESULTS AND DISCUSSION

Harvest frequency. The shoot biomass of the three treatments and the control over the experimental period are shown in figure 2. Harvesting every other month (treatment 1) allowed regrowth to 368 g dw m^{-2}, whereas treat-

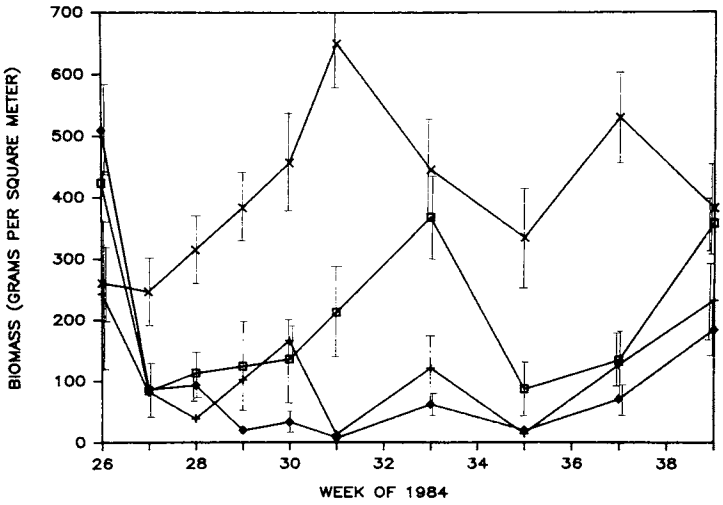

Figure 2. Biomass of shoots (g dw m^{-2}) for three harvest frequency treatments and the control (site 4) by week of the year. Bars indicate ± 1 standard error, no bar indicates a standard error of less than 2. □ Treatment 1 (semi-monthly); + Treatment 2 (monthly); ◇ Treatment 3 (biweekly); × Control.

ment 2 (every month) maintains biomass below 167 g dw m^{-2} and treatment 3 (every other week) was maintained below 94 g dw m^{-2} during the experimental period (weeks 27-35, June 25-August 20). Harvesting every two and every four weeks did not allow regrowth to attain that of control levels one month after the last harvest treatment, whereas the treatment 1 plot regrew to control levels four weeks after the last harvest event.

The growth rate after harvest was highest for treatment 1, and lowest for treatment three (Table 1). However, these rates are dependent on initial biomass. Relative growth rates, indepedent of biomass, are equivalent for treatments 2 and 3, which are higher than treatment 1.

The efficiency of harvesting (percent removed relative to preharvest biomass) is similar for the three treatments, indicating a density or biomass dependence on the amount of material removed. The amount of biomass remaining after harvesting decreases with subsequent harvests, to a basal level depending on bottom topography. Harvest treatment 1 maintains biomass to an average of 44% of control, treatment 2 to 25%, and treatment 3 to 18%. The percent of bottom area covered did not change with harvesting, but merely toprowth was removed. Plant frequency in biomass samples was 100% for a 0.2 m^2 sampler.

One effect of harvesting that was not measured was a reduction in tuber production. Ogg *et al.* (1969) noted that an increased frequency of topgrowth removal reduced the rate of tuber formation. This effect could decrease plant density in subsequent years, an effect which should be investigated.

Treatments two and three acheived very similar results, maintaining biomass levels below 200 g dw m^{-2}. Harvesting once per month is therefore as effective in acheiving control as harvesting alternate weeks. However, harvesting twice per growing season (every other month) is not effective in maintaining control. Harvesting delays flowering and senescence. The control population had flowered and was senescing in September, while all treatments were actively regrowing from the previous harvest treatment and had not flowered. This phenomenon has also been observed for managed and unmanaged *Ranunculus* in England (Ham *et al.* 1982). Harvesting should be done early, while biomass is still low, to maintain lower biomass levels. Biomass will then take longer to reach nuisance proportions, and less effort will need to be expended to maintain the much lower remainder for cuts subsequent to the first harvest.

Harvest efficiencies were much higher in the harvest frequency test site than in the oxygen mass-balance experimental reach (77% to 82% versus 50%). We can think of three possible reasons for this discrepancy:

1. The harvesters knew that the harvest frequency sites were a test of harvesting efficiencies, while the experimental reach seemed to be a routine harvest assignment. They may therefore have consciously or subconsciously "tried harder" on the former sites; 2. The harvest test sites were located in another region of the stream which appeared to have a more level, homogeneous bottom. A large proportion of the oxygen mass-balance experimental reach is riprapped, creating a surface difficult to harvest efficiently. The biomass values for this region are much more heterogeneous, with some spots missed entirely while others were closely cropped; and 3. The oxygen mass-balance experimental reach is much larger (600 m versus 100 m), therefore inherently more heterogeneous than the harvest test sites.

Actually, we think that each of these factors may have contributed to the reduced efficiency of harvesting at the experimental reach.

Oxygen mass-balance. Preharvest macrophyte biomass was 353 g m^{-2}. Harvesting was only 50% efficient, reducing biomass to 175 g m^{-2}. Incident light was similar on the pre- and posttreatment trial days (Total incident light: 6500 W m^{-2} d^{-1} for June 20 versus 6200 W m^{-2} m^{-1} for June 27). Net primary production before harvesting was –0.81 mg O_2 l^{-1} d^{-1}, with a maximum of 0.98 mg O_2 l^{-1} h^{-1} (Figure 3, Table 2). Gross primary productivity was 6.2 mg O_2 l^{-1} d^{-1}, with a maximum of 1.2 mg O_2 l^{-1} h^{-1}; respiration was 7.01 mg O_2 l^{-1} d^{-1}, with a maximal rate of 0.65 mg O_2 l^{-1} h^{-1} and a basal (predawn) rate of 0.22 mg O_2 l^{-1} h^{-1}. Postharvest net primary productivity (NPP) was –2.63 mg O_2

TABLE 1. REGROWTH RATES AND HARVEST EFFICIENCIES OF TREATMENTS IN THE HARVEST FREQUENCY EXPERIMENT (NEAR SITE 4) AND THE OXYGEN MASS-BALANCE REACH (NEAR SITE 1).

Parameter	Treat 1	Treat 2	Treat 3	O_2 Exp.
Growth Rate (g dw m^{-2} d^{-1})	8.8	5.7	3.4	—
Rel. Growth Rate (d^{-1})	0.048	0.083	0.078	—
% Harvested (Efficiency)	78	82	77	50
% Control	44	25	18	—
Remainder: (g dw m^{-2})				
Maximum	88	82	87	463
Minimum	85	13	8	16
Average	87	37	34	175

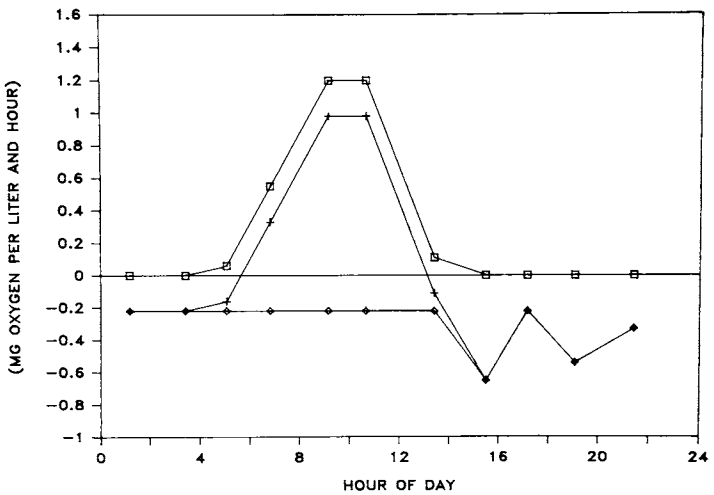

Figure 3. Community gross primary roductivity (GPP), net primary productivity (NPP) and respiration (R) (mg O_2 l^{-1} h^{-1}) before harvesting (June 20), versus time of day. □ GPP; + NPP; ◇ R.

TABLE 2. COMMUNITY METABOLISM BEFORE AND AFTER HARVESTING IN THE OXYGEN MASS-BALANCE EXPERIMENTAL REACH.

Parameter	Preharvest (June 20)	Postharvest (June 27)
Community NPP (mg O_2 l^{-1} d^{-1})	–0.81	–2.6
Maximum NPP rate (mg O_2 l^{-1} h^{-1})	0.98	0.60
Community GPP (PS) (mg O_2 l^{-1} d^{-1})	6.2	2.6
Maximum GPP (PS) rate (mg O_2 l^{-1} h^{-1})	1.2	0.75
Community R (mg O_2 l^{-1} d^{-1})	7.0	5.2
Basal R rate[1] (mg 0_2 l^{-1} h^{-1})	0.22	0.15
Community P/R	0.88	0.49
Microbial GPP (mg O_2 l^{-1} h^{-1})	0.048	0.20
Microbial NPP (mg O_2 l^{-1} h^{-1})	–0.053	0.096
Microbial R (mg O_2 l^{-1} h^{-1})	0.10	0.10
Macrophyte GPP: mg O_2 l^{-1} h^{-1}	0.63	0.023
mg O_2 l^{-1} d^{-1}	5.6	0.21
Macrophyte NPP: mg O_2 l^{-1} h^{-1}	0.05	–0.42
mg O_2 l^{-1} d^{-1}	1.40	–3.8
Macrophyte R: mg O_2 l^{-1} h^{-1}	0.19	0.12
mg O_2 l^{-1} d^{-1}	4.6	2.8
Macrophyte P/R	1.2	0.076

[1]Predawn respiration.

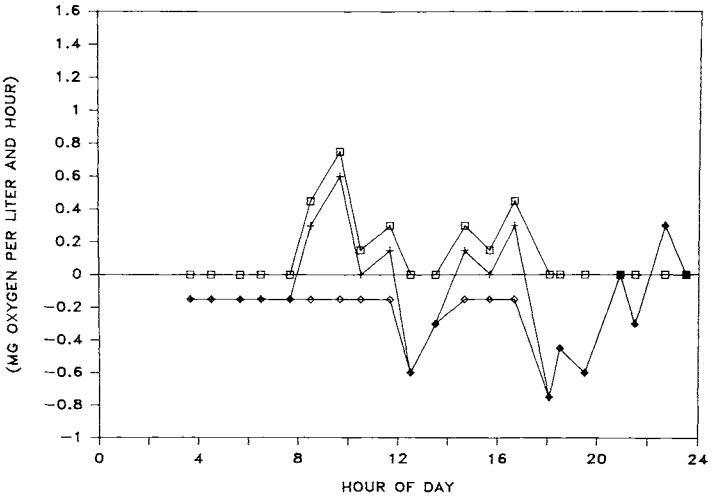

Figure 4. Community gros primary productivity (GPP), net primary productivity (NPP) and respiration (R) (mg O_2 l^{-1} h^{-1}) after harvesting (June 27), versus time of day. □ GPP; + NPP; ◇ R.

l^{-1} d^{-1}, with a maximum rate of 0.60 mg O_2 l^{-1} h^{-1} (Figure 4, Table 2). Gross primary productivity (GPP) was 2.55 mg O_2 l^{-1} d^{-1}, with a maximum of 0.75 mg O_2 l^{-1} h^{-1}, and a severe midday depression that greatly reduces overall productivity (Figure 4). Stormflow runoff from the previous day may have caused this depression by increased loading of oxygen-demanding materials in addition to increasing turbidity, reducing photosynthesis. Respiration was 5.18 mg O_2 l^{-1} d^{-1}, with a maximum of 0.75 mg O_2 l^{-1} h^{-1} and a basal (predawn) rate of 0.15 mg O_2 l^{-1} h^{-1}. Microbial water column respiration was similar before and after harvesting. In general, harvesting decreased the range of both community respiration and photosynthesis, which should increase minimum dissolved oxygen concentrations. However, no differences in average ambient dissolved oxygen concentrations were noted. Average dissolved oxygen for June 20 was 2.8 (± 1.8) mg O_2 l^{-1} versus 2.4 (± 1.7) mg O_2 l^{-1} for June 27. Correcting for water column metabolic activity, macrophyte respiration decreased nearly 100% after harvesting, a decrease directly proportional to the decrease in biomass. However, photosynthesis was also greatly decreased, but this may also be attributed to the change in environmental conditions. Whereas the macrophyte community had a positive carbon gain before harvesting, on this particular postharvest day the macrophyte community appears to be at a carbon deficit (Table 2). The stream community before and after harvesting is heterotrophic, as evidenced by a P/R less than 1.

Harvesting of macrophyte material seemed to reduce both photosynthesis and respiration, which should result in higher dissolved oxygen minima and average oxygen concentrations. Thyssen (1982) indicates that macrophytes in unpolluted streams with a biomass of less than 150 g m^{-2} have a negligible impact on oxygen metabolism and cites several other studies (e.g., King and Ball 1967) that show that macrophytes have a negligible impact on stream oxygen budgets in polluted streams, with periphyton dominating community oxygen metabolism. However, for the purposes of maintaining adequate oxygen in the stream environment, the effect of removing macrophytes should be considered as the combined effect of the macrophytes and their associated epiphytes. Although macrophytes themselves may not dominate productivity and community oxygen metabolism, increased biomass greatly increases the surface area for epiphytes, both autotrophic and bacterial, that do dominate community oxygen metabolism.

In addition, the biomass levels in Badfish Creek reached 620 g m^{-2}, four times the biomass in the study reported by Thyssen (1982). As evidenced in this study, the macrophyte-epiphyte complex dominates oxygen metabolism in polluted, macrophyte-dominated streams. In agreement with this finding, Jorga and Weise (1977) found macrophyte biomass in excess of 250 g m^{-2} in a polluted stream to cause severe early morning oxygen depletion, as well as autumnal oxygen depression from the decomposition of the macrophytes. They recommended control to maintain biomass below this value. Edwards and Owens (1962) indicated that macrophyte respiration is approximately 30% of total community respiration. In this study, a rough approximation of the contribution of the macrophyte-epiphyte complex to community respiration is 52% pretreatment and 26% posttreatment, slightly higher than the findings of Edwards and Owens (1962).

The results of the oxygen mass-balance experiment were less definitive than desired, in part due to the complications of a storm runoff event during posttreatment analysis, as well as the failure of the continuous recording apparatus. This experiment should be repeated using a reliable continuous recording apparatus, with analysis of several days before and after treatment to give a replicated estimate of community metabolism and allow statistical comparisons.

In summary, harvesting at either monthly or bimonthly intervals was adequate to maintain the desired control levels in Badfish Creek. Although macrophytes are an important component of community oxygen metabolism in Badfish Creek, harvesting in this stream was efficient only in reducing the magnitude of diel oxygen variations, and did not increase average oxygen concentrations.

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Long-term Effects of Mechanical Harvesting on Eurasian Watermilfoil

D. SCOTT PAINTER

ABSTRACT

The long-term efficacy of mechanical harvesting of Eurasian watermilfoil (*Myriophyllum spicatum* L.) was examined over a four year period. The harvesting strategy chosen was a double cut performed in June and September of each year. Milfoil biomass, shoot weight and plant density were reduced; however, plant height continued to reach the water's surface in the fourth year of the study. Smaller root masses were observed in the harvested area. A linear relationship between shoot weight and root weight was determined suggesting that harvesting of shoot material would result in some root die-back. Tissue phosphorus concentrations were at all times above growth-limiting levels, nor were any trends discernible that would explain the impact of harvesting on milfoil biomass. Carbohydrate concentrations were reduced in the spring, but any differences between harvested and control plants were eliminated by mid-summer. The effect of harvesting on biomass did not appear to be related to shoot or root carbohydrate concentration trends. Sediment biologically-available phosphorus concentrations were reduced in the last two years of the study; however, since tissue concentrations were not limiting, the effect of harvesing would not appear to be related to changes in sediment phosphorus.

Key words: Myriophyllum spicatum, carbohydrates, phosphorus, sediment phosphorus, nutrition, plant biomass.

INTRODUCTION

Mechanical harvesting is commonly employed to control the nuisance aquatic plant, Eurasian watermilfoil (*Myriophyllum spicatum* L.). The ability of harvesting to achieve long-term control is desirable but questionable. Perkins and Sytsma (1982) reported that no long-term control of biomass was achieved in their harvesting experiments in Union Bay, Lake Washington. Kimbel and Carpenter (1979) reviewed several research harvesting projects and observed that harvesting had an impact on regrowth in the second year in 12 of 13 reported projects. Painter and Waltho (1985) observed that if a fall harvest

[1]Aquatic Ecology Division, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada, L7R 4A6.