The Aquatic Macrophyte Community of Black Earth Creek, Wisconsin

Roy Bouchard and John D. Madsen

Abstract. *The aquatic macrophyte community of Black Earth Creek, Wisconsin, was studied in June and July of 1985 and compared to data collected in 1981. Macrophyte distribution was examined by the line intercept method, with macrophyte cover negatively correlated to light reduction by tree canopy. The dominant species in the stream was* Potamogeton crispus. *Other species included* P. pectinatus, P. vaginatus, Elodea canadensis, Ranunculus longirostris, Hypericum boreale *and filamentous algae, namely* Rhizoclonium *sp. Average total cover of all macrophytes was 55.6%. Cover of macrophytes was only slightly lower in 1985 than in 1981, which was thought to be due to random population fluctuations rather than directional change in the community. Macrophyte biomass was estimated at three unshaded stations. Maximum macrophyte biomass was 789 g dw* m^{-2}*, with no relation found between biomass and the inflow of a sewage treatment plant. Samples of* Potamogeton crispus *and* Rhizoclonium *sp. analyzed for tissue phosphorus indicated that plants are not near limiting concentrations for P; rather, present data indicate that light availability limits the growth of macrophytes in Black Earth Creek. Oxygen mass balance was used to estimate community photosynthesis and respiration, and the macrophyte/epiphyte contribution to community respiration estimated by* in situ *incubations. Macrophyte/epiphyte respiration contributed 47% to 68% of community respiration. The P/R ratio was 0.62, indicating a heterotrophic stream community.*

Aquatic macrophytes are an important component of stream ecosystems, influencing physical, chemical and biological processes. Aquatic macrophytes stabilize the stream substrate, reducing turbidity and erosion. They also increase deposition of suspended solids, further reducing turbidity, and oxygenate the water by means of photosynthesis. Stream channels deepen and current increases between adjacent plant beds, improving habitat diversity. Aquatic macrophytes and attached epiphytic algae provide food and habitat for macroinvertebrates and other small organisms, as well as protection for large fish species. Macrophytes increase stream productivity beyond energy gained by allochthonous inputs. In addition to these benefits, macrophytes provide surface area for microbes, which contribute significantly to many chemical processes in the stream, such as nitrification, respiration, and decomposition.

However, excess growths of macrophytes can also create problems for the stream ecosystem. Bank-to-bank growths of aquatic macrophytes will slow current velocities, causing flooding and siltation. Homogeneous growths of macrophyte species reduce habitat heterogeneity. Most importantly, excessive plant growths create large daily dissolved oxy-

John D. Madsen, formerly at the University of Wisconsin-Madison, is now a research associate at the Fresh Water Institute, Rensselaer Polytechnic Institute, Troy, New York.

Roy Bouchard is a member of the Maine Department of Environmental Protection.

gen fluctuations. Nighttime respiration may reduce dissolved oxygen to levels that are stressful or lethal to oxygen-sensitive organisms.

Recent concern for Black Earth Creek centered on potential eutrophication and the resultant effect on this highly productive trout stream. Decisions on the management of plants require some assessment of their distribution, abundance, and impact on the stream. With this in mind, we addressed the following:

1. Species and plant distribution in 1981 and 1985 and their relationship to several physical factors.
2. The relationship between tree canopy, light availability, and plant growth.
3. Macrophyte biomass in Black Earth Creek, with sampling above and below a point source of nutrients.
4. The contribution of macrophyte respiration to the oxygen balance of the stream.
5. Potential phosphorus limitation of macrophyte biomass.

Macrophyte Cover

Previous work (Madsen 1982; Madsen and Adams 1985) on Black Earth Creek surveying the plant communities and physical environment in four sections of Black Earth Creek (Segments 1–4, Figures 1 and 2) indicated that light limitation by tree canopy and turbidity are probably the most important factors limiting plant productivity. The relationship between in-stream plant communities and shading has been extensively studied. Light availability is likely the most important factor limiting plant growth (Dawson and Kern-Hansen 1978; Dawson *et al.* 1978; Krause 1977; Barko *et al.* 1985; Peltier and Welch 1969). The effects of removing the tree canopy were noted by Hunt (1979) in the Little Plover River (Wisconsin), where first year increases in macrophyte cover of more than 200% were seen, with accompanying increases in water temperature and trout production.

Biomass

The actual impacts of macrophytes on the stream environment depend heavily on the amount of plant tissue, or biomass, present in the stream. Methods for estimating plant cover are valuable in allowing rapid quantitative surveys but cannot be used to estimate biomass at higher cover frequencies. Quantification of in-stream biomass is difficult due to the heterogeneity of such systems and the large number of samples needed to obtain statistically meaningful estimates. Recent work in Badfish Creek, Wisconsin (Madsen 1986), indicated that even short stretches (50–100 m) of relatively homogeneous steam may need sample sizes in excess of 15 to 20 samples.

Respiration and Dissolved Oxygen Modeling

Diel variation in dissolved oxygen levels are caused in part by macrophyte photosynthesis (Ps) and respiration (R) (Kelly *et al.* 1983). Macrophytes are only one oxygen consumer in an aquatic system. Bacteria, algae, macroinvertebrates, and higher fauna all contribute to overall respiratory load (McDonnell 1982). Estimates of reaeration coefficients (K2), Ps, and R for the community may be made by finite difference models without detailing their components. Single station models commonly rely on assumptions such as homogeneity of the study reach for some distance above the sampling point, Ps proportional to light intensity, and constant R and K_2 despite changes in temperature (Mace *et al.* 1984, Owens 1966).

Phosphorus Limitation

Unquantified observations of increased macrophyte growth below the sewage treatment plant in Cross Plains caused Brynildson and Mason (1975) to suggest

that P input at that point is responsible. Values reported for total and soluble P for 1985 (WDNR data, unpub.) indicate a substantial input of P due to a point source in the upper watershed. In response to the speculation that phosphorus input to Black Earth Creek may increase macrophyte growth, we analyzed tissue phosphorus from the dominant macrophyte *(Potamogeton crispus)* at several sites to check for limiting tissue P concentrations. In a literature review of nutritional and ecological growth controlling factors, Barko *et al.* (1985) concluded that there are few examples of naturally occuring macrophyte populations exhibiting limitation by phosphorus. Inorganic carbon and physical factors (e.g., light) seem to play a dominant role in limiting aquatic macrophyte growth (Huebert and Gorham 1983; Peltier and Welch 1969).

Work on lake systems (e.g., Carignan 1982; Carignan and Kalff 1979, 1980; Barko and Smart 1981) indicates that sediments provide the bulk of tissue P. Estimates of the sediment contribution to plant tissue phosphorus range from 70 to 100% (Huebert and Gorham 1983). Total removal of P from experimental water columns resulted in unimpeded growth by plants with sufficient sediment nutrients. Mace *et al.* (1984) speculated that the macrophytes in Black Earth Creek utilized sediment P more than water column P, based on a model for other Wisconsin streams.

Literature reports of tissue P in natural populations indicate concentrations ranging from 0.15 to 0.6%. Plants immersed in greatly enriched waters (e.g., Badfish Creek, Dane County, WI) may show concentrations as high as 0.7 to 1.0% P (Madsen 1986). Tissue P levels for all species of plants sampled in Wisconsin by Mace *et al.* (1984) ranged from 0.13 to 0.67%, all of which were above the critical growth level of 0.1% established by Gerloff (1973, 1975).

Methods

Site Description

Black Earth Creek is a highly productive, calcareous stream in western Dane County, Wisconsin (Fig. 1). This limestone stream is classified as a "class-one" trout stream by the Wisconsin Department of Natural Resources (WDNR), indicating that it sustains a population of naturally reproducing trout (Brynildson and Mason 1975). Black Earth Creek is a valuable natural resource to the state, with trout productivity (472 kg ha^{-1} y^{-1}; Brynildson and Mason 1975) nearly as high as the Horokiwi Stream in New Zealand (540 kg ha^{-1} y^{-1}; Allen 1951) and higher than other trout streams studied in the midwest.

Water quality is rated from good to fair, with some water quality degradation related to high concentrations of phosphorus and coliform bacteria (Lathrop and Johnson 1979). Groundwater and artesian spring water maintain low temperatures and high oxygen levels, such as

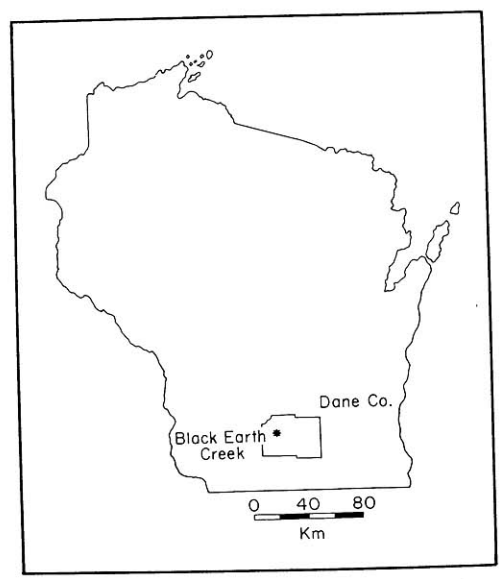

Fig. 1. A map of Wisconsin indicating location of Dane County and Black Earth Creek.

are necessary to support trout and other oxygen-sensitive organisms in Wisconsin (Threinen and Poff 1963).

Black Earth Creek is on the edge of the unglaciated Driftless Area of southwestern Wisconsin. The watershed is largely agricultural (Born 1986). Our study area extends from above the Village of Cross Plains to just above the Town of Black Earth, with seven study sections indicated (Fig. 2). One significant point source of pollution is the Cross Plains Sewage Treatment Plant. However, nonpoint pollution occurs from agricultural activities throughout the watershed as well as urbanization and development in the Village of Cross Plains and the Town of Middleton at the headwaters.

Macrophyte Cover and Physical Environment

During June and July of 1985, four areas previously studied in 1981 were remapped (sections 1–4), along with three additional sections (Fig. 2) to quantify any major changes in macrophyte cover and characterize downstream segments of the creek. Line-intercept methods were consistent with those used in 1981 (Madsen 1982). Once each month, twenty stratified-random transects were sampled in each segment. The transect was placed across the stream, and the occurrence of each macrophyte species in each 1 dm segment recorded. A species found in the 1 dm segment was considered to "cover" that 1 dm segment. Overhead tree canopy was estimated by eye to the nearest 10% at each transect site. Photosynthetically active radiation (PAR) was measured at the stream surface in the center of the channel as well as 1.5 m from each shore using a LiCor quantum meter and probe, with light availability expressed as a percentage of open-field light intensity. Water depth and depth of silt deposits were measured at 1 m intervals, and stream width at each transect. The per-

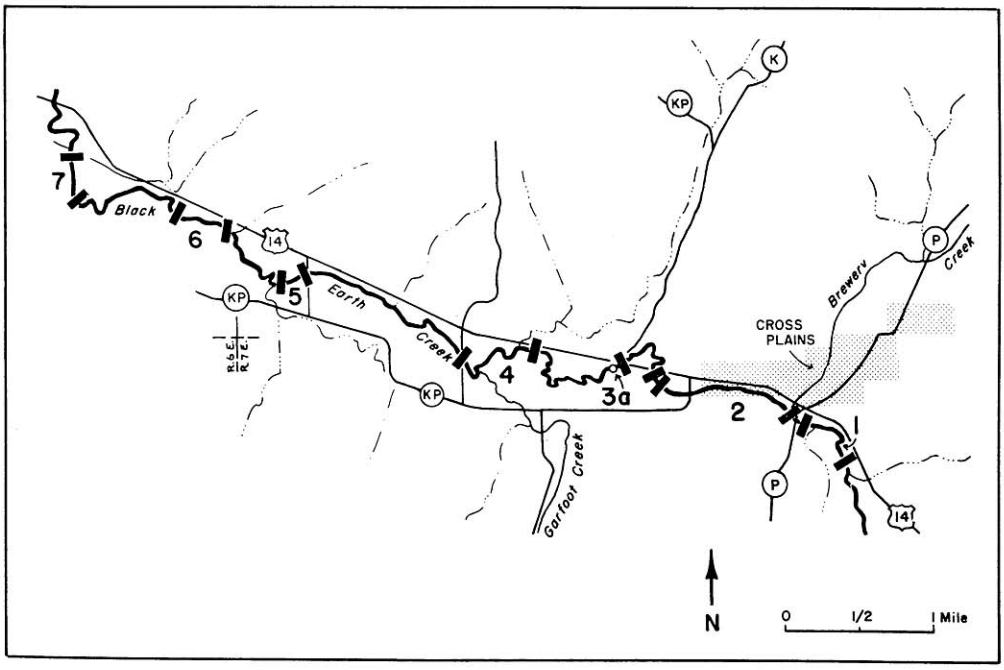

Fig. 2. Map of Black Earth Creek, indicating study sites 1 through 7. Figure reprinted from Water Resources Management Workshop Report (Born 1986).

centage of substrate composed of silt, sand, and gravel at the surface was estimated at each transect.

Biomass

The ability of the stream to support plants was quantified by taking standing crop biomass samples in three representative unshaded areas. Phenological evidence from the literature (Sastroutomo 1981; Kunii 1982) and previous observations on Black Earth Creek (Madsen 1982) suggested plant biomass would peak in early to mid-July. Sampling peak biomass provides a crude estimate of the potential productivity in the stream.

One site within each of three sections (1, 3 and 7) was chosen based on the lack of shade, presence of dense macrophyte growths, and position relative to the sewage treatment plant at Cross Plains. Fifteen stratified random samples were taken from each site. Sites 1 and 7 were 150 m in length; site 3 was 100 m long (Fig. 2). These sites had heterogeneous bottoms of silt over gravel with open channels scoured to bare gravel between dense macrophyte beds. Each sample was harvested from a 0.19 m^2 quadrat at the sediment surface, with inclusion of less than 10% root material. Samples were sorted by dominant species and dried at 70°C. Species identifications and nomenclature follow Fassett (1957).

Respiration and Dissolved Oxygen Modeling

Dissolved oxygen variations of 6–8 mg O_2 l^{-1} observed in the stream over 24-hour periods (WDNR data, unpubl.) prompted a concern for adequate oxygen to sustain sensitive organisms (e.g., trout). The percentage contribution of macrophytes and attached epiphytes to the whole stream respiration of one area of Black Earth Creek was estimated to indicate the role of macrophytes in community oxygen depletion.

A single station model developed by Mark Tusler (WDNR) was applied to Site 1 (Fig. 2). Temperature and dissolved oxygen data (uncorrected probe readings) were obtained from the U. S. Geological Survey (USGS) from the gaging station at Cross Plains (downstream end of Site 1) for June 12–14. Simultaneous temperature and dissolved oxygen measurements were taken at 8 A.M. and 2 P.M. at each end of the study stretch on June 13. Low variation in temperature (less than 0.2°C) and dissolved oxygen (less than 0.1 mg O_2 l^{-1}) indicated uniformity of the water mass in the stretch, a necessary requirement to satisfy the assumptions of the single station model utilized.

Dark respiration estimates for the dominant macrophytes (*P. crispus* at site 1 and *P. vaginatus* at site 7) were done on June 13 and 14 with a total of 12 replicates for each species. Twenty cm terminal sections of healthy shoots were incubated *in situ* in 300 ml BOD bottles (taped to exclude light) for periods of 2–3.5 hours, along with stream water controls. Dissolved oxygen concentrations were determined by the azide modification of the Winkler method (APHA Standard Methods 1981). Plants were removed from the bottles immediately after acidification and dried to constant weight at 70°C. Subsamples were used to determine total ash content at 550°C. No attempt was made to remove epiphytes prior to incubation because these contribute directly to respiration as part of the macrophyte-epiphyte complex in the stream.

Phosphorus Limitation

Following the rationale of Gerloff (1973), composite samples of the 10 cm terminal segments of healthy *P. crispus* shoots were randomly harvested on June 20 from all study sites (excluding site 5, which had little growth of *P. crispus*). Additionally, a sample of filamentous algae was harvested from site 6. Samples from

each site were oven-dried, ground in a Wiley mill, and split samples analyzed by the vanadomolybdate procedure (APHA *Standard Methods* 1981) in our laboratory and by the Wisconsin State Laboratory of Hygiene.

Results and Discussion

Macrophyte Cover

The physical environment in Black Earth Creek is heterogeneous with respect to depth, current, and substrate. These three interrelated factors have a large impact on plant distribution, resulting in highly variable species distribution and abundance. The stream channel widens considerably downstream, increasing from 4.9 m in site 1 to 12.9 m just above Black Earth. The width/depth ratio averages 16.5:1, and also increases in a similar fashion (Table 1). Much of Black Earth Creek is composed of relatively uniform runs broken up by short riffles and pools.

Figure 3 shows the relative distribution of silt, sand, and gravel covering the bottom of the sections surveyed. While the base materials of the stream are gravel and cobbles, silt deposits have altered the character of the substrate throughout the stream, with considerable depths of silt deposited in places (up to 1 m). Sections 3 and 4 were the only ones that had greater than 60% gravel substrate and were similar in width/depth ratios. Downstream sections 5 and 7 had 30% or more sand deposits. Silt deposits were moderately correlated with plant cover ($r = 0.4$, $p < 0.001$). Average depths of silt by site are listed in Table 1. Observations indicate that while depths of sediment as great as 80 cm build up in places along the stream edges, much of the areal distribution is made up of shallower (ca. 10 cm) deposits held in place by macrophyte beds. Mace *et al.* (1984) found a 69% (presence/absence) occurrence of macrophytes on silty substrates. Kullberg (1974) also noted the increased frequency of macrophytes on silt substrates. Dense beds of *R. longirostris,* which is usually located on gravel/cobble substrate, commonly trapped 10 cm or more of sediment where the plants were not located directly in a riffle area. Previous observations on Black Earth Creek (Madsen 1982; Madsen and Adams 1985) of *P. crispus* rooting in silt over gravel tend to confirm the impression of its significant local impact on deposition. Macrophytes cause local sedimentation within a plant bed by reducing current velocities (Haslam 1978; Gregg and Rose 1982; Madsen and Warncke 1983). Although moderate siltation may cause a favorable substrate rich in nutrients for macrophyte growth, heavy siltation causes burial and decomposition of macrophyte beds. Therefore, the

Table 1. Averages for environmental factors for study reaches 1 through 7 for June and July.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*all reaches*
% Light	91.8	71.4	29.6	55.6	100	47.1	100	67.1
% Canopy	7.8	33.2	59.2	27.5	0	49.7	0	28.8
Width (m)	4.9	6.1	6.5	8.5	11.2	10.1	12.3	8.1
Depth (cm)	69	45	43	48	38	42	55	49
Width/Depth	7.1	13.6	15.1	17.7	29.5	24.1	22.4	16.5
% Silt	74.7	38.7	15.3	25.9	14	16.2	33.2	32.2
% Sand	5	12.1	5.1	2.2	33.5	27.1	34.8	15.3
% Gravel	20.6	47.6	79.6	71.9	52.5	56.7	32	52.4
Silt Depth (cm)	35	22	10	15	10	16	34	22

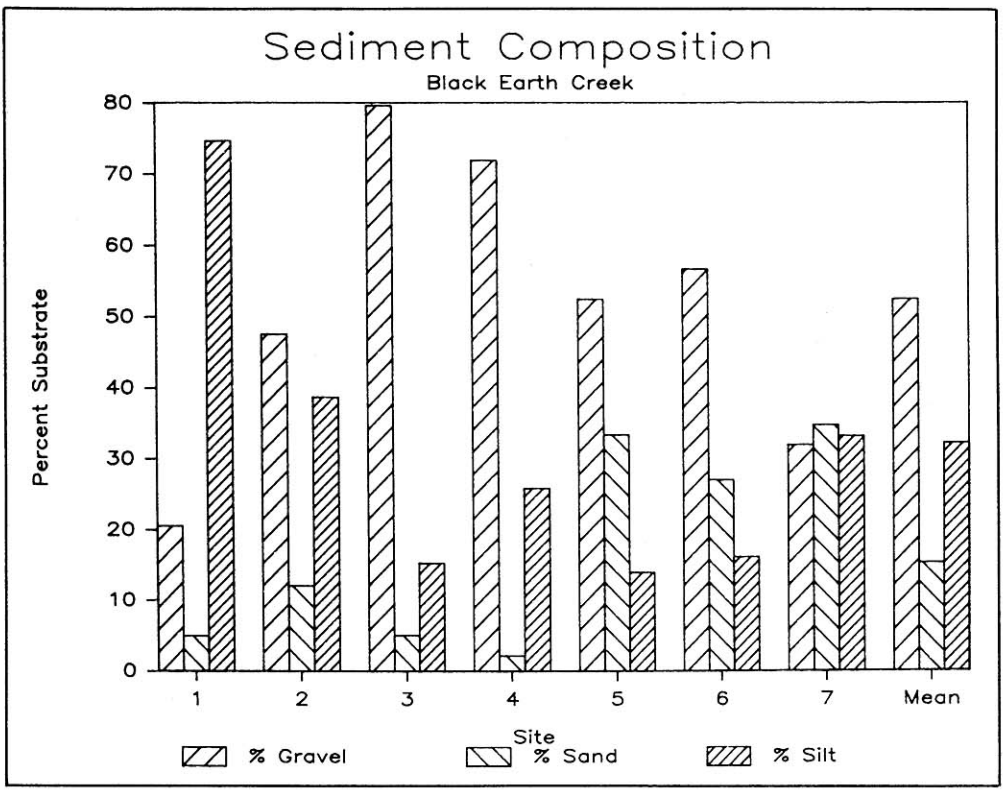

Fig. 3. Substrate composition in percent gravel, sand and silt for study reaches, and mean for all reaches.

higher frequency of macrophytes on silt substrates may be caused by increased siltation in a macrophyte bed, in addition to favorable current velocity or substrate conditions.

The average cover of macrophytes for all seven sites was 55.6% (S.E. = 2.1) for June and July combined. The average for sites 1 through 4 was 60.4%, compared to the 1981 estimates of 68.8% (Fig. 4). Section-to-section variability is high between and within years, especially in section 1. The major change from 1981 is an average decrease in the abundance of the dominant, *Potamogeton crispus*. However, this is most likely due to annual variation rather than directional change in the community.

The community in 1985 was composed of seven species that together made up more than 96% of total cover (Fig. 5). One of the notable differences from 1981 was the scarcity (< 1%) of formerly dominant *N. officinale,* and the relative abundance of *H. boreale,* with 4% cover. In addition, *P. vaginatus* occurred with *P. pectinatus* in similar abundance, especially at site 7. A striking growth of filamentous algae identified as *Rhizoclonium* sp. began in late June and covered large areas of site 5, which previously showed very little vegetation despite its lack of shading. The site is shallow with primarily gravel substrate and scattered *R. longirostris* patches providing anchoring substrate for the usually periphytic filaments. Localized patches of dense filamentous algal growths were also encountered at sites 3, 4, and 6 in shallow areas with exposure to sunlight. Filamentous algae were not quantified in 1981. The increased importance of *Elodea, Potamoge-*

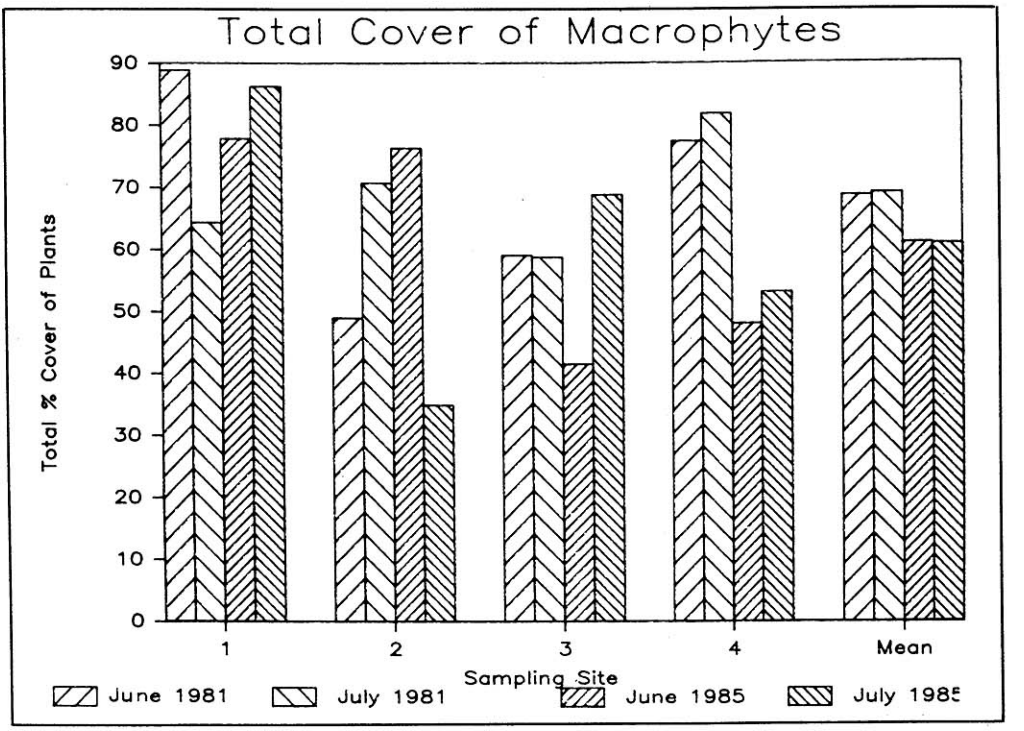

Fig. 4. Percent total community cover in Black Earth Creek for June and July of 1981 and 1985.

ton vaginatus and *Ranunculus* in 1985 versus 1981 is largely due to sampling of the lower reaches (5, 6, and 7) in 1985 that were not sampled in 1981. Similarly, the much higher relative percentage of *P. crispus* in 1981 is in part due to the sampling of only sections 1 through 4. *Potamogeton pectinatus* and *P. vaginatus* are much more prevalent in section 7. A smaller amount of variation in species composition between the two years is due to interannual fluctuations in dominance (Dawson *et al.* 1978).

Overhead canopy was negatively correlated with percent cover of macrophytes ($r = -0.58$, $p < 0.001$) and with the percentage of ambient light reaching the stream surface ($r = -0.87$, $p < 0.001$). This indicates that shading reduces cover and biomass development by significantly reducing in-stream light intensity. The average width of the stream (8–10 m) is narrow enough for effective shade control of aquatic vegetation.

Control of stream macrophytes by shading has been extensively studied and utilized in European streams (Dawson 1978; Dawson and Haslam 1983; Krause 1977; Jorga *et al.* 1982). In Wisconsin, (Madsen 1986) found a 60% reduction in incident light and a 50% reduction in macrophyte biomass in areas of Badfish Creek with natural tree vegetation, as compared to areas with only herbaceous riparian cover. Riparian shading by either naturally propagated or planted tree cover could be a feasible control technique for Black Earth Creek macrophytes. Control of macrophytes should only be implemented if the macrophyte standing crop is considered to be detrimental to the oxygen balance of the stream community.

Over shorter periods of time, light availability in Black Earth Creek may be

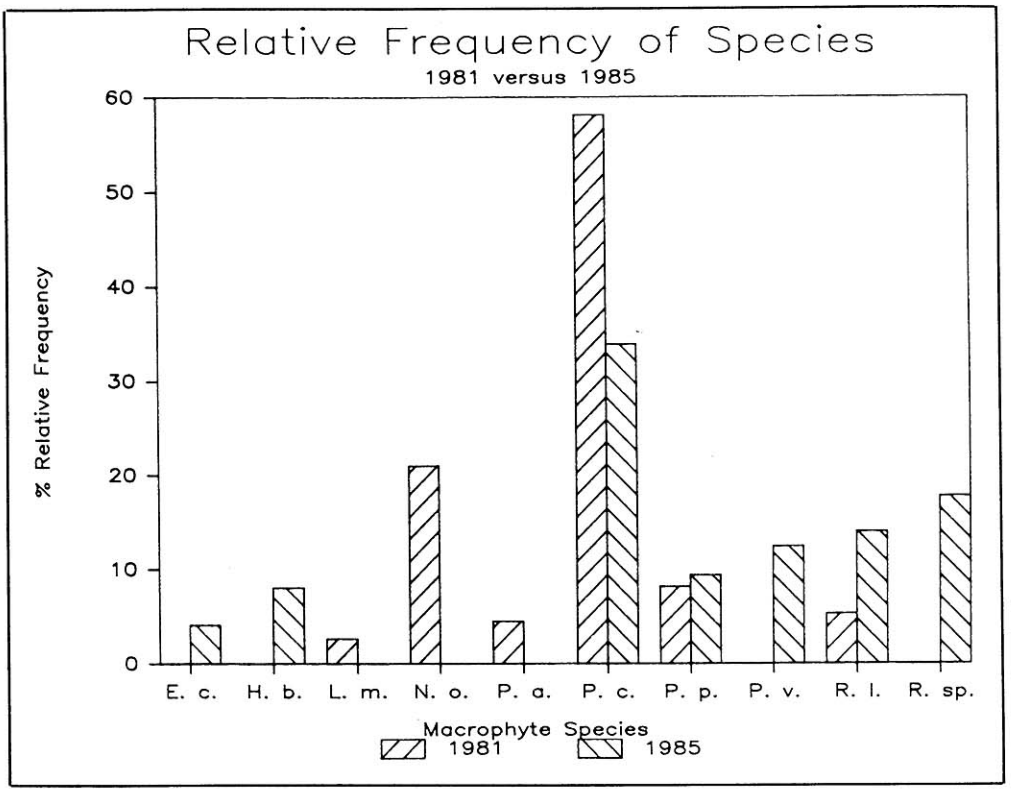

Fig. 5. Relative frequencies of species for 1981 and 1985; E. c., Elodea canadensis; *H. b.,* Hypericum boreale; *L. m.,* Lemna minor; *N. o.,* Nasturtium officinale; *P. a.,* Phalaris arundinacea; *P. c.,* Potamogeton crispus; *P. p.,* Potamogeton pectinatus; *P. v.,* Potamogeton vaginatus; *R. l.,* Ranunculus longirostris; *R. sp.,* Rhizoclonium *sp.*

reduced by water turbidity. Periods of heavy runoff may create turbid conditions for many days, or even weeks (pers. obs.). Variability in turbidity from year to year is one contributor to interannual variability in macrophyte biomass.

Biomass

Biomass provides an estimate of the ability of Black Earth Creek to support macrophyte growth (Table 2). Areas of high biomass and dense growth occurred in and above site 1, indicating that the stream is highly productive well before it encounters the point source of nutrients at Cross Plains. The input of treated sewage effluent from the Cross Plains Sewage Treatment plant does not increase macrophyte biomass, but may stimulate the growth of periphytic algae. Biomass at sites 1 and 7 may be higher than site 3 because of edaphic factors, specifically higher percentage silt. Data from both 1981 and 1985 show site 3 to have lower total cover, due to both different sediment characteristics and higher percent tree canopy.

Biomass sampling was done on Black Earth Creek by Mace *et al.* (1984) in September, 1982 at a location 11 km downstream from Cross Plains yielding an estimate of 282 g m^{-2}. This estimate does not truly reflect potential biomass on Black Earth Creek, since the sample was taken after the senescence of the dominant species *(Potamogeton crispus, P.*

Table 2. Above-ground biomass of macrophytes at three sites in Black Earth Creek (July 1, 1985).

Site	Mean Crop $g\ m^{-2}$	Standard Error	% of species by weight*					
			R	P.c.	P.spp.	H.b.	R.l.	E.c.
1	789.4	92.7	—	45	—	22	10	23
3	334.8	27.0	—	19	—	—	—	81
7	512.1	62.9	4	—	96	—	—	—
MEAN	545.4							

* Species codes: R = *Rhizoclonium* sp. and other filamentous algae; P.c. = *Potamogeton crispus;* P.spp. = *P. pectinatus* and *P. vaginatus;* H.b. = *Hypericum boreale;* R.l. = *Ranunculus longirostris;* E.c. = *Elodea candensis.*

pectinatus and *P. vaginatus).* A maximum biomass range of 500 to 800 g dw m^{-2} is more reasonable and is comparable to values reported for fertile limestone streams in Britain, as well as other streams (Table 3). Mace *et al.* (1984) found an average biomass of 365.5 g dw m^{-2} for Mount Vernon Creek, a nearby stream that receives less point and non-point pollution. Peak values for Badfish Creek, a nearby stream receiving sewage effluent, were 700 g dw m^{-2} in 1983 and 626 g dw m^{-2} in 1984 (Madsen, in prep.). The similarity of values between Black Earth Creek and Badfish Creek support our contention that the macrophytes in these streams are not nutrient limited.

Respiration and Dissolved Oxygen Modeling

Respiration estimates for *P. crispus* and *P. vaginatus* averaged 2.43 and 2.90 mg 0_2 g $AFDW^{-1}$ h^{-1}, respectively (S.E. was 0.59 and 0.14, corrections for AFDW were 0.854 and 0.843). While these are higher than the suggested value of 1.5 mg 0_2 g dw^{-1} h^{-1} as suggested by Westlake (1966), they compare well with values found for similar species by Mace *et al.* (1984) and our unpublished data for *P. pectinatus.* Respiration attributed to microbial and algal activity in the water column was estimated to average 4.3 mg 0_2 1^{-1} d^{-1}, which is approximately 10% of the whole stream respiration estimated below.

The model estimated K_2 (adjusted to 25 C) at 8.52 d^{-1} and Ps and R as 25.1 and 40.7 mg O_2 1^{-1} d^{-1} respectively. The estimated K_2 appears high compared to the estimates of 8.5 to 10 d^{-1} by Grant and Skavroneck (1983) for an area downstream of Cross Plains that has a higher gradient and shallower flow than site 1. However, the K_2 calculated had a rather large confidence interval (5.9–11.1 95% C.I.), and thus the disparity with the expectations based on the results of Grant and Skavroneck is not surprising. Lack of

Table 3. Macrophyte biomass for representative streams and lakes.

Community	Species	$g\ m^{-2}$ Biomass	Reference
Fox Lake, WI	*Potamogeton pectinatus*	293	Kollman & Wali 1976
River Ivel, UK	*Berula—Callitriche*	520	Edwards & Owens 1960
River Test, UK	*Ranunculus pseudofluitans*	385	Owens & Edwards 1962
River Ivel, UK	*Ranunculus pseudofluitans*	320	Owens & Edwards 1962
River Yare, UK	*Potamogeton lucens*	381	Owens & Edwards 1962
River Chess, UK	*Callitriche* sp.	322	Owens & Edwards 1962
Bear River Delta, Man.	*Potamogeton pectinatus*	517	Robel 1961
Lake Suwa, Japan	*Potamogeton crispus*	86.8	Ikusima 1970
Badfish Creek, WI 1983	*Potamogeton pectinatus*	700	Madsen 1986
Badfish Creek, WI 1984	*Potamogeton pectinatus*	626	Madsen 1986

correction in the model for temperature effects may produce an overestimation of K_2. MacDonnell (1982), working on a highly productive hardwater stream in Pennsylvania, noted that K_2 may be overestimated by as much as 27% in such situations.

Effects of dissolved oxygen changes on respiration are probably small, as the observed range was between 6.8 and 13.9 mg 0_2 1^{-1} for the period. This is above the level (5 mg 0_2 1^{-1}) at which large effects on respiration are noted (MacDonnell 1982). Model assumptions about the uniformity of the stream flow can be questioned on the basis of USGS data on groundwater input. Flow may be augmented approximately 40% in the area. While information on the dissolved oxygen content of groundwater is limited, estimates used by a Waste Load Allocation Study in 1977 (WDNR, unpubl.) were approximately 8 mg 0_2 1^{-1}. Input of oxygenated water would tend to reduce calculated rates of respiration with a consequent overestimation of the proportion of macrophyte respiration to total community oxygen usage.

Using the biomass estimate for site 1 of 789.4 g m^{-2} (Table 2) and a conservative estimated respiratory rate of 1.5 mg 0_2 g dw^{-1} h^{-1} (Westlake 1966), macrophyte community respiration would be 28,418 mg 0_2 m^{-2} d^{-1}. Model whole stream R estimated as 40.7 mg 0_2 1^{-1} d^{-1} and an average depth of 0.67 m yields 60,430 mg 0_2 m^{-2} d^{-1}. Thus, a conservative estimate of macrophyte respiration may account for about 47% of the daily ecosystem respiration in the study section. Our respiration estimates for *P. crispus* were somewhat higher than the value suggested by Westlake, so that 68% of community respiration might be due to macrophytes if all species at the site had similar respiration rates to *P. crispus*.

The overall P/R ratio of 0.62 would classify Black Earth Creek as an heterotrophic stream ecosystem, meaning that it is a net consumer of oxygen and theoretically uses more allochthonous than autochthonous energy. This value is within the ranges noted by Hannan and Dorris (1970). While this stream is highly productive on a seasonal basis, the combined respiratory activity of biota require more oxygen from the stream than was produced during this period. While a P/R <1 is surprising in light of the lush growth and healthy condition of the plants at the time of the trials, the model estimates of other small streams commonly produce similar results (M. Tusler, pers. comm.). Small streams are net consumers of dissolved oxygen, and naturally variable faunal production during the season often produces heterotrophy in productive streams (Hynes 1970). A seasonal analysis of P/R may show a great deal of variability in P/R over the year. The P/R ratio may be greater than one during winter, spring and early summer due to low respiratory biomass and low temperatures. As macrophyte (and periphyton) biomass increases, self-shading occurs so that only the upper portion of the macrophyte canopy exhibits net oxygen production, but all of the biomass respires, creating a mid- to late summer depression of the P/R ratio to less than one (Naiman and Sedell 1980). Autumnal P/R will remain below 1 due to decomposition of senescent macrophytes and allochthonous input of deciduous tree leaves. Therefore, a one-time measurement of P/R does not indicate the overall character of a stream as a net producer or consumer of energy and oxygen, but it does indicate whether the stream is a net consumer of oxygen in the summer—the time of critical oxygen levels for sensitive organisms.

Phosphorus Limitation

Table 4 indicates the location of samples and the mean values of tissue P

Table 4. Tissue phosphorus concentrations in Black Earth Creek *Potamogeton crispus* or *Rhizoclonium* sp.

Site/ location	[P](%)	Number of Samples
1 Mid-site	0.89	2
2 Below Brewery Cr.	0.56	1
2 Above CP STP	0.81	1
3 Below CP STP	0.83	1
3 Downstream end	0.87	1
4 Upstream end	0.75	1
4 Scherbel Rd.	0.73	1
6 Mid-site	1.03	1
6 *Rhizoclonium*	0.53	1
7 Mid-site	0.64	2

found. Samples run by both laboratories yielded results within 5% of each other. Macrophyte tissue P values found were significantly above limiting critical concentrations, indicating that P is not limiting macrophyte growth. Although rooted vascular macrophytes are able to take up P from the water column via the shoots, the bulk of P is usually taken up by the roots from the sediment (Carignan and Kalff 1979, 1980; Carignan 1982; Barko and Smart 1981; Huebert and Gorham 1983).

Tissue P concentrations of filamentous algae were lower than those for *P. crispus,* but were still substantially above critical concentrations exhibited for Cladophoran species. Work done on filamentous algae indicate a range of tissue P critical concentrations for growth from approximately 0.06% *(Cladophora glomerata)* to 0.18% *(Draparnaldia plumosa)* (Gerloff 1975; Gerloff and Krombholz 1966; Neil and Jackson 1982).

While growth-controlling levels and dynamics of P in *Rhizoclonium* are not known, extension of knowledge of *Cladophora* is reasonable. These genera are closely related, possibly even variants of the same genus. Thus, nutritional and other physiological requirements may be quite similar (Linda Graham, pers. comm.). Investigations of Great Lakes *Cladophora* growth would indicate that *Rhizoclonium* in Black Earth Creek is not limited by P concentration in the water column (Canale and Auer 1982; Auer and Canale 1982a,b). Moore (1977) found that filamentous algae in British streams were regulated more by temperature and light than nutrients.

Dense growths and rapid spread of filamentous algae were observed in early July. Temperature conditions and light are probably optimal at this time of year for Cladophoran algae based on responses of related species in the Great Lakes (Graham *et al.* 1982; Lorenz and Herrendorf 1982) and flowing waters (Moore 1977).

Summary

Although percent cover was lower in 1985 than 1981, no significant change in total community cover or composition was detected. *Potamogeton crispus* remained the dominant macrophyte in this community. Filamentous algae were not quantified in the 1981 study, but personal observation indicates that there has been an increase in noticeable filamentous algal colonization.

Tree canopy significantly reduced incident light levels at the stream surface and was thus correlated with decreased macrophyte cover. These data suggest that light is a significant limiting factor to macrophytes in this stream and that shading by streambank trees may be potentially useful in the control of macrophytes.

Biomass in unshaded areas ranged from 335 to 790 g dw m^{-2}, indicating that the Cross Plains Sewage Treatment Plant does not increase macrophyte biomass, as the highest value was found above the treatment plant.

The estimated respiratory contribution to the stream ecosystem of the epiphyte-macrophyte complex was 47 to 68%. This

suggests that macrophytes contribute a substantial proportion of the in-stream oxygen demand wherever their growth is dense. If oxygen levels are considered to be seriously depleted in such areas, the control of rooted vegetation by shading may be the only feasible remedial action available. Filamentous algae would also respond to control by shading.

Dramatic growth of filamentous algae in the stream this year prompts questions as to its impact on oxygen levels. Control of algal growth may be amenable to reductions of P from point sources since algae acquire nutrients solely from the water column, but important questions remain to be answered as to the nonpoint levels of P available and whether in-stream levels could be reduced below limiting concentrations for filamentous algae. Our tissue P data indicate that the algae are not limited by P availability. Phosphorus removal from the sewage treatment plant at Cross Plains is unlikely to have an impact on the growth of either rooted macrophytic vegetation or filamentous algae.

Macrophyte growth in Black Earth Creek is probably controlled by dynamics other than phosphorus limitation. Macrophyte tissue samples analyzed were well above critical concentrations, exhibiting luxury uptake. We reject the notion that macrophyte growth in Black Earth Creek is responding to point source nutrient enrichment, particularly that of phosphorous, because (1) biomass at separate sites bears no relation to point sources of nutrients, (2) plant tissue P concentrations show no evidence of P limitation, and (3) biomass levels found in Black Earth Creek are similar to those found in calcareous streams in other areas of Wisconsin, the United States, and Britain—streams that have a broad range of impacts from human enrichment, from near-pristine to heavily polluted.

The impact of macrophyte-induced sediment deposition in the stream has not been adequately addressed, especially as it affects space and reproduction potential for fish. Optimum values for macrophyte cover have not been estimated in this respect or in regard to spatial requirements of fish or food production.

Aquatic macrophytes provide many benefits to the stream ecosystem, including those used as trout fisheries. However, anthropogenic disturbance of the watershed may cause excessive growths of macrophytes with deleterious effects on natural ecosystems.

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