THE AQUATIC MACROPHYTE COMMUNITIES OF TWO STREAMS IN WISCONSIN

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Abstract

The aquatic macrophyte communities of two streams, Black Earth and Lawrence Creeks, were examined using the line intercept method from May through August, 1981. The data were analyzed using multivariate statistics. The seasonal succession of species was significant in both streams. Differences within and between their plant communities were also examined, as well as the distribution of the plant species in relation to environmental factors.

INTRODUCTION

Aquatic macrophytes are an important, but neglected, component of stream communities. Macrophytes contribute a large portion of the energy budget in some streams (Minshall 1978). In addition, they stabilize the stream bed and provide food and shelter for macroinvertebrates and small fish (Dawson 1978; Haslam 1978). In some instances, eutrophication has caused large growths of macrophytes that are deleterious to fish habitat and undesirable for human recreation. For these reasons, a greater understanding of stream macrophytes is necessary to an understanding of stream ecosystems as a whole.

Plants living within the stream ecosystem have to contend with an environment that is entirely different from that of lentic ecosystems. The stream environment is complex and heterogeneous, having many habitat patterns superimposed on each other at varying scales. There is a gradual change in character from the headwaters to the mouth (Vannote *et al.* 1980) with local variation in habitats primarily due to geology, geomorphology and a patchy distribution of microhabitats (Hynes 1975; Dawson, Castellano and Ladle 1978). All of these factors create environmental differences that affect the distribution and abundance of aquatic macrophyte species.

The macrophyte communities of temperate streams respond to a complex array of environmental factors in a definite seasonal pattern as well. During the year, various environmental events in the watershed affect the stream, giving one species a competitive advantage over another. Along with seasonal changes of temperature and photoperiod, seasonal rainfall and intermittent flooding cause dramatic changes in microhabitats, sediment contours, and current regimes. One intense flood may scour a stream so intensely as to effectively remove a large proportion of plant biomass and change the contours of the stream bottom (Bilby 1977; Westlake 1975; Wetzel 1975). Flooding at one stage may remove more propagules of one species than another, or may occur at a time when one species is more susceptible to disturbance than another. Therefore, different species may dominate from one period or year to another (Dawson, Castellano and Ladle 1978; Kimmerer and Allen 1982).

Terrestrial plant ecology has used quantitative methods for many years. These methods have been applied only recently to aquatic systems. Swindale and Curtis (1957)

used the quadrat method in developing their index of aquatic plant associations in Wisconsin. Lind and Cottam (1969) used the line intercept method of McGinnies (1952) to quantify the changes in macrophyte composition which resulted from the eutrophication of Lake Mendota, Wisconsin. Lind and Cottam found this method preferable to the quadrat method in measuring aquatic plant cover.

In stream environments, quantitative methods are even less commonly used. Haslam (1978) used presence/absence data in her study of the stream vegetation in England. Other studies which used this method were those of Holmes and Whitton (1977) and Smith (1978). The presence/absence method is adequate for large-scale investigation across many sites, such as in the case of whole riverine systems or provinces, but is not intensive enough for the study of one or two streams. A method for study on a smaller scale has been to measure biomass (Kullberg 1974; Hannan and Dorris 1970), but this method requires much time and a large number of samples due to variability.

We have chosen to measure cover using the line intercept method, for several reasons. First, no problem arises with quadrat size affecting the measure of cover. Second, line intercept is a rapid method that does not require cover estimation (McGinnies 1952). Third, reliance on cover alone avoids the difficulty of counting or estimating the number of individuals. Fourth, with the cross-channel transect we were able to measure vegetation along the entire cross-section of the stream, not just a small segment, as with the quadrat method (Grieg-Smith 1957).

We studied the macrophyte communities of Black Earth and Lawrence Creeks to examine the successional trends within the streams as well as quantitative differences within and between the streams. By measuring environmental data, we correlated these trends to measureable environmental factors.

Materials and Methods

Sites

Black Earth Creek

Black Earth Creek is a class-one trout stream in Dane County (Figure 1). The study area was near the Village of Cross Plains. The average stream gradient is 1.96 m/km, and the stream drains 116.78 km² (Dane County Regional Planning Commission DCRPC 1979). The area surrounding Black Earth Creek has a variety of land uses. Most of the land directly along the banks is in a public fishing easement, fenced off to maintain the streambank. In many places, arboreal vegetation has returned. The drainage basin as a whole is mostly agricultural, with 38% in pasture and 15% cultivated. The remainder is largely composed of wetlands (DCRPC 1979).

The average yearly water flow for Black Earth Creek is 0.879 m³/s; however, this is not evenly distributed over the year (USGS

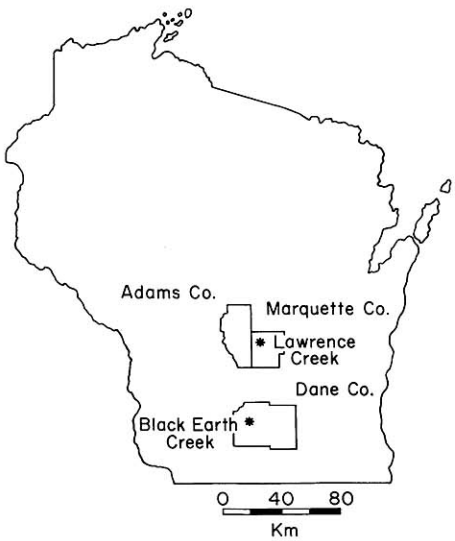

Fig. 1. Location of Black Earth and Lawrence Creeks within the State of Wisconsin.

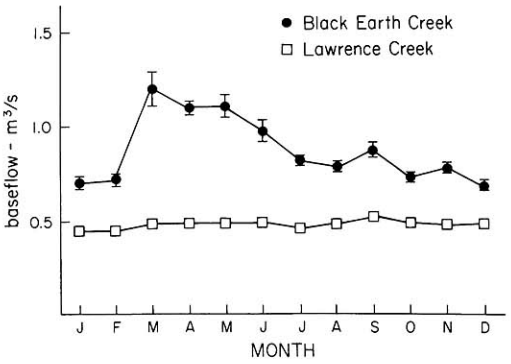

Fig. 2. Water flow for Black Earth and Lawrence Creeks (data from USGS). Bars indicate ± standard deviation; standard deviation smaller than square for Lawrence Creek data.

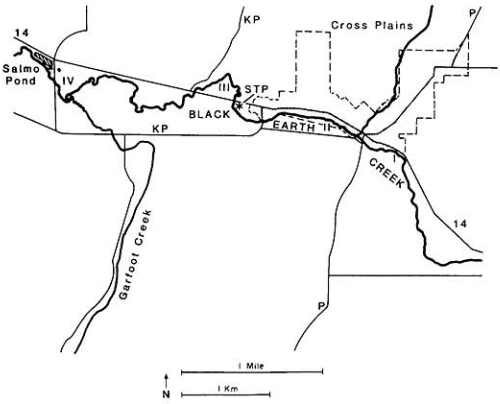

Fig. 3. Map of study sections on Black Earth Creek. Roman numerals indicate section numbers.

1973b; Figure 2). Flow is low in early winter when precipitation is low and in a solid form (snow or frozen rain). Black Earth Creek has a tendency to flood in late winter or early spring (DCRPC 1979). The average flow is also highest during this period. Flow generally decreases over the summer, probably due to increased transpiration and flow resistance caused by plants. However, in August of the sampling year, heavy rains caused a spate with a maximum flow of 3.059 m^3/s on 27 August 1981 and 4.816 m^3/s on 1 September 1981 (U.S. Geological Survey (USGS), personal communication, 1981). Although Black Earth Creek receives a base flow of artesian spring water and ground water, high flows commonly occur from heavy surface runoff of adjacent agricultural land.

Black Earth Creek is a "rich" limestone stream. High concentrations of nutrients support high productivity of plants and other aquatic organisms (Brynildson and Mason 1975). This is largely due to the parent limestone material surrounding the stream, which provides a needed high inorganic carbon source for high primary productivity. A moderately high amount of suspended solids is present. The major pollution problems are coliform bacteria and phosphorus, due to both surrounding agriculture and the sewerage plant (DCRPC 1980).

The stream flows through a variety of land use categories in the four study sections (Figure 3). Above County Highway (CTH) P, Section I, it flows through a wetland area. Section II, below CTH P, flows through a city park area behind the Village of Cross Plains. It then passes a light industrial area and the Cross Plains sewerage treatment plant. Section III, the "horseshoe," flows through a residential area in the lower half. Section IV flows through agricultural fields and pastures. Along most of its length in II through IV, the Wisconsin Department of Natural Resources (WDNR) has a streambank easement where trees, mostly cottonwood and willow, have grown back, along with some planted red cedar.

Lawrence Creek

Lawrence Creek is a class-one trout stream located in western Marquette and eastern Adams counties near Westfield (Figure 1). Most of the 6.5 km stream and a significant portion of its 16.4 km^2 drainage basin lie within the 338 ha Lawrence Creek Public Hunting and Fishing Area (Hunt 1966). The basin is predominantly wooded with red oak forests and several pine plantations. Cattail and sedge marshes lie along the stream

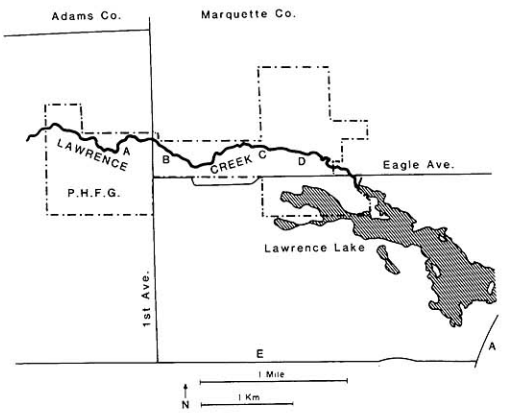

Fig. 4. Map of study sections on Lawrence Creek. Letters indicate sections.

course. This gives the basin the characteristics of a forested watershed. The runoff and groundwater lack significant anthropogenic inputs.

The yearly water flow for Lawrence Creek is regular, varying slightly throughout the year (Figure 2). Largely due to its forested watershed and the high percentage of groundwater and springs that constitute its flow, it is not subject to flooding (USGS 1973a). The annual average flow is 0.473 m^3/s. The elevation drop is about 8.8 m for an average slope of 1.62 m/km.

Lawrence Creek is also divided into four sections (Figure 4). The upper section, A, is characteristic of headwater streams with shallow depths, a few riffles and a predominantly gravel substrate. It is largely surrounded by forested land. Section B is much slower and deeper, but also has a significant amount of gravel. It flows through a marsh. Section C and D also flow through marshes, but differ in having an almost total absence of gravel. The predominantly sand substrate greatly influences the character of the lower portion of the stream.

Field Methods

Each of the streams was divided into four arbitrarily determined study sections approximately 1 km in length (as discussed above). Once per month (May through August 1981) we sampled 20 transects in each section. The transect site was selected using a stratified-random system. At each site we measured the following environmental data: width, water temperature, light extinction, canopy and substrate. The transect was constructed with a plastic-coated wire clothesline (Lind and Cottam 1969) with 1 dm and 1 m graduations indicated. Width was determined using the transect. In the middle of each 1 m interval, depth and current were measured. Depth was measured with a meter stick. Current was measured using an orange as a float for a distance of one meter following the method of Hynes (1970). Water temperature was recorded with a Yellow Springs Instruments thermistor-thermometer #44. Light (photosynthetically active radiation, or PAR) was measured with a Lambda quantum sensor 3LI-17Q and submersible probe; and light extinction was calculated using an equation from Nichols (1971; Hutchinson 1957). Canopy, although part of the terrestrial biotic community, is most conveniently considered with the physical environment. Canopy was estimated as the total percentage of overhead tree or shrub cover to the nearest 10%. The substrate type for the site was classified as either gravel, sand or silt.

The transect was also used to measure the cover of plant species as points of line interception. Each species that was present under a 1 dm segment was considered to "cover" that 1 dm segment. In addition to percent cover, relative cover was calculated to assess plant species composition. Relative cover is calculated by dividing the percent cover of a species by the sum of cover for all species, or

$$\text{relative cover} = \frac{X_i}{\sum_{i=1}^{n} X_i} \times 100$$

where X_i is the cover for species i and n the total number of species. Relative cover in-

dicates the percentage of the plant community represented by an individual species, and so the sum of relative cover for all species is 100. Relative cover is a measure of dominance in the plant community.

Species identification was based initially on Fassett (1957), although taxonomic names were used after Gleason and Cronquist (1963). Voss (1972) was especially helpful in identifying species of *Potamogeton.*

The U. S. Geological Survey (USGS) provided water flow data for Lawrence and Black Earth Creeks from October, 1967 to September, 1973 (1973a,b). Water flow data for this six year period was averaged for each stream to indicate mean base flow, as shown in Figure 2.

Water chemistry data for Black Earth Creek came from two reports by the Dane County Regional Planning commission (DCRPC 1979; 1980). Water quality data from Hunt (1966) and Mason (unpublished) were used for Lawrence Creek.

SEDIMENT SAMPLES

In July, five sediment samples were taken from each section of both streams. Sample sites were determined using a stratified-random sampling procedure. The sample was obtained from the thalweg of the stream course using an Eckman dredge. The sediment samples were transported in polyethylene bags to the laboratory where they were refrigerated in polyethylene containers with sealing tops. Particle Size Analysis was performed using the Bouyoukos Hydrometer method (Foth 1978; Love, Corey and Gilmour 1977). The U. S. Department of Agriculture (USDA) system of particle classes was used (Foth 1978).

Crucibles for analysis of organic and $CaCO_3$ content were first heated to 950 C for 24 hours and then cooled under dessication for taring. Dry weight, organic matter, and $CaCO_3$ were determined using the Thermolyne muffle furnace F-A1740 after Wetzel (1970) and Adams, Guilizzoni and Adams (1978b) on wet samples from 50 to 100 grams. Organic matter composition was determined by combustion at 550 C, as compared to oven dry weight (105 C). Percent $CaCO_3$ was measured by conversion of CO_2 lost at 950 C to % $CaCO_3$ present in the sample (Adams, Guillizzoni and Adams 1978b).

STATISTICAL ANALYSES

Average cover values were entered along with environmental data for 600 transects in

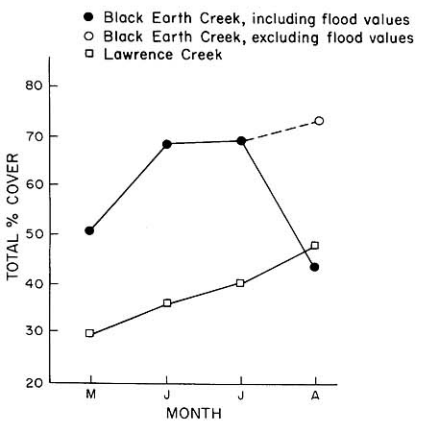

Fig. 5. Total percent cover of macrophytes for Black Earth and Lawrence Creeks over the growing season (M, May; J, June; J, July; A, August).

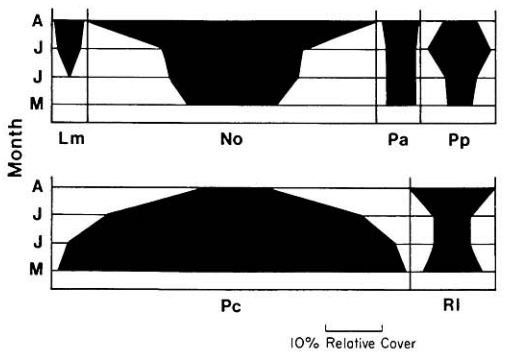

Fig. 6. Seasonal succession as indicated by relative cover for Black Earth Creek (Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* M, May; J, June; J, July; A, August).

order to perform statistical analyses on a Sperry-Univac 1100 at the University of Wisconsin-Madison Academic Computing Center (MACC). Descriptive statistics were computed for each section and sampling period. Descriptive statistics, one-way analysis of variance (ANOVA) and Discriminant Analysis were performed using the Statistical Package for the Social Sciences (SPSS; Nie *et al.* 1975). Discriminant Analysis was also performed using the BMDP Statistical Package (BMDP; Dixon *et al.* 1981).

Analyses for seasonal succession were performed by grouping the data from all sections for each month. Differences between sections were examined by grouping data for all months for each section. Therefore, each month or each section has data for eighty transects, which is an adequate sample size for these analyses. Examination of the differences between the two streams used all data for each stream, or the data for 320 transects.

Results and Discussion

Succession

Black Earth Creek

The total cover of Black Earth Creek increases rapidly from May to June (Figure 5).

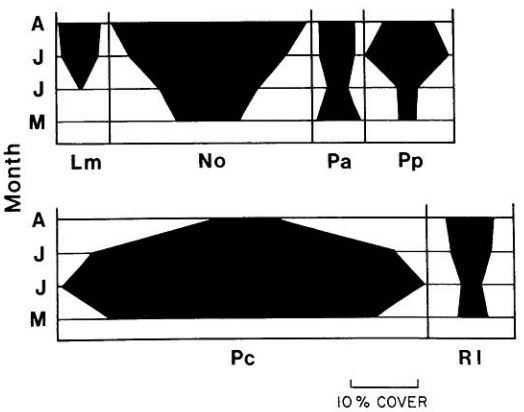

Fig. 7. Seasonal succession as indicated by percent cover for Black Earth Creek (Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus,* Rl, *Ranunculus longirostris;* M, May; J, June; J, July; A, August).

By June, total cover peaks and senescence of *Potamogeton crispus* begins (Figure 6). Due to a large amount of rain over a two week period, a large flood occurred on Black Earth Creek in August after sampling sections I and II, but before sampling sections III and IV. This flood greatly reduced total cover, leaving vegetation only along the banks and a few protected sites. The data for Black Earth Creek are presented both including and excluding values affected by the flood.

Potamogeton crispus has its highest relative cover in May when it is nearly full grown due to overwinter growth (Figure 6; Haslam 1978). Dominance continues through June, when *P. crispus* literally fills many stretches of the stream from bank to bank. In June *P. crispus* senesces, with large mats of it floating downstream and lodging around obstructions. Although cover is still fairly high, biomass was observed to be down significantly by July. A sparse, though continuous, cover of *P. crispus* is then maintained through the rest of the summer. However, the flood removed most of the stems remaining, explaining the sudden decrease in cover in the lower two sections.

Nasturtium officinale increases steadily in cover throughout the summer. Its high relative cover for August is due to the absence of other vegetation after the flood (Figure 7). The flood apparently did not affect *N. officinale* due to its protected streambank habitat.

Phalaris arundinacea is fairly constant in relative cover throughout the summer, starting growth early from rhizomes. The flood did not affect it due to its stable gravel and stream bank habitats.

Potamogeton pectinatus increases in dominance after the senescence of *P. crispus,* apparently replacing it. However, the flood in August removed this species also from the lower stretches of the stream.

Ranunculus longirostris steadily increases in cover throughout the summer. Being tolerant of spates, it is second in importance to

N. officinale for August. Its dominance in May is due to overwintering evergreen stems.

Lemna minor appears later in the summer, probably due to its need for warm waters to initiate vegetative reproduction.

For most temperate stream communities, several species share dominance over the season as environmental conditions change in the stream. In this respect, the phenology of *P. crispus* shows an interesting ecological adaptation. Turions germinate in late autumn, with growth occuring all winter. Maximum development is achieved in late spring, with flowering and fruit formation in late May or in June. Turions then develop on the stems or rhizome during this period and are dormant until autumn, and the majority of the above-ground biomass senesces. Dormancy is broken by cold temperatures (Sastroutomo 1981). *Potamogeton crispus* is adapted to grow rapidly in early spring to compete with other species in a eutrophic environment. It then dies off in midsummer, allowing other species to grow, especially *N. officinale* and *P. pectinatus.* However, the flood in August removed most of the plants in the mid-stream area, especially the remaining *P. crispus* and *P. pectinatus.* This left the streambank macrophytes *(Nasturtium* and *Phalaris)* and the more spate-tolerant vegetation, such as *Ranunculus,* to dominate. Such floods are fairly common on Black Earth Creek, and are an important factor in plant distribution. The seasonal succession of species in Black Earth Creek was highly significant (at the $p = 0.01$ level) as determined by Discriminant Analysis, with significant changes occuring in *Lemna, Nasturtium, P. crispus,* and *P. pectinatus.*

Lawrence Creek

The total cover for Lawrence Creek increases regularly throughout the summer, as expected in a situation without disturbance (Figure 5). However, the underlying change in species is more complex. *Elodea canadensis* and *Nasturtium officinale* have overwintering stems that allow rapid growth in the spring. *Elodea* is the dominant species for all but the month of May, when *P. pectinatus* is more common due to its early phenology. *Elodea canadensis* grows rapidly from overwintering stems (Figure 8). Cover values increase throughout the summer, but relative cover decreases due to increased emergence of other species (Figure 9).

High overwintering cover of *Nasturtium officinale* allows it to have high relative

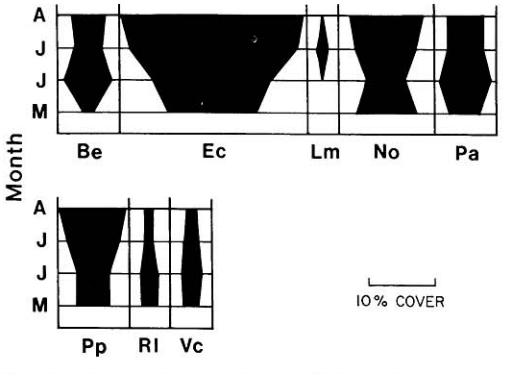

Fig. 8. Seasonal succession as indicated by percent cover for Lawrence Creek (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor;* No. *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata;* M, May; J, June; J, July; A, August).

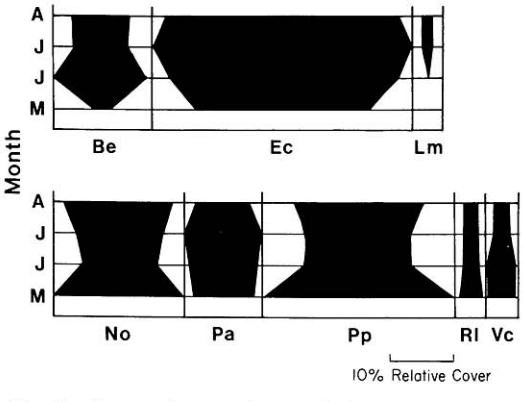

Fig. 9. Seasonal succession as indicated by relative cover for Lawrence Creek (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata;* M, May; J, June; J, July; A, August).

cover due to the relative scarcity of other species. Percent cover increases throughout the summer, with an increase in dominance. *Potamogeton pectinatus* has high relative cover compared to percent cover due to wide distribution and occurrence where other species are lacking. The cover values of *Phalaris arundinacea* are slightly affected by man. One section was mowed in July, removing some of the cover. However, flowering and seed set also occur at this time, with ensuing senescence reducing cover (Sculthorpe 1967).

Berula erecta grows from underground rhizomes during late May and early June. *Veronica catenata* and *Ranunculus longirostris* also have an early period of outgrowth. *Lemna minor* is late in appearing, and at low levels due to the fast current of this stream. Few refugia exist for the growth of *Lemna minor* in Lawrence Creek, such as backwaters and slow-moving pools.

For Lawrence Creek, relative cover is high in early spring for those plants with high overwintering cover and rapid growth from dormant perennial parts. This is especially true of *Elodea canadensis, Nasturtium officinale,* and *Potamogeton pectinatus.* These three plants are dominant throughout the year. Discriminant Analysis found seasonal differences, to be highly significant, with *B. erecta, E. canadensis, L. minor,* and *P. pectinatus* to be significant elements in this seasonal change (at the $p = 0.01$ level). Late in summer or early autumn, most of the plant biomass senesces, returning to low overwintering levels. Limited waterflow records for Lawrence Creek seem to indicate that spates are extremely infrequent and are therefore less important in plant community regulation than observed in Black Earth Creek.

Temperate stream communities tend to exhibit a cyclic relationship between cold and warm temperature plants. Several species dominate during the winter and early spring due to a tolerance of colder water and/or lower light regimes (e.g., *N. officinale* and *E. candensis*). As spring and summer progress, total cover and diversity of macrophytes increase. After this period of growth, plants begin to senesce. *Potamogeton crispus* senesces early in the summer, allowing other species to replace it. As winter approaches, there is rapid senescence of the remaining species. Although a few plants remain intact throughout the winter, most are protected in dormant vegetative propagules. Some propagules, such as tubers, roots, and rhizomes, may be under the sediment; others are above the sediment, as in the case of turions and hibernaculae. Such structures allow rapid germination for the next growing season. The actual pattern found in the plant community depends on environmental factors affecting the watershed. Some factors, such as flooding, may be randomly occuring historical events. In some streams, such as Lawrence Creek, the watershed has few floods so that this factor is of little importance to the plant community. In others, such as Black Earth Creek, occasional floods alter species pattern and result in different dominant species than in non-flood years.

INTRASTREAM DIFFERENCES

Physical Environment

Black Earth Creek

The sediment of Black Earth Creek is largely gravel mixed with silty alluvium. The highest proportions of gravel and sand occur in II and III (Table 1), the areas with higher current velocity. The largest silt deposits occur in I and IV, the areas of lower current velocity. All sections are high in organic matter and $CaCO_3$. The $CaCO_3$ may be from three causes: silt material, marl ($CaCO_3$) formation on plants in the stream, or gravel material of limestone origin. The latter appears to be the major cause, as the highest percentages of $CaCO_3$ appear in samples with a high percentage of gravel. In general, the appearance of these substrates in I and IV are a covering of silt over a gravel or sand substrate. Riffles are commonly free of silt.

The water temperature of the headwaters

TABLE 1. Sediment composition of each section and stream averages for Black Earth and Lawrence Creeks.

Stream Section	*% Gravel*	*% Sand*	*% Silt*	*% Clay*	*% O.M.*	*% $CaCO_3$*
Black Earth Creek						
Ave.	17.9	66.0	24.8	9.2	9.2	21.0
I	12.0	52.7	30.9	12.1	12.3	12.4
II	30.3	74.5	16.6	8.9	2.7	24.0
III	29.2	73.2	20.4	6.4	7.0	31.4
IV	0.0	59.1	31.3	9.6	14.8	15.8
Lawrence Creek						
Ave.	0.8	97.5	1.4	1.4	0.5	0.6
A	0.7	97.3	1.2	1.5	0.5	0.6
B	0.0	97.7	0.9	1.4	0.4	0.6
C	0.0	97.7	1.1	1.2	0.4	0.7
D	0.0	97.2	1.3	1.5	0.6	0.6

TABLE 2. Environmental data for stream sections and averages for each stream, including standard error (S.E.), for Black Earth and Lawrence Creeks.

Section	*Water Temp (C)*	*Canopy %*	*Light Extinc*	*Depth (m)*	*Current (m/s)*
BLACK EARTH CREEK					
I	12.2	15.5	1.4	0.52	0.12
(S.E.)	0.53	4.0	0.24	0.02	0.01
II	12.1	18.9	1.34	0.32	0.23
(S.E.)	0.38	4.2	0.11	0.01	0.01
III	13.5	59.2	1.81	0.40	0.25
(S.E.)	0.54	4.6	—	0.01	0.01
IV	16.2	20.5	2.56	0.45	0.20
(S.E.)	0.45	3.8	0.29	0.02	0.01
AVERAGE	13.5	28.7	1.88	0.42	0.20
(S.E.)	0.29	2.3	—	0.01	0.01
LAWRENCE CREEK					
A	12.8	10.1	1.15	0.45	0.25
(S.E.)	0.34	3.0	0.19	0.02	0.01
B	12.8	4.74	1.95	0.51	0.22
(S.E.)	0.31	2.2	0.18	0.02	0.01
C	15.8	3.6	1.24	0.35	0.26
(S.E.)	0.39	1.4	0.21	0.01	0.01
D	13.0	9.6	1.29	0.39	0.26
(S.E.)	0.40	2.9	0.33	0.01	0.01
AVERAGE	13.5	7.0	1.37	0.43	0.25
(S.E.)	0.22	1.2	0.12	0.01	0.01

region is low and fairly constant, with progressive warming below the sewerage plant in III and IV. Water temperature in IV is statistically different from that of sections I and II (Table 2,DCRPC 1979).

Section III has a significantly higher overhead canopy of trees than the other sections, according to a one-way ANOVA (Table 2).

The current velocity in I and IV is less than in II and III. No significant difference exists between II and III at the $p = 0.05$ level (Table 2).

Lawrence Creek

The sediment of Lawrence Creek is composed largely of sand (Table 1), due to its parent material, Potsdam sandstone. The sediment is low in both organic matter and $CaCO_3$. The lower sections of Lawrence Creek, C and D, lack any gravel beds and are mostly sandy and sinuous in character. The upper two sections, A and B, have large areas of gravel (Hunt 1977; Table 1; Figure 4).

In a section-by-section comparison, C, being more shallow, had a much higher average water temperature. Continuous influx of ground water and increased water depth led to a temperature decrease farther downstream. (Table 2).

Since most of the stream is bordered by marshy vegetation, the canopy over Lawrence Creek is quite sparse (Table 2). This allows a great deal of light to reach the stream.

The current velocity in B is significantly lower than in C and D. The average depth of B may explain this difference (Table 2).

VEGETATION

Black Earth Creek

The graph of total cover for each section shows that macrophyte cover is much higher in I and IV than in II and III (Figure 10). The major environmental difference between these sections are the siltier substrates in I and IV (Table 1). Both Kullberg (1974) and Hannan and Dorris (1970) report that macrophyte production is much higher on silty substrates than gravel or sand, within a given stream system. Silty sediments absorb more nutrients, especially phosphorus, that are then available for plants. Higher levels of available nutrients may therefore encourage macrophyte growth in these types of sediments (Barko and Smart 1980; 1981).

Potamogeton crispus is the dominant species in all but the upper section. The relative

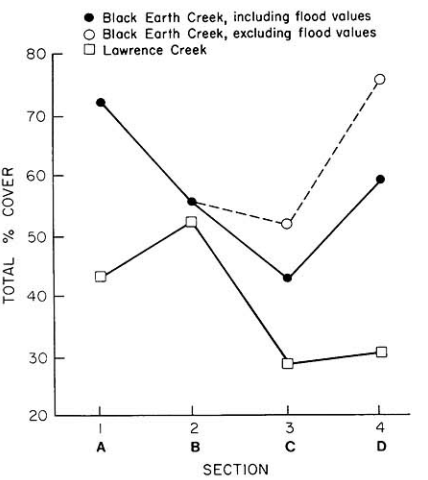

Fig. 10. Total cover of sections of Black Earth and Lawrence Creeks.

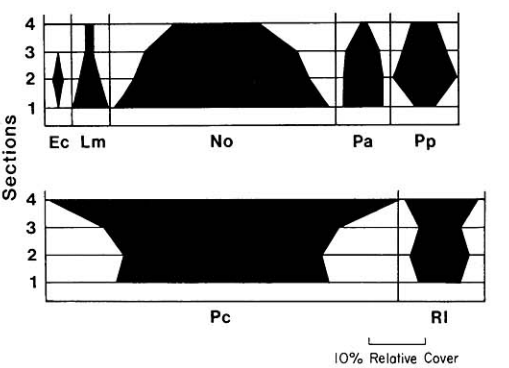

Fig. 11. Relative cover of species for sections in Black Earth Creek (Ec, *Elodea canadensis;* Lm, Lemna minor; No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris*).

cover of *P. crispus* decreased in II and III, due to higher current and increased gravel. The increase in relative cover for IV corresponds to the increased silt (Figure 11). The environment of Black Earth Creek is ideally suited to *P. crispus:* a small layer of silt over a layer of gravel or hardened limestone (Haslam 1978), with areas of overhead shade and moderate turbidity.

The relative cover of *Nasturtium officinale* in each section corresponds inversely to the width of the stream. This downstream decrease in the dominance of *N. officinale* may also be related to shade, increased pollution, and increased water temperature (Figure 11, Table 2).

The relative cover of *Potamogeton pectinatus* is directly related to the amount of sand in the substrate (Figure 11, Table 1). Sand is a difficult medium in which to root and remain, and *P. pectinatus* is better adapted to this substrate than the other macrophytes.

Ranunculus longirostris is common in the upper two sections, being found in the gravel areas. The relative cover decreases in the lower sections, possibly from pollution (Figure 11). The increase in dominance in IV is due to its survival of the August spate.

Phalaris arundinacea is fairly common in the upper three sections, growing out into shallow gravel runs (Figure 11). This habitat disappears almost entirely in IV, explaining the absence of *P. arundinacea.*

Lemna minor is found in sheltered areas throughout the stream but is most common in the upper two sections (Figure 11). In I, many water areas occur in which *L. minor* can reproduce. This upstream sanctuary provides a continuous supply of *L. minor* to the lower sections, explaining the relatively high concentration in II.

Elodea canadensis was found exclusively in II, probably due to the silt substrate without the pollution of the lower sections. This section is mesotrophic, with an environment most similar to that of Lawrence Creek. This similarity may explain why both *Elodea* and *V. catenata* were found in only this section of Black Earth Creek.

In summary, the dominant cover of *P. crispus* is directly related to a silty substrate and increased width. *Nasturtium officinale* decreases in cover as the width of the stream increases. Discriminant Analysis shows this sectional difference to be significant at the $p = 0.05$ level, with *Lemna, Nasturtium, Phalaris, Potamogeton crispus, P. pectina-*

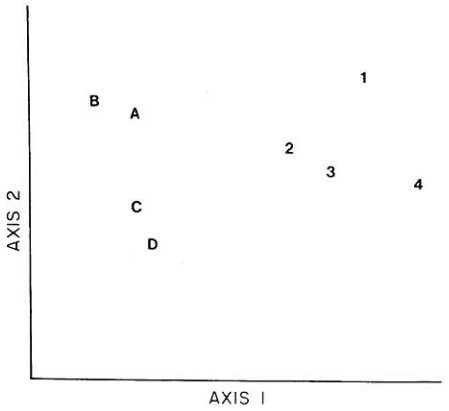

Fig. 12. Discriminant Analysis plot for sections of Black Earth and Lawrence Creeks as based on vegetation composition (numbers-sections of Black Earth Creek; letters-sections of Lawrence Creek).

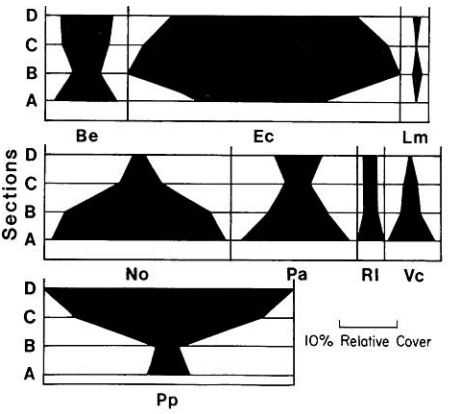

Fig. 13. Relative cover of species for sections of Lawrence Creek (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor; No, Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata*).

tus and *Ranunculus* being a significant part of this difference (Figure 12).

Lawrence Creek

When inspecting Lawrence Creek, it is immediately obvious that the lower sections (C and D) are quite different from the upper ones (A and B). A graph of total macrophyte cover shows that the lower sections have significantly less cover than the upper sections (Figure 10). This is due to a combination of less stable sandy substrate, shallower depths (which bring vegetation in contact with faster current, as the area of highest current velocity is near the surface), and unsupported banks (Haslam 1978; Kullberg 1974). These factors allow the channel to wander, providing poor conditions from macrophyte establishment and growth. Many species cannot root in this unstable environment.

In relative cover for each section (Figure 13), *N. officinale, P. arundinacea,* and *E. canadensis* are the three most important species for A and B (N. officinale dominant in A, *E. canadensis* in B); whereas *B. erecta, E. canadensis,* and *P. pectinatus* are the three most important species in C and D (*E. canadensis* dominant in C, *P. pectinatus* in D).

The dominance of *N. officinale* in section A is due to cold water from many springs and proportionately more bank habitat required for growth (Figure 13). This area is narrow, with bank-type vegetation predominating (e.g., *N. officinale, B. erecta,* and *P. arundinacea*). *Nasturtium officinale* is unable to root adequately in the unstable substrate of the lower sections.

The importance of *Phalaris* is inversely related to the width of the stream (Figure 13, Table 2). As it only invades the stream by vegetative growth from the banks, it should decrease in importance with increased stream width. It is also unable to root in the sand of the lower sections and is relinquished to the more stable banks.

Elodea is common in the quiet, deep pools of A and B (Figure 13, Table 2). As this habitat is more common in B, it is dominant here. Its cover is sharply reduced in section C. However, *Elodea* is still a dominant in C due to the low total cover of all species.

Berula erecta decreases in importance from A to B, presumably for the same reason as *N. officinale.* However, it increases again in the lower sections due to the open habitat with a sandy substrate (Figure 13; Haslam 1978).

Ranunculus longirostris and *Veronica catenata* do best in A, where the highest current and proportion of gravel occur (Figure 13, Table 1). Personal observations of these species indicate that they tend to occur together in this type of habitat and thrive best under these conditions. However, they are represented in the other sections in isolated areas of higher current velocities and stable substrates, such as submerged logs or large rocks.

Potamogeton pectinatus is infrequent in the upper stretches but is a dominant species in the lower sections (Figure 13). It is the only plant that is able to grow in the middle of the shallow sandy channels in these lower sections, where growth is extremely sparse. This macrophyte is probably a case of being the only species "available" to fill this habitat, as is often the case with macrophytes: their distribution may be limited (Haslam 1978).

Several less important species occur in Lawrence Creek, and two deserve special comment. *Lemna minor* was found along the whole stream, but in small quantities. It requires still waters. However, a continuous source of *L. minor* comes from the marshes surrounding the stream. A *Potamogeton richardsonii* colony existed in one 100 m area of section D, which could represent either a new introduction or a remnant of a large population. Haslam (1978) indicates that this species grows in silty areas of rocky streams. This colony was attached to several contiguous submerged logs and silt beds adjacent to the bank.

In summary, the most remarkable aspect of the vegetation of the stream is a pronounced shift from *N. officinale* as a dominant in the upper sections (A and B) to *P. pectinatus* in the lower two sections. The shift in dominance is due to the unstable nature of the sediment in the lower sections where *N. officinale* cannot root. *Potamogeton pectinatus,* however, cannot coexist in the upper sections with those plants which have lower nutrient requirements. *Elodea canadensis* is common throughout the stream and is predominant in the slower, deeper section B. A Discriminant Analysis between sections A through D showed a highly significant difference between the sections based upon all of the major species, with the exception of *Lemna minor.* In this analysis, A and B were similar and grouped as significantly different from sections C and D (Figure 12).

The community compositions of contiguous sections within the two streams were significantly different in most cases. These differences correlated well with changes in environmental factors, such as sediment type, depth and current. In Lawrence Creek a shift from a dominance of *Nasturtium, Phalaris,* and *Elodea* in the upper two sections to *Elodea* and *P. pectinatus* in the lower sections correlated with a shift to shallow, sandy and sinuous conditions in the lower sections. For Black Earth Creek, *Nasturtium* decreased with an increase in water temperature and width. Habitat types for each species derived from this study compared favorably with those observed by other authors.

Environmental Amplitude of Macrophyte Species

As a result of the extensive amount of data collected in this study, it is possible to obtain a quantitative evaluation of the optimal en-

Table 3. Relationship of species with environment. 0: no observed relationship −: negative relationship, +: positive relationship, numbers indicate optimal value or limits.

Species	*Width (m)*	*Water Temp (C)*	*Canopy %*	*Substr.*	*Light Extinc.*	*Depth (m)*	*Current (m/s)*
Berula erecta	− <4.5	0	0	gravel	0	0	+ .25
Elodea canadensis	0	0	−	sand, silt	turbid 1.40	+ .50	− <.20
Lemna minor	0	+ >15.00	− 0.0	0	0	+ >.40	− <.10
Nasturtium officinale	− <4.5	−	0	0	− 1.25	0	− <.20
Phalaris arundinacea	0	0	− <30.0	gravel	− 1.25	− <.30	0
Potamogeton crispus	0	0	0	silt on gravel	+ 1.80	+ .50	− <.30
Potamogeton pectinatus	0	0	0	silt, sand	+ 1.80	+ .50	− <.30
Ranunculus longirostris	− <4.0	0	0	gravel	0	− <.30	+ >.30
Veronica catenata	− <4.0	0	− <30	gravel	0	− <.30	+ >.40

vironment for each of the species (Table 3). Ideally, these optima should be constant wherever the species is found. However, the plant responds to such a large range of variables that it is difficult to be entirely sure which factor is limiting or encouraging success. For each species we will compare optima from the literature (Table 4) with those derived from our data (Table 3). References used were Fassett (1957), Gleason and Cronquist (1963), Haslam (1978), and Sculthorpe (1967). A full list of macrophyte species found in the two streams is given in appendices I and II. A complete discussion of these species can be found in Madsen (1982).

Berula erecta was not found in the sandy substrates discussed in the literature due to the extreme instability of this substrate in Lawrence Creek. Other discrepancies occur with turbidity and depth.

Elodea candensis is found in sandier substrates than that mentioned in the literature, due to the sandy nature of Lawrence Creek. *Elodea* was also found under a broader range of turbidity in Lawrence Creek because it was found in marshy areas of the stream that produce high amounts of organic matter.

The distribution of *Lemna minor* was consistent with the literature, considering that increased depth is usually associated with slower currents. *Nasturtium officinale* is also consistent in distribution with literature reports. *Nasturtium officinale* is most commonly associated with cold spring waters; therefore, it is associated with smaller tributaries.

Phalaris arundinacea was only found in the stream in fast, shallow areas with gravel substrates or along the banks. This differs from literature reports.

Potamogeton crispus is shade and turbidity tolerant. The optimal substrate is silt over a gravel or hard substrate. *Potamogeton*

TABLE 4. Relationship of species with environment, as determined from literature review. 0 = no observed relationship; − negative relationship; + positive relationship.

Species	Width (m)	Water Temp (C)	Canopy %	Substr.	Turbidity	Depth	Current
Berula erecta	−	−	0	gravel	−	−	+
Elodea canadensis	0	0	−	silt	−	+	−
Lemna minor	0	+	0	0	0	0	−
Nasturtium officinale	−	−	0	0	−	−	−
Phalaris arundinacea	0	0	0	0	0	−	0
Potamogeton crispus	0	0	+	silt	+	+	−
Potamogeton pectinatus	0	0	+	silt	+	+	−
Ranunculus longirostris	0	0	−	gravel	−	−	+
Veronica catenata	0	0	−	0	−	0	0

pectinatus is found in similar environments, except for preferences for sandy or silty environments.

Ranunculus longirostris was consistent with literature values. However, the distribution of *Veronica catenata* does vary significantly from literature reports. This discrepancy is due to the association of *Veronica* with *Ranunculus*. *Veronica* is often associated with clumps of other plants. This tendency has altered its usual distribution pattern (Haslam 1978).

Interstream Differences

Physical Environment

The light extinction of Black Earth Creek is significantly higher than that of Lawrence Creek (Table 2). This is due to higher turbidity from erosion, siltation and sewage effluent. Black Earth Creek also has greater canopy cover. These factors reduce potential macrophyte productivity (Krause 1977; Dawson and Kern-Hansen 1978; Dawson 1978, 1981). Whereas nutrients or substrate may limit growth in Lawrence Creek, light must be the limiting factor for growth in some stretches of Black Earth Creek.

SEDIMENT

The sediments of the two streams differ significantly (Table 1). In the predominantly sandy sediment of Lawrence Creek, little organic matter and $CaCO_3$ are present. Black Earth Creek sediment has significantly higher percentages of gravel, silt, clay and organic matter. It is highly calcareous as well. These factors make the sediment of Black Earth Creek a better medium for rooting and for retaining nutrients.

WATER CHEMISTRY

Differences in geology, soil, and land use patterns result in important differences in water chemistry (Table 5). Significantly higher levels of ammonia and reactive phosphate occur in Black Earth Creek, probably from the application of fertilizers on adjacent agricultural fields and output from the sewage treatment plant. This is a recognized pollution problem (DCRPC 1980) and may account for the higher productivity of trout

TABLE 5. Summary of water chemistry data from Black Earth and Lawrence Creek with p-value from a Mann-Whitney two sample nonparametric test used to compare the two streams.

Test	*Black Earth Creek*	*Lawrence Creek*	*Mann-Whitney P-Value*[a]
pH	7.95	8.04	0.122
Ammonia (ppm)	0.29	0.03	0.013*
Nitrate (ppm)	1.56	1.85	0.225
Organic N (ppm)	0.33	0.57	0.153
Total N (ppm)	2.76	2.45	0.762
Reactive P (ppm)	0.26	0.07	0.100*
Total P (ppm)	0.31	0.08	0.110
Conductivity (mhos/cm)	465.5	304.7	0.011*
Alkalinity (mg $CaCO_3$/1)	281.6	158.9	0.006*
Turbidity (JTU)	4.60	1.57	—

[a] an asterisk (*) indicates significance at the p = 0.10 level.

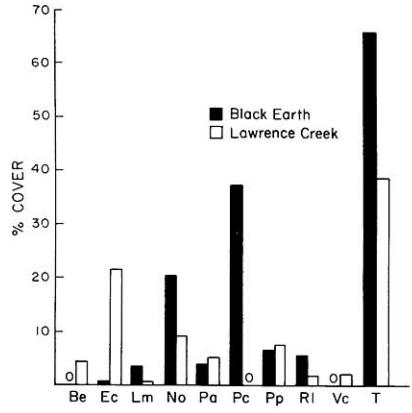

Fig. 14. Average percent cover of species and total macrophyte cover for Black Earth and Lawrence Creeks (Be, *Berula erecta;* Ec, *Elodea canadensis;* Lm, *Lemna minor;* No, *Nasturtium officinale;* Pa, *Phalaris arundinacea;* Pc, *Potamogeton crispus;* Pp, *Potamogeton pectinatus;* Rl, *Ranunculus longirostris;* Vc, *Veronica catenata;* T, total cover).

and aquatic macrophytes (Brynildson and Mason 1975). Higher alkalinity and conductivity in Black Earth Creek results from watershed soils and bedrock. Greater amounts of total dissolved inorganic carbon are available for photosynthesis, resulting in higher productivity in Black Earth Creek compared to Lawrence Creek (Adams *et al.* 1978a).

VEGETATION

One aim of this study is to compare quantitatively the differences in the vegetation of the two streams. This was achieved using Discriminant Analysis. The separation of the two streams by BMDP Discriminant Analysis was highly significant ($p < 0.001$) with a correct classification of 92.5% (86.9% for Black Earth Creek and 98.5% for Lawrence Creek; Figure 12). This analysis selected *P. crispus* and *R. longirostris* as representative of Black Earth Creek, with the higher cover values of *N. officinale* as somewhat representative of Black Earth Creek. *Berula erecta, E. canadensis* and *V. catenata* were chosen to represent Lawrence Creek, with *P. pectinatus* somewhat less important in discriminating the two streams on the basis of cover values. We then performed a BMDP Discriminant Analysis on the sections of each stream. This was also highly significant ($p < 0.001$), with a correct separation to each section of 93.0%. *Potamogeton crispus* and *R. longirostris* were selected again as representative of Black Earth Creek; *Berula erecta, E. canadensis* and *V. catenata* represented Lawrence Creek. *Nasturtium officinale* represented the upper sections of both streams, and *P. pectinatus* was indicative of the lower two sections of Lawrence Creek.

In general, growth is more luxuriant in Black Earth Creek. Total cover of macrophytes in Black Earth Creek averaged 75.2%, whereas in Lawrence Creek it was 49.5% (Figure 14). Ecological differences may also be seen from the species composition in each stream (Figure 14). The presence and success of *Potamogeton crispus* in Black Earth Creek indicates that the stream is mesotrophic or eutrophic, polluted and silted. The dominant species in Lawrence Creek is *Elodea canadensis,* which prefers quiet, clear waters and silt banks. This species is rare in Black Earth Creek, probably due to its intolerance of turbidity. The second most common plant in both streams is *Nasturtium officinale.* However, it covers twice the percentage of area in Black Earth Creek that it does in Lawrence Creek (Figure 14). This macrophyte is most common in the upper portions of both streams, due to cooler water temperatures. The third most common macrophyte in both streams is *Potamogeton pectinatus.* In each, it appears to fill a gap in stream habitat. In Lawrence Creek this is a spatial habitat of shifting sand in which other macrophytes cannot become established. In Black Earth Creek *P. pectinatus* occupies a temporal microhabitat left open after the mid-summer senescence of *P. crispus.* Other macrophytes are not as successful in the combination of pollution, turbidity and silt.

Ranunculus longirostris is also found in both streams, but achieves cover in Black Earth Creek five times that in Lawrence Creek (Figure 14). The limiting factor for *R. longirostris* in Lawrence Creek seems to be gravel substrate; it cannot root well in sand or silt. More than five times as many sites with appropriate gravel substrates occur in Black Earth Creek (Madsen 1982).

Both *Berula erecta* and *Veronica catenata* were found commonly only in Lawrence Creek; in the case of *B. erecta,* its absence in Black Earth Creek is due to its intolerance of siltation, pollution, and spates. *Berula* also prefers either fine sand or silt substrates. Less is known about *Veronica catenata.*

There is no significant difference in the occurrence of *Phalaris arundinacea* in the two streams. As it is generally a streambank species, this is an expected result.

Lemna minor is much more common in Black Earth Creek than Lawrence Creek, possibly due to a headwaters refuge and

reproductive area, as well as many areas of slack water for habitation.

SYNTHESIS

In comparing the differences in vegetation between stream sections or two entire stream communities, confusion may occur. In studying sections or "reaches" of a given stream, slight differences in the environment or other factors may result in a slight difference in the community composition of those two sites. However, these differences are small when compared to the differences between the two streams, as in the case of Black Earth and Lawrence Creeks. Using Discriminant Analysis, this relationship can be seen (Figure 12). The differences between all sections except C and D are significant at the $p = 0.05$ level. The separation between the streams is significant at the $p = 0.01$ level. These relationships may be thought of in a hierarchical fashion, with the differences between sections or reaches being local and variable, and the differences between streams being of a larger scale and due to environmental differences characteristic of the streams.

ACKNOWLEDGMENTS

We thank Carolyn Madsen for her assistance in preparing and reviewing this manuscript, and the Davis Fund Committee (Department of Botany, University of Wisconsin-Madison) for providing travel funds for this project. An anonymous reviewer provided constructive comments.

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Appendix 1
Species observed in Black Earth Creek.

1. *Batrachospermum* sp. (Rhodophycophyta)
2. *Callitriche verna* (Callitrichaceae)
3. *Cladophora glomerata* (Chlorophycophyta)
4. *Draparnaldia* sp. (Chlorophycophyta)
5. *Elodea canadensis* (Hydrocharitaceae)
6. *Fissidens fontanus* (Muscopsida)
7. *Lemna minor* (Lemnaceae)
8. *Nasturtium officinale* (Brassicaceae)
9. *Phalaris arundinacea* (Poaceae)
10. *Polygonum* sp. (Polygonaceae)
11. *Potamogeton crispus* (Najadaceae)
12. *P. foliosus* (Najadaceae)
13. *P. pectinatus* (Najadaceae)
14. *Ranunculus longirostris* (Ranunculaceae)
15. *Sagittaria brevirostra* (Alismaceae)
16. *Solanum dulcamara* (Solanaceae)
17. Typha angustifolia var. *elongata (glauca?)* (Typhaceae)
18. *Veronica catenata* (Scrophulariaceae)

Appendix 2
Species observed in Lawrence Creek.

1. *Alnus rugosa* (Betulaceae)
2. *Amblystegium riparium* (Muscopsida)
3. *Berula erecta* (Apiaceae)
4. *Caltha palustris* (Ranunculaceae)
5. *Cladophora glomerata* (Chlorophycophyta)
6. *Drepanocladus* sp. (Muscopsida)
7. *Elodea canadensis* (Hydrocharitaceae)
8. *Lemna minor* (Lemnaceae)
9. *Machantia* sp. (Hepaticopsida)
10. *Mentha arvensis* (Labiaceae)
11. *Nasturtium officinale* (Brassicaceae)
12. *Phalaris arundinacea* (Poaceae)
13. *Polygonum* sp. (Polygonaceae)
14. *Potamogeton pectinatus* (Najadaceae)
15. *P. richardsonii* (Najadaceae)
16. *Ranunculus longirostris* (Ranunculaceae)
17. *Solanum dulcamara* (Solanaceae)
18. *Symplocarpus foetidus* (Araceae)
19. *Veronica catenata* (Scrophulariaceae)