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Long-Term Ecological Research On Spring-Fen Communities At The St. Croix Watershed Research Station Washington County, Minnesota

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The project involved intense monitoring of two permanent plots of spring-fen vegetation at the St. Croix Watershed Research Station, Washington County, Minnesota, during the growing seasons of 1994-1999.

Plot C was covered by a thin layer of mineral sediment, deposited during the heavy rains of summer 1993. At each plot, the research measured the peat surface, water-table elevations, hydraulic heads, cover by open water, and litter cover. Researchers analyzed water samples for pH, specific conductance, and absorbance, took samples for diatom analysis, and conducted vascular-plant surveys during each survey. The bryophyte flora was surveyed in 1991 and again in 1994 and 1999. The vegetation cover was photographed seasonally and initially included stereographic air photos as baseline images.

Very little unidirectional change can be observed on plot C. Comparisons of the recorded changes between the plots and among the results of the seasonal surveys suggest that only the seasonal amplitude of variation on plot C might have increased. After summer 1996 relative water tables and piezometer heads drop on both plots. The hydrological measurements suggest that both plots have become significantly drier, but the vegetation appears not to have responded yet, nor has the peat build-up stopped.

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LONG-TERM ECOLOGICAL RESEARCH ON SPRING-FEN COMMUNITIES AT THE ST. CROIX WATERSHED RESEARCH STATION WASHINGTON COUNTY, MINNESOTA

Final Report

Prepared by
J.A. Janssens Ph.D., M.G. Noble Ph.D.,
S.P. Main Ph.D., and J.L. Haferman

Lambda-Max Ecological Research
1061 25th Ave SE
MPLS, Minnesota 55414-2637
(612) 379-4604, fax (612) 378-5087
janss008@ tc.umn.edu

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Prepared for the
St. Croix Watershed Research Station,
Science Museum of Minnesota,
16910 125th Street N,
Marine-on-St. Croix, MN 55047

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This project was conducted with funding provided by the St. Croix Watershed Research Station, Science Museum of Minnesota, the Minnesota Department of Transportation, and from the A.W. Mellon Foundation grant to Prof. Eville Gorham, Department of Ecology, Evolution and Behavior, University of Minnesota. We greatly appreciate the help by Eville Gorham in reviewing the interim status reports and the draft of the final report.

EXECUTIVE SUMMARY

Two permanent plots of spring-fen vegetation at the St. Croix Watershed Research Station, Washington County, Minnesota, have been intensively monitored during the growing seasons of 1994-1999. The plots are part of a network of permanent monitoring sites throughout Minnesota established by the Department of Ecology, University of Minnesota, through grants to Dr. E. Gorham by the A.W. Mellon Foundation.

Plot C was covered by a thin layer of mineral sediment, derived from road construction along Highway 95 and deposited during the heavy rains of the summer of 1993. Plot A was spared the inundation because of the divergence of the surface runoff. This report summarizes all pre-disturbance data and presents the results of the monitoring of the post-disturbance period from 1994 to 1999.

At each plot the peat surface, water-table elevations, hydraulic heads, cover by open water, and litter cover were measured. Water samples were analyzed for pH, specific conductance, and absorbance (color). Samples for diatom analysis were taken and vascular-plant surveys were conducted during each survey. The bryophyte flora was surveyed in 1991 and again in 1994 and 1999. The vegetation cover was photographed seasonally and initially included stereographic air photos as base-line images. The vouchers specimens of diatoms, bryophytes and vascular plants, and the photos are deposited at the St. Croix Watershed Research Station and The Science Museum of Minnesota.

On plot C very little unidirectional change can be observed in the composition of the diatom flora and bryophyte and vascular-plant vegetation after 1994, the start of the growing season immediately following the disturbance by road silt. Comparisons of the recorded changes between the plots and among the results of the seasonal surveys suggest that only the seasonal amplitude of variation on plot C might have increased. This could be an effect of the disturbance, or it is also possible that plot C is inherently more variable, that the methodology employed here is not sensitive enough to pick up a trend against the inevitable ecological noise, or that the time-frame allotted for intensive monitoring is too brief.

The peat surface follows the same trend on both plots, but its increase in thickness has been most obvious in the undisturbed plot A. After the summer of 1996 relative water tables and piezometer heads drop on both plots. The hydrological measurements suggest that both plots have become significantly drier, but the vegetation appears not to have responded yet, nor has the peat build-up stopped. Both plots are at the head of a small watershed. The gradual drop 1997-1999 in local water levels and piezometer heads might have been caused because the outlet of plot C into the creek has become "unplugged", letting more surface water to drain away from the entire stream-head system. If the drying continues and the composition of the spring-fen vegetation eventually becomes altered, it might be possible to remedy the situation by restoring a higher threshold on the outlet.

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INTRODUCTION

Pre-disturbance research

Three permanent plots for long-term ecological research were established within spring fens north of 152nd Street N on the St. Croix Watershed Research Station property. The funding was provided by the A.W. Mellon Foundation through a grant to E. Gorham at the Department of Ecology, University of Minnesota [1].

The plots (A.W. Mellon database identifiers 1625AA, BA, and CA, described here as plots A, B, and C) were established on June 28, 1990 (45°10'45"N, 92°45'53"W, NE of SW, section 18 T31N R19W, 250 m a.s.l.). Plot B was abandoned in 1991 because of excessive disturbance by deer. The two plots still monitored (Figure 1) are A, located in a small spring-fen opening and 25 m^2 in extent, and C, down slope in a larger opening, and 100 m^2 in extent.

Prior to the disturbance (see below) that initiated the present project, data for plots A and C contained the following classes of information (A.W. Mellon database, Department of Ecology, University of Minnesota):

- water level measurement for Sept. 12, 1991
- soil temperature profiles for June 28, 1990, and Sept. 12, 1991
- water chemistry determinations for June 28, 1990, May 19, June 2, June 11, and Sept. 12, 1991
- diatom collections (vouchers JAJ 64-66, 82-85, 89, LAB 37, 38) from June 28, 1990, May 19, June 2, Sept. 12, 1991, and May 28, 1993
- bryophyte collections (vouchers JAJ 20213-20240) for June 28, 1990
- vascular-plant collections (vouchers EJV 3005-3017 and 3030-3035) for May 19 and June 2, 1991

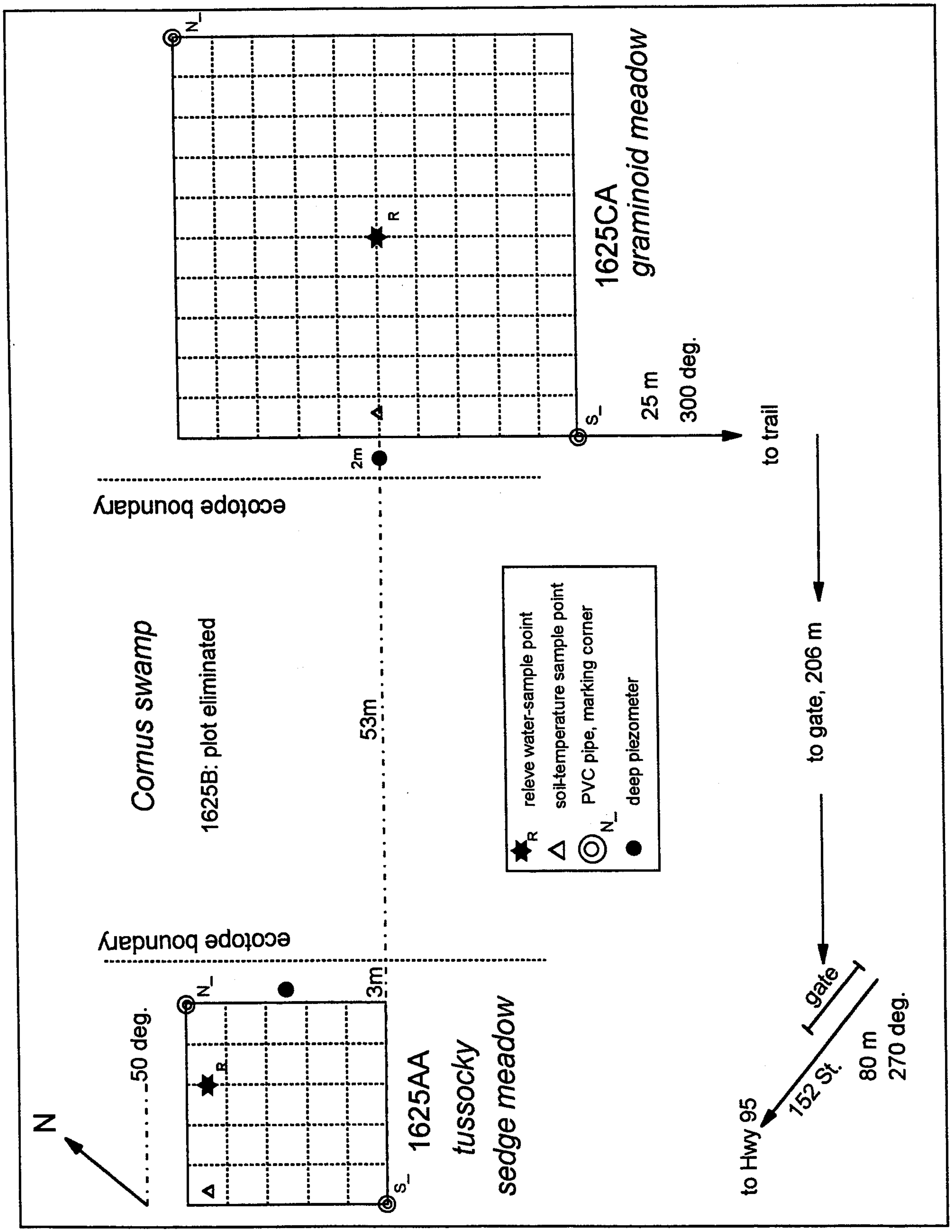

Figure 1. Permanent-plot location at the St. Croix Watershed Research Station

Post-disturbance research

Plot C was covered by a thin layer of mineral sediment, derived from road construction along Highway 95 and deposited during the heavy rains of the summer of 1993. Plot A was spared the inundation because of the divergence of the surface runoff alongside the southwestern and southeastern edge of the plot. A five-year monitoring project was planned to follow response of the vegetation at the permanent plots and compare the disturbed and undisturbed sites.

This final report summarizes all pre-disturbance data (see above) and presents the results of the monitoring of the post-disturbance period. The plots were surveyed during each growing season of the years 1994 to 1997 and during 1999. These data are part of the A.W. Mellon database at the Department of Ecology, University of Minnesota and are also deposited at the St. Croix Watershed Research Station. Specific retrievals of these data from the A.W. Mellon database can be obtained from the senior author. The slide collections with the original photography and the voucher collections of vascular plants, diatoms, and bryophytes are deposited at the St. Croix Watershed Research Center and the Science Museum of Minnesota.

METHODS & RESULTS

Peat-surface, water-table elevations, and hydraulic heads

Both plots A and C are permanently marked by capped PVC pipe in the north and south corners (Figure 1) inserted down to mineral contact. The other corners of the permanent plots are marked by more expendable PVC as temporary guides. Plot locations are mapped (Figure 1) in relation to other permanent markers. Plot identifier labels on aluminum tags are attached to the PVC pipes. During each survey the extension of each one of the permanent PVC pipes is measured in mm above (1) the peat surface and (2) the local water table. A modified carpenter's level [2] or a small pit is used to avoid parallax during reading when the local water table is below the peat surface. The measurements of the north and south pipes are averaged for each plot. The pre-disturbance 1991 peat-surface measurements have been used as datum and subsequent post-disturbance measurements have been calculated relative to this 1991 level. The results are plotted in Figure 2.

On plot A the local water table was consistently near or just below the rising peat surface until the summer of 1996. Presently (1999) the peat surface itself is nearly 22 cm above its level in 1991. After the summer of 1996 the water table has slowly dropped relative to the peat surface and is now 16 cm below it. On plot C total peat depth has increased only 5 cm above the level of disturbance in 1991, and the local water table is now about 4 cm below the level of the 1991 peat surface and 9 cm below its present level. Before the fall of 1995 the water table was consistently 2-4 cm above the peat surface. Since the summer of 1996 it has been consistently below the peat surface. Both plots have thus become drier since the summer of 1996, but the water-table drop has not inhibited peat growth.

Each plot also has a piezometer installed, screened below the peat base (Figure 1). During each of the 1995, 1996, 1997, and 1999 surveys the water level within and outside the piezometers has been measured. The hydraulic heads relative to the local water table are also plotted on Figure 2. Piezometer heads above the water table indicate upwelling (groundwater discharge); piezometer heads below the water table indicate downward groundwater movement (groundwater recharge). On plot A, which has the local water table consistently below the peat surface, the piezometer head is, in turn, nearly consistently below the water table, suggesting recharge. However, on plot C the piezometer heads have been consistently above the local water table, suggesting continuous discharge, and have only recently fallen below the peat surface.

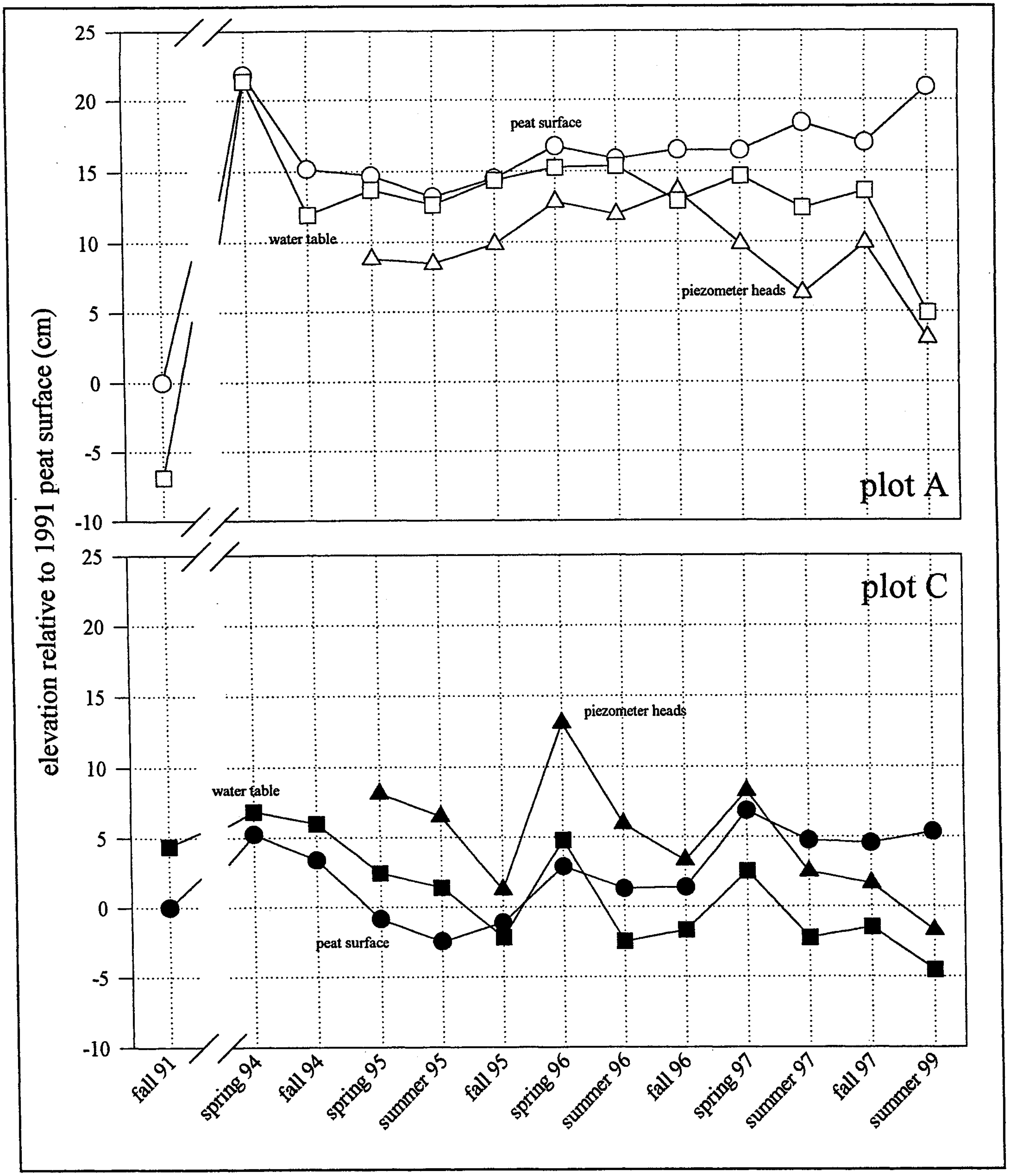

Figure 2. Elevation of the local peat surface, water table, and hydraulic heads in piezometers screened below the peat base at permanent plots A and C. All elevations at each plot are relative to the local peat surface during the fall of 1991.

Open-water and litter cover

The percentage of open water (pools) and litter was estimated on an ocular cover scale and Figure 3 summarizes all pre- and post-disturbance data. The high water tables during spring 1996 for plot C (see Fig. 2) are also obvious in this graph, but the other estimates do not correlate well with the relative water table plotted in Fig. 2.

Litter cover is related to season: during the spring the plots are still covered with undecomposed plant material from the previous growing season obvious in the fall estimates. During the summer the litter cover is lowest.

Water chemistry

During each survey one water sample was taken per plot in an acid-washed Nalgene bottle at the water-sample point (Figure 1), in addition to several samples from the surrounding ecotopes during the 1991 field season. Standing water was preferred if available, otherwise a depression sample (where the surface vegetation was depressed without disturbing the peat) was taken.

As soon as possible after collection, pH was measured. After all samples and buffers were at room temperature pH was determined on a 10-ml sample, decanted from the collecting bottle, with a pH meter and a combination electrode. Buffer adjustments both at pH 4 and 7 were made, and the pH values were recorded to the nearest 0.01 unit (after 1996 to 0.1 unit) without stirring after the reading was stable for at least 2 minutes.

Specific conductivity was measured at the same time as the pH and the hydrogen-ion contribution was subtracted (calculated as reduced specific conductivity ($K^{20°C}_{red}$) in µS cm^{-1} at 20°C).

Absorbance was measured as soon as possible on decanted water from stored, non-acidified water samples in 1-cm quartz cells with a spectrophotometer set at 350 nm. Values above 1.500 are below the sensitivity of the spectrophotometer and such samples can be diluted before measuring absorbance (dilution is linearly related to absorbance according to Beer's Law).

The results of water-chemistry measurements of pre- and post-disturbance collections are plotted as yearly averages in Figure 4 (including 95% confidence intervals). None of the water-chemistry variables appear to have changed significantly (95% C.I.) between 1990 and 1999, except for one highly anomalous value for pH in plot C during the summer of 1999.

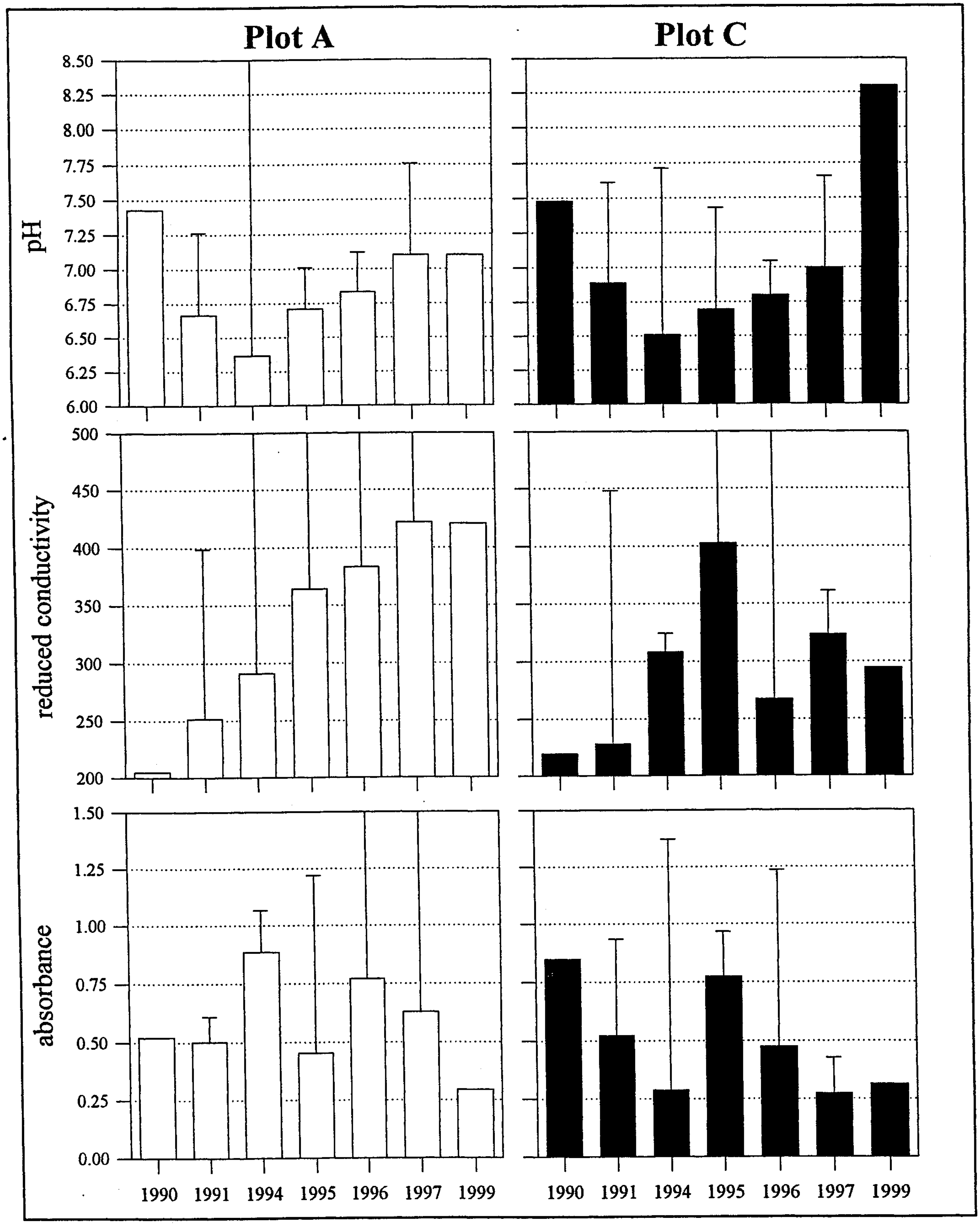

Figure 3. Summary of water-chemistry data for the St. Croix Watershed Station spring-fen plots.

Diatom survey

Diatom samples from the spring-fen plots were collected using clean disposable pipettes for suspensions and fine silts; peat surfaces, mosses and other macrophytes were sampled by hand. A composite sample was collected from all these surfaces during each survey from each plot.

Analysis of the samples began with microscopic observation to list presence of non-diatom algae and other living organisms. This was done before preservation in 5% formaldehyde unless observation was not possible within 24 hours of collection. Diatom suspensions for permanent microscope slides were cleaned by gently boiling the samples in concentrated nitric acid until oxidation became undetectable. The cleaned diatoms were rinsed by settling for 24 hours, decanting, adding distilled water, and repeating this sequence until the pH was neutral. When pipetted from the well-mixed suspension, the concentration of the diatoms was adjusted to give an even dispersion of non-overlapping diatom valves on a coverslip. Dried coverslips were mounted in Naphrax. Two slides were prepared in this way, one for counting which is in the junior author's (SPM) personal herbarium and one for deposition at the St. Croix Watershed Research Station.

Each prepared slide was scanned to list the species present, and approximately 500 diatom valves were identified to quantify relative abundances (Appendix B). An ordination analysis (Detrended Correspondence Analysis [3]) was performed with the 28 diatom samples and the results are shown in Figure 5, including trajectories for both plots. In an ordination assemblages that are more similar in composition are clustered closer together.

Three results can be derived from the ordination diagram: (1) plot A and C diatom compositions are nearly always distinctly different from each other; (2) for each plot: samples from the same year clearly resemble one another more than within-season samples, *i.e.,* spring assemblages (and summer, and fall assemblages) from year to year are distinctly different from one another and do not cluster together, but samples from the same year do; (3) the plot C trajectory appears to be slightly longer (more variation) than the one for plot A.

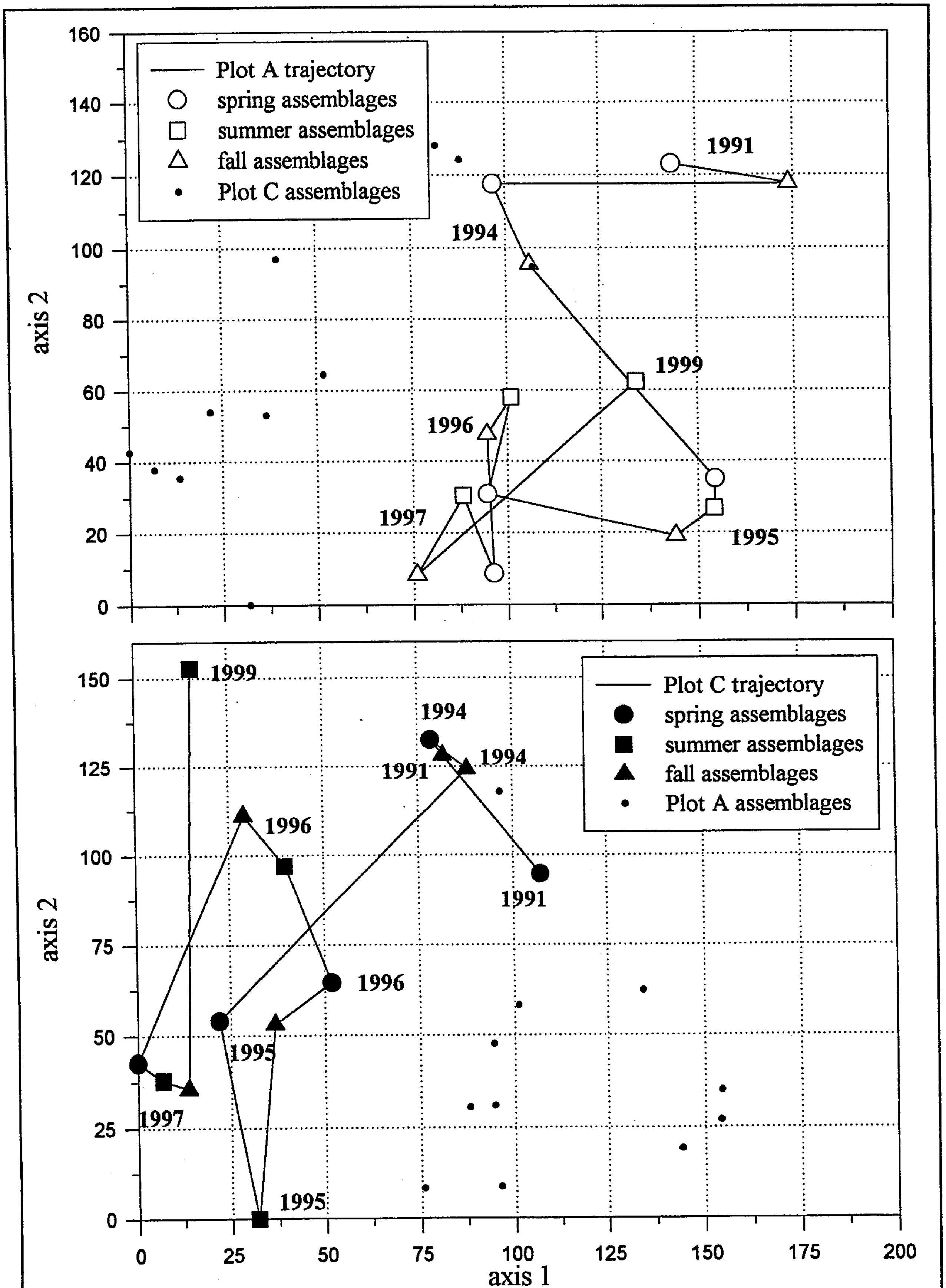

Figure 4. DCA ordination of diatom assemblages from the St. Croix Watershed spring-fen plots.

Bryophyte survey

The bryophyte cover in the plots has been and is very low, less than 5 % on A and 3% of C. No attempt was made to obtain either frequency or cover abundances. Table 1 lists the species collected during the partial 1990, and the more complete 1994 and 1999 surveys. The only species of note is *Campylium radicale,* which is a rare (probably an under-collected) species in the State of Minnesota [4].

Table 1. Bryophyte records within the limits of ecotopes A and C of the spring-fen communities at the St. Croix Watershed Research Station. The table is a compilation of all collections inside and outside the permanent plots, collected during the field seasons of 1990, 1994, and 1999.

	Ecotope A			Ecotope C		
Species	1990	1994	1999	1990	1994	1999
Amblystegium serpens var. *juratzkanum*		+	+			
Brachythecium oedipodium	+	+	+	+	+	+
Campylium radicale	+	+	+	+	+	+
Drepanocladus aduncus				+	+	+
Plagiomnium cuspidatum		+	+	+		
Plagiomnium ellipticum	+	+		+	+	+

Vascular-plant survey

The methodology for the vascular-plant surveys of the permanent plots followed the one used by the Heritage Program of the Minnesota Department of Natural Resources [5]. Only from the year 1994 on was an attempt made to survey all taxa within and immediately surrounding the permanent plots. To follow future development and response to disturbance these 1994 data will be used as baseline. The Braun-Blanquet abundance/cover scale was used to describe their presence (r = a single individual within the plot, + = few individuals, total canopy cover <5%, 1 = many individuals, cover still below 5%; 2 to 5 are strictly cover estimates, respectively up to 25%, 50%, 75% and 100%).

Figure 6 shows the results of a detrended correspondence analysis (DCA ordination [3]) of the yearly composition for each plot (Appendix C). This yearly composition is derived by using maximal seasonal cover for each of the vascular-plant species (synplots), including all species without down-weighing. The ordination distances among the synplots (open circles for plot A and solid circles for plot C) plotted on the graph in Figure 6 reflect the degree of similarity among the vascular-plant compositions. The closer the symbols are in 3-D space, the more similar are the compositions of the synplots they represent. Plot A and C are clearly different from each other and never approach each other in composition. The annual composition of plot A does vary a lot less that that of plot C. There is no unidirectional change indicated among the annual surveys of plot C. The last survey in 1999 is actually more similar to the first 1994 survey than to any survey from the other years.

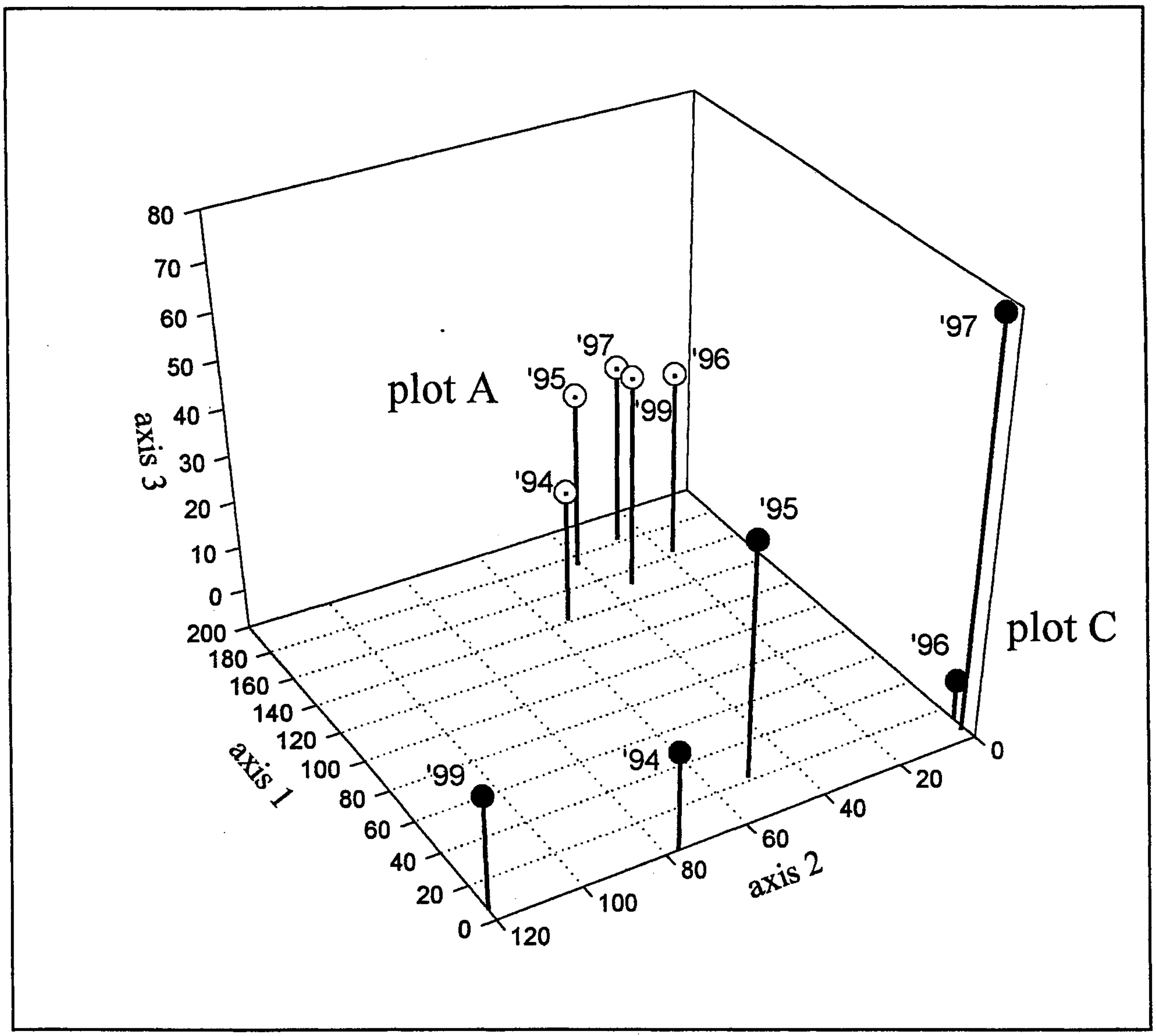

Figure 5. DCA ordination of vascular-plant vegetation from the St. Croix Watershed spring-fen plots.

Plot photography and balloon stereophotography

During nearly all surveys plots A and C were photographed. At each corner of the plots a photograph was taken toward the center of the plot, from a height of 1.5 m. The photographic slides are deposited at the St. Croix Watershed Research Station. The photos indicate clearly the great seasonal variation.

Balloon stereophotography of plots A and C was carried out on June 3 and July 5, 1994, and September 11, 1995. Table 2 lists the most suitable images obtained and deposited at the St. Croix Watershed Research Station as long-term baseline images.

Table 2. Balloon-stereophotography images of the permanent plots at the St. Croix Watershed Research Station obtained during the surveys of 1994 and 1995.

	Left-image ID	Right-image ID	Date	Lens (mm)	Height (m)
Plot A					
	94-15-30	94-16-28	5-Jul-94	50	15.5
	94-15-35	94-16-32	5-Jul-94	50	48.5
	95-41-4	95-42-3	11-Sep-95	35	11.0
Plot C					
	94-4-17	94-5-13	3-Jun-94	50	30.5
	94-13-19	94-14-20	5-Jul-94	50	31.5
	94-13-27	94-14-27	5-Jul-94	50	73.0
	95-39-13	95-40-13	11-Sep-95	35	18.6

CONCLUSIONS

On plot C very little unidirectional change can be observed in the composition of the diatom flora and bryophyte and vascular-plant vegetation after intensive surveys started in the spring of 1994, the start of the growing season immediately following the disturbance by road silt. Comparison of recorded changes on plot A (which was not disturbed) and plot C suggest that only the amplitude of variation on the latter might have increased among individual seasons, possibly because of the disturbance. It is also possible that plot C is either inherently more variable (being a larger plot?), that the methodology employed here is not sensitive enough to pick up a trend against the inevitable ecological noise, or that the time-frame allotted for intensive monitoring is too brief.

The peat surface follows the same trend on both plots, but its increase in thickness has been more obvious in the undisturbed plot A (Fig. 2). Until the summer of 1996 the level of the peat surface seems to be related to piezometer values, suggesting that artesian pressure may be important in controlling the expansion or contraction of the peat column. However, after the summer of 1996 relative water table and piezometer head drop, but the peat surface keeps rising slowly. Both plots have become significantly drier, as indicated by these hydrological trends, but the vegetation appears not to have been irreversibly damaged, nor has the peat build-up stopped. There is at present no evidence of substantial contraction of the amount of open water available for the more aquatic and semi-terrestrial species (Fig. 3). Both plots are the head of a creek watershed, plot A elevated above plot C, each in the center of a small peat-filled depression (JAJ, unpublished bathymetry data). The piezometer data suggests that plot A receives water from the surrounding upland as runoff or shallow sub-surface flow. The water then seeps through the shallow peat above the subsurface ridge that separates plot A and C, discharging eventually near the outlet of plot C. The 1997-1999 gradual drop in local water levels and piezometer heads might have been caused because the outlet of plot C into the creek has become "unplugged", letting more surface water drain away from the entire stream-head system (J. Almendinger, personal communication). If the drying continues, and the composition of the spring-fen vegetation eventually becomes altered (which is not yet the case), it might be possible to remedy the situation by restoring a higher threshold on the outlet from the basin into the creek near plot C. There is no significant change among water-chemistry variables.

The low abundance and diversity of the bryophyte flora is caused mainly by the very luxurious development (both in density and height) of the aboveground, annual growth of vascular plants, which shades out most mosses and liverworts except for some of the more weedy species and the ones that successfully colonize standing-dead litter.

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APPENDIX A

WATER CHEMISTRY DATA

WATER-CHEMISTRY DATA

plot A

pH

	1990	1991	1994	1995	1996	1997	1999
	7.8	6.5	6.8	6.8	6.9	7.4	7.1
	7.4	6.9	6.0	6.7	6.9	7	
	7.6	6.6		6.6	6.7	6.9	
	7.4						
average	7.5	6.7	6.4	6.7	6.8	7.1	7.1
n	4	3	2	3	3	3	1
st. dev.	0.2	0.2	0.6	0.1	0.1	0.3	
st. err.	0.1	0.1	0.4	0.1	0.1	0.2	

conductivity

	1990	1991	1994	1995	1996	1997	1999
	213	199	357	306	195	353	421
	212	316	225	301	534	486	
	229	240		485	419	427	
	205						
average	214	252	291	364	382	422	421
n	4	3	2	3	3	3	1
st. dev.	10	59	93	105	172	66	
st. err.	5	34	66	61	100	38	

absorbance

	1990	1991	1994	1995	1996	1997	1999
	0.537	0.474	0.870	0.260	0.550	0.149	0.293
	0.420	0.552	0.900	0.290	1.580	1.520	
	0.530	0.481		0.810	0.183	0.220	
	0.522						
average	0.502	0.502	0.885	0.453	0.771	0.630	0.293
n	4	3	2	3	3	3	1
st. dev.	0.055	0.043	0.021	0.309	0.724	0.772	
st. err.	0.028	0.025	0.015	0.179	0.418	0.446	

plot C

pH

	1990	1991	1994	1995	1996	1997	1999
	6.7	7.0	6.6	6.7	6.9	7.2	8.3
	6.9	6.8	6.4	6.4	6.8	7.1	
	6.9			7.0	6.7	6.7	
	7.5						
	7.6						
	7.5						
average	7.2	6.9	6.5	6.7	6.8	7.0	8.3
n	6	2	2	3	3	3	1
st. dev.	0.4	0.1	0.1	0.3	0.1	0.3	
st. err.	0.2	0.1	0.1	0.2	0.1	0.2	

conductivity

	1990	1991	1994	1995	1996	1997	1999
	178	246	310	403	124	336	295
	189	210	307	222	408	328	
	185			583	271	307	
	284						
	230						
	220						
average	214	228	308	403	268	324	295
n	6	2	2	3	3	3	1
st. dev.	40	26	2	180	142	15	
st. err.	16	18	1	104	82	9	

absorbance

	1990	1991	1994	1995	1996	1997	1999
	0.850	0.558	0.378	0.860	0.280	0.202	0.314
	0.623	0.490	0.198	0.710	0.830	0.313	
	0.660			0.750	0.321	0.305	
	0.870						
	0.580						
	0.848						
average	0.739	0.524	0.288	0.773	0.477	0.273	0.314
n	6	2	2	3	3	3	1
st. dev.	0.131	0.048	0.127	0.078	0.306	0.062	
st. err.	0.054	0.034	0.090	0.045	0.177	0.036	

APPENDIX B

DIATOM SURVEY DATA

Plot A diatom counts

	1991		1994		1995			1996			1997			1999
	spring	fall	spring	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall	
Achnanthidium exiguum var. heterovalvum (Krasske) Czar.		1		0	14	4	16	10	4	12	7	8	10	11
Achnanthidium hungaricum Grun.		0												
Achnanthidium lanceolatum Breb. in Kuetz.	40	127	138	130	68	55	28	22	33	34	27	19	27	37
Achnanthidium lanceolatum subsp. frequentissimum L.-B.					86	110	131	128	113	105	101	112	152	149
Achnanthidium lanceolatum var. rostrata					25	8	15							
Achnanthidium minutissimum (Kuetz.) Czar.					2									10
Amphora libyca Ehrenb.		0												
Caloneis bacillum (Grun.) Cl.	2	2	4	2	1		2		0			4	5	
Caloneis bacillum var. fontinalis (Grun.) Mayer						1	1		0	0	0		0	0
Caloneis lauta Carter & Bailey-Watts										2				
Caloneis schumanniana var. biconstricta (Grun.) Reichelt														1
Caloneis silicula (Ehrenb.) Cl.						0					0		0	
Caloneis thermalis (Grun.) Krammer									2					
Craticula cuspidata (Kuetz.) D.G. Mann			0						0		0			0
Cymbella aspera (Ehrenb.) H. Perag.			0	0							0		0	0
Cymbella minuta var. pseudogracilis (Choln.) Reim.		2			0	0			0			1	0	0
Cymbella naviculiformes Auersw. ex Heib.			10	6	2	4	8	15	12	6	9	0	4	0
Diploneis oblongella (Naeg. ex Kuetz.) Ross	1	1		2	1		2		0	0	0		0	3
Diploneis ovalis (Hilse) Cl.	0				0	0				1	0	0	1	
Epithemia turgida (Ehrenb.) Kuetz.		1												
Eunotia curvata (Kuetz.) Lagerst.	2	4	11	0	16	8	4	4	4	4	8	2	4	6
Eunotia parallela Ehrenb.						1	2							
Eunotia sp. P8										4			1	
Eunotia valida Hust.				0	1						0			
Fallacia insociabilis (Krasske) D.G. Mann	0							1				1		
Fragilariforma nitzschioides (Grun.) Williams & Round	41	39	18	22	51	27	26	0	22	4	32	11	44	42
Frustulia vulgaris (Thwaites) DeT.				0	0	0			0			1	1	
Gomphonema affine var. insigne (Greg.) Andrews											0			
Gomphonema amoenum Lange-Bertalot		2												
Gomphonema angustatum (Kuetz.) Rabh.	2	4	38	7	12	11	1	7	3	0			0	2
Gomphonema angustatum var. sarcophagus (Greg.) Grun.	4	6	7	2	11	1	3	0	5		0	0	1	4
Gomphonema angustum Ag.					1									
Gomphonema brebissonii Kuetz.											0	0	0	
Gomphonema clavatum Ehrenb.								9	2	0	7		10	
Gomphonema gracile Ehrenb. emend V. H.	2		4	0	0				6	2	0		2	
Gomphonema intricatum var. vibrio (Ehrenb.) Cl.											9		0	
Gomphonema micropus Kuetz.					26	6					5	0	1	
Gomphonema parvulum (Kuetz.) Kuetz.		4		3	6	2	9	26	6	13	11	8	13	2
Gomphonema sp. P12			2	2	7	0	0		2		0	0	1	
Gomphonema sp. P13					3		0	2	0		1		0	
Gomphonema sp. P14					4	3	2	7	27	0	21	2	6	
Gomphonema sp. P15					48	21	20	6		5	20		4	
Gomphonema sp. P16					4	4	3							
Gomphonema sp. P17							0							
Gomphonema sp. P18						27			0	2	0			
Gomphonema subclavatum (Grun.) Grun.														4
Hantzschia amphioxys (Ehrenb.) Grun.	2	9	0	0	1	0	2	0	0	3	0	1	0	0
Luticola mutica (Kuetz.) D.G. Mann														2
Meridion circulare var. constrictum (Ralfs) V. H.	0	3	72	7	20	11	2	9	3	1	27	4	9	0
Navicula arvensis Hust.			9		1						5	6		
Navicula atomus (Kuetz.) Grun.			1	1				2	1					
Navicula begeri Krasske										2				
Navicula contenta var. biceps (Arnott) V. H.		8		1									0	
Navicula cryptocephala Kuetz.			4	2	1		3					6	4	0
Navicula elginesis (Greg.) Ralfs	4	3	10	28	10	8	26	7	36	12	7	8	15	9
Navicula fossalis Krasske	88	3			1	3				0				
Navicula hambergii Hust.							1						0	
Navicula joubaudii Germain	9	29	4	3	8	5	7	2	12	11	17	1	7	10
Navicula kirchneriana Florin	0	2			3		3	0	0			2		0
Navicula lagerheimii var. intermedia Hust.	6	11		1	1	2	5	0		3		3	0	
Navicula lapidosa Krasske			2			1								
Navicula minima Grun.	99	56	49	59	26	83	61	165	118	141	62	186	97	102
Navicula notha Wallace	0				1					4	1	8	3	11
Navicula paludosa fo. rhomboidea Reim.	0	16		4	3	0	2					0	0	
Navicula pupula Kuetz.	12	2	0	24	3	11	19	4	7	12	0	12	4	8
Navicula pupula var. P1										2				
Navicula pupula var. P2 "small"									4	31				1
Navicula pupula var. pseudopupula (Krasske) Hustedt								4		0	3		5	
Navicula pupula var. rectangularis (Greg.) Grun.	0	5	4	0							1	5	6	
Navicula radiosa Kuetz.	1			2	0				0	5	0	2	1	0
Navicula seminulum Grun.	17	6	13	18	4	2		63	61	40	7	31	15	22
Navicula sp. P24				55	0	9	24			0				

Plot A diatom counts

	1991		1994		1995			1996			1997			1999
	spring	fall	spring	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall	
Navicula sp. P26	28	9						2						
Navicula sp. P27	0						4			0				
Navicula sp. P29		1												
Navicula sp. P30		1												
Navicula sp. P31														7
Navicula sp. P32					1	1	2							
Navicula sp. P33							3					1		
Navicula sp. P34							2	2						
Navicula sp. P35						1				1				
Navicula sp. P37												1	2	
Navicula sp. P38										0				
Navicula sp. P39												6	3	
Navicula sp. P40										1				
Navicula sp. P41											2			
Navicula sp. P42														2
Navicula sp. P9 (N. subnympharum Hust.)			0	8	3		4				0	5	0	
Navicula tenelloides Hust.				6		2			0					
Navicula venata Kuetz.		2												
Navicula viridula var. argunensis Skv.	8	6	4	1	4	2	5	2	4	7	4	7	3	8
Neidium affine var. undulatum (Grun.) Cl.	1		0						0		2		0	0
Neidium ampliatum (Ehrenb.) Krammer	0					1								
Neidium bisulcatum (Lagerst.) Cl.	0								0				1	
Neidium bisulcatum var. P1						1								
Neidium bisulcatum var. subampliatum Krammer		0					0							
Neidium hercynicum A. Mayer	1													
Nitzschia acidoclinata Lange-Bertalot	30	8	40	19	10	55	14	19	23	24	15	17	18	21
Nitzschia alpina Hust. emend Lange-Bertalot														1
Nitzschia amphibia Grun.	0	4	6	0	8	1	4	1	0	5	2	1	1	2
Nitzschia archibaldii Lange-Bertalot											70	10	7	
Nitzschia commutata Grun.					0				0					
Nitzschia debilis Arnott	1			0										
Nitzschia gessneri Hust.								4						
Nitzschia liebetruthii Rabenhorst														5
Nitzschia linearis (Ag. ex W. Sm.) W. Sm.			2						0	1				
Nitzschia linearis var. tenuis (W. Sm.) Grun.											0	2	0	
Nitzschia modesta Hust.					1		0							
Nitzschia palea (Kuetz.) W. Sm.	23	9				3	5		10	16		7	9	6
Nitzschia palea var. tenuirostris Grun.			26		4									
Nitzschia perminuta (Grun.) M. Peragallo	19	5		31		4			2	7	6			
Nitzschia pseudofonticola Hust.	3	77	15	34	7	9	7		8	6	4	3	5	
Nitzschia pusilla Grun.			2	4										
Nitzschia radicula Hust.							3	10		1		1		
Nitzschia sp. P12								2						2
Nitzschia terrestris (Petersen) Hust.	8	64	8	4	1	0	5		2	4		0	0	18
Pinnularia acrosphaeria W. Sm.	0				0		1		0	0		0	2	
Pinnularia appendiculata (Ag.) Cl.	2	0					0					1		
Pinnularia brevicostata Cl.	0						0							
Pinnularia gibba var. linearis Hust.		3										0		
Pinnularia legumen (Ehrenb.) Ehrenb.												2		
Pinnularia microstauron (Ehrenb.) Cl.			0		0	1	0							0
Pinnularia nodosa (Ehrenb.) W. Sm.					0						0	0	0	0
Pinnularia obscura Krasske	7	0	4	2		2		2				2	1	
Pinnularia sp. P2	3													
Pinnularia stomatophora (Grun.) Cl.			2	4					0		0			2
Pinnularia streptoraphe Cl.										0			2	1
Pinnularia subcapitata Greg.	0		11	18	1	3	1	2	0	0	0	0	0	
Pinnularia tenuis Greg.	2		6				0			1				
Pinnularia viridis (Nitz.) Ehrenb.			2		1	1	3		0	0	0	1	1	
Rhopalodia gibba (Ehrenb.) O. Muell.				0	14	1	6		0	0	18	2	3	17
Rhopalodia gibberula var. vanheurckii O. Muell.										1		3	0	10
Rhopalodia operculata (Ag.) Hakansson					0	1	1							
Stauroneis anceps Ehrenb.			0		1	1	3	2			1	0	0	2
Stauroneis kriegerii Patrick				2			4	2	6	5	0	5	2	0
Stauroneis phoenicenteron (Nitz.) Ehrenb.											0			
Stauroneis phoenicenteron fo. gracilis (Ehrenb.) Hust.			0	0	1	1	2		0		0	1	3	0
Stauroneis pseudosubobtusoides Germain						2								
Stauroneis smithii Grun.												0		
Stauroneis smithii var. incisa Pant.		1			2	2			3			1	0	
Stauroneis thermicola (Petersen) Lund													2	
total number counted	468	536	528	514	531	523	507	543	541	541	512	523	518	540

Plot C diatom counts

	1991		1994		1995			1996			1997			1999
	spring	fall	spring	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall	
Achnanthidium exiguum var. heterovalvum (Krasske) Czar.				2		0		2		0	0	0	1	2
Achnanthidium lanceolatum Breb. in Kuetz.	2	1	18	104	4	15	4	2	6	15	5	7	2	1
Achnanthidium lanceolatum subsp. frequentissimum L.-B.					56	59	26	61	32	41	70	50	58	23
Achnanthidium linearis var. P1							2			1				
Achnanthidium minutissimum (Kuetz.) Czar.							1							
Amphora montana Krasske						1					0			
Caloneis bacillum (Grun.) Cl.	0	1		6	8		10	4	5	4		4		
Caloneis bacillum var. fontinalis (Grun.) Mayer											1	0	2	
Caloneis lewisii var. inflata (Schultze) Patr. (form)			0	2	0	2	2	0			0	0	4	
Caloneis thermalis (Grun.) Krammer													0	
Craticula cuspidata (Kuetz.) D.G. Mann		0												
Cyclotella meneghiniana Kuetz.														0
Cymbella aspera (Ehrenb.) H. Perag.		0	0				0					0	2	
Cymbella minuta var. pseudogracilis (Choln.) Reim.	1	0	0				2				2	0	0	0
Cymbella naviculiformes Auersw. ex Heib.	0		12	4	3		4	20	11	4	5	9	14	0
Diploneis oblongella (Naeg. ex Kuetz.) Ross		2		3	2			0		0	0			
Diploneis ovalis (Hilse) Cl.						1	1	2						
Encyonema minutum (Hilse ex Rab.) D.G. Mann		0												0
Eunotia curvata (Kuetz.) Lagerst.	15	2	18	18	28	26	30	1	13	15	4	7	5	7
Eunotia diodon Ehrenb.					2		5		0		0		2	0
Eunotia sp. P8						5								
Eunotia tecta Krasske							1							
Eunotia valida Hust.	2	0	2	2		0								
Fallacia insociabilis (Krasske) D.G. Mann								3						
Fragilariforma nitzschioides (Grun.) Williams & Round	238	13	69	0	36	18	80	0	23	18	22	11	20	4
Frustulia vulgaris (Thwaites) DeT.				5		1	1						0	
Gomphonema affine var. insigne (Greg.) Andrews			0											
Gomphonema angustatum (Kuetz.) Rabh.	0	0	11	2			2	7	2					3
Gomphonema angustatum var. sarcophagus (Greg.) Grun.				1		1	2	1				0		
Gomphonema angustum Ag.					0									
Gomphonema brebissonii Kuetz.													0	
Gomphonema clavatum Ehrenb.					31	5	18	14	12	8	3	4	3	
Gomphonema gracile Ehrenb. emend V. H.	3				2	1	1	2	6	4	5	0	4	
Gomphonema intricatum Kuetz.			0											
Gomphonema intricatum var. vibrio (Ehrenb.) Cl.													0	
Gomphonema montanum Schum.					4		2	0	5					
Gomphonema parvulum (Kuetz.) Kuetz.	17	0	31	6	25	27	29	28	45	39	33	21	11	17
Gomphonema sp. P10			12	2										
Gomphonema sp. P14					6		4	16	26	0	12	1	2	
Gomphonema sp. P15					22	2					0		1	
Gomphonema sp. P16						5	7							
Hantzschia amphioxys (Ehrenb.) Grun.	0	2	0	2			4	0	4	2	0	0	0	2
Luticola mutica var. subundulata (Grun.) comb. nov.												0		2
Meridion circulare var. constrictum (Ralfs) V. H.	8	0	10	2	3	1	5		0	1	0	1	0	0
Navicula arvensis Hust.				8									4	1
Navicula atomus (Kuetz.) Grun.				1					3			1		
Navicula begeri Krasske		28	0		6	28		28		6	2	1	1	6
Navicula contenta var. biceps (Arnott) V. H.			10			2								
Navicula cryptocephala Kuetz.			6	28	6				7	7	13	8	13	3
Navicula elginesis (Greg.) Ralfs	7	2	6	2	11	21	42	32	28	12	3	24	27	8
Navicula fossalis Krasske		1												
Navicula hambergii Hust.	2					5		8						
Navicula heufleri Grun.						2								
Navicula joubaudii Germain				8	9	5			2				2	2
Navicula lagerheimii var. intermedia Hust.	1	4	0	1	2	5	2			2	0		0	
Navicula lapidosa Krasske	6							2						
Navicula minima Grun.	52	313	57	151	49	118	41	121	124	136	110	155	137	218
Navicula notha Wallace						2	0							
Navicula paludosa fo. rhomboidea Reim.	2			2		0	0							0
Navicula pupula Kuetz.	0	2		2	27	15	16	54	26	25	3	6	7	
Navicula pupula var. P2 "small"								3	15	27				2
Navicula pupula var. pseudopupula (Krasske) Hustedt													1	
Navicula pupula var. rectangularis (Greg.) Grun.	0	2	6		6					4	21	14	18	
Navicula radiosa Kuetz.			0	16		4	2	0		8	10	4	12	4
Navicula schmassmannii Hust.												2	5	
Navicula seminulum Grun.	17	47	3	32	2	6	19	6	14	20	8	11	5	41
Navicula sp. P24	12			8	3	4	21				1		6	
Navicula sp. P25	1													
Navicula sp. P26								11	4					
Navicula sp. P28		2					5		1	2				

Plot C diatom counts

	1991		1994		1995			1996			1997			1999
	spring	fall	spring	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall	
Navicula sp. P31				8			0		0	6	1	0	6	2
Navicula sp. P35								10		6				
Navicula sp. P36						1								
Navicula sp. P37						1					7	3	7	
Navicula sp. P38							0							
Navicula sp. P39										7	13	37	16	
Navicula sp. P41												2		
Navicula sp. P43														2
Navicula sp. P9 (N. subnympharum Hust.)	6		0											
Navicula tenelloides Hust.					7	14					1	4	5	
Navicula tripunctata (O. F. Maell.) Bory													0	
Navicula trivialis Lange-Bertalot						2	1							
Navicula venata Kuetz.									4					
Navicula viridula var. argunensis Skv.			2	2		1	0			6	4	1	10	4
Neidium affine (Ehrenb.) Pfitz											2			
Neidium affine var. undulatum (Grun.) Cl.			0		1									
Neidium ampliatum (Ehrenb.) Krammer													0	
Neidium bisulcatum var. subampliatum Krammer								0					1	
Nitzschia acidoclinata Lange-Bertalot	26	23	86	37	37	52	25	40	58	34	39	51	32	15
Nitzschia amphibia Grun.	2			4		0	1			3				2
Nitzschia archibaldii Lange-Bertalot					72	10	5	2	14		62	4	8	26
Nitzschia debilis Arnott						0	3	0					0	0
Nitzschia dissipata (Kuetz.) Grun.						1							0	
Nitzschia frustulum (Kuetz.) Grun.										8				
Nitzschia gessneri Hust.								0			2			
Nitzschia hantzschiana Rabh.														73
Nitzschia hungarica Grun.												0		
Nitzschia intermedia Hantzsch					3	4								
Nitzschia linearis (Ag. ex W. Sm.) W. Sm.			0		1	2			0					4
Nitzschia linearis var. tenuis (W. Sm.) Grun.											0	0		
Nitzschia palea (Kuetz.) W. Sm.	46	21			12	15	12	22	12	25	10	10	5	37
Nitzschia palea var. tenuirostris Grun.			100	5	16				12	6				
Nitzschia perminuta (Grun.) M. Peragallo	16	15	30	8										
Nitzschia pseudofonticola Hust.	1	16	14	18	5	7	6	8	3	5	14	25	23	10
Nitzschia pusilla Grun.			19	6						2				
Nitzschia radicula Hust.					4	4	6			4	7	15	9	
Nitzschia sp. P12										5				
Nitzschia sp. P13									2					
Nitzschia terrestris (Petersen) Hust.	3	0	12	2	2	5	8	14	0	1	2	0	2	7
Pinnularia acrosphaeria W. Sm.	0	0			1		1		0	0	3	0	0	0
Pinnularia brevicostata Cl.													0	
Pinnularia gibba var. linearis Hust.		0							4					
Pinnularia ignoblis (Krasske) Cl.-Euler							1	0	4		13	8	13	2
Pinnularia legumen (Ehrenb.) Ehrenb.		0	0		8	1	3	0			0	0	0	
Pinnularia microstauron (Ehrenb.) Cl.						1				0		0		
Pinnularia nodosa (Ehrenb.) W. Sm.	0		4		19	6	29	2	2	0	6	5	1	0
Pinnularia obscura Krasske	4	2	0	4			3	1	0		1		1	
Pinnularia stomatophora (Grun.) Cl.		4											2	2
Pinnularia streptoraphe Cl.												0		
Pinnularia subcapitata Greg.	10	2	0	2	2	8	10	10	2	2	8	2	5	0
Pinnularia tenuis Greg.	2	8		2	2		7	0					1	
Pinnularia viridis (Nitz.) Ehrenb.	2	0				1	4				0	0	0	
Rhoicosphenia curvata (Kuetz.) Grun.														1
Rhopalodia gibba (Ehrenb.) O. Muell.		0	0					2	0			2	0	0
Stauroneis anceps Ehrenb.			0		2	5	4	2	0	0	1	0	1	
Stauroneis kriegerii Patrick				2			0		2				3	
Stauroneis phoenicenteron (Nitz.) Ehrenb.													0	
Stauroneis phoenicenteron fo. gracilis (Ehrenb.) Hust.	1	0	8			4	3	4	0	0	2	2	5	0
Stauroneis thermicola (Petersen) Lund						1	1							
Staurosira construens fo. subsalina (Hust.) Wiliams & Round	1													
Surirella angusta Kuetz.			0	2	2						1		0	
Synedra pulchella var. minuta Hust.										0				
Synedra radians Kuetz.					1									
Synedra rumpens var. fragilarioides Grun.										1				
total number counted	506	513	546	522	550	533	524	545	533	522	532	512	525	533

APPENDIX C

VASCULAR-PLANT SURVEY DATA

VASCULAR-PLANT SURVEY DATA

	plot A					plot C				
	1994	1995	1996	1997	1999	1994	1995	1996	1997	1999
Acer negundo				r	r		+	+	1	
Acer rubrum		r	+	r	+	r		r	r	
Angelica atropurpurea	r		+	1	1					
Asclepias incarnata						+	+	+	1	+
Aster borealis	+		1	1	1					
Aster puniceus	1	1	1	1	1	1	1	1	1	
Athyrium angustum		+	+	+						
Bidens cernua						1	2	2	1	
Boehmeria cylindrica	+	r	+		+			r		+
Calamagrostis canadensis						+		+	+	
Campanula aparinoides						1	1	1	+	1
Carex bebbii							1	1	1	+
Carex hystericina		+	+	+						
Carex lasiocarpa						2	2	2	2	1
Carex lasiocarpa var. americana								+		
Carex praegracilis									+	
Carex prairea								+		
Carex stipata		+	+	+			1	1	1	1
Carex stricta	3	3	4	4	4	4	4	4	4	3
Chelone glabra	+		+	+		1	1	+	+	
Cornus amomum						r				
Cornus stolonifera								+	+	
Cuscuta glomerata	1	+	+	+	1					
Dryopteris cristata		+	+	+				+	+	
Epilobium ciliatum	+	+	+	+			r	+		
Epilobium leptophyllum						+	+		+	+
Equisetum arvense		+	+	+	+			+	+	
Eupatorium maculatum	3	3	3	3	2	2	2	2	2	2
Eupatorium perfoliatum		+	+	+	+	+	+	1	+	1
Galium asprellum	+	2	1	1	1	+	1	1	1	1
Galium obtusum		+	+	+						
Galium tinctorium								+	1	
Galium trifidum		+					+		+	
Glyceria striata								+		
Impatiens capensis	2	2	2	2	2	1	2	2	2	2
Lathyrus palustris						+	+	+	1	
Leersia oryzoides	3	2	1	1	1	+	1	+	1	+
Lemna minor			+					+	1	
Lycopus americanus			+					+	+	+
Lycopus uniflorus	+		+	+	+	1	1	+	+	1
Lysimachia thyrsiflora						+	+	+		
Myosoton aquaticum	r	r								
Onoclea sensibilis	1	2	2	1	1	+	1	1	1	+
Parthenocissus inserta		+								
Parthenocissus quinquefolia			1		+					
Phalaris arundinacea						2	2	2	3	2
Pilea fontana		1	1	1	2		2	1	1	1
Platanthera hyperborea										+
Platanthera psycodes										+
Poa palustris	1	1	1	1	1	+	+	+		
Polygonum punctatum						+	r	+	+	
Polygonum sagittatum	1	1	1	1	1	1	2	1	1	+
Rumex orbiculatus						1	1	1	1	1
Scirpus atrovirens		+		+						
Scirpus cyperinus						+		+	+	+
Scutellaria lateriflora	+	+				2	+			+
Solidago gigantea	1	1	1	1	1	+	1	+	+	+
Sphenopholis obtusata		+		1						
Spiraea alba						1	1	1	1	1
Stellaria longifolia	1	+	+	+	+		+	+	+	
Symplocarpus foetidus		1	1	2						
Thelypteris palustris	1	1	1	1	+	1	1	1	1	1
Typha latifolia						+	+	+	+	2
Urtica dioica		+	r	+						
Verbena hastata						+				

Office of Research & Strategic Services
395 John Ireland Blvd., Mail Stop 330
Saint Paul, Minnesota 55155

(651) 282-2274