A COMPARATIVE STUDY OF STANDING CROPS AND OF PHOSPHORUS AND NITROGEN CONTENTS OF FOUR MACROPHYTE STREAM COMMUNITIES

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ABSTRACT

A COMPARATIVE STUDY OF STANDING CROPS AND OF PHOSPHORUS AND NITROGEN CONTENTS OF FOUR MACROPHYTE STREAM COMMUNITIES

By

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Four 100 meter study sections were chosen in three Michigan streams to evaluate the influence of varying levels of eutrophication upon submerged macrophyte communities. Choice of study sites was based upon appearance of the streams and prior estimates of physical, chemical, and biological parameters.

Phosphorus content within plant tissue reflected concentrations in the water. The percentage of phosphorus in tissue was high in spring, but could not be shown to change significantly during the latter part of the growing season. Nitrogen content in tissues appeared to remain at levels required to maintain constant N:P ratios rather than reflect water concentrations.

The size of standing crop seemed to be influenced more by stream morphology within the study site than by levels of enrichment. However, percent deviation of organic standing crop from the May 1 to October 1 average

in each stream increased directly with apparent increased eutrophication: August deviations of 8%, 60%, 130%, and 280% were recorded at the sites, listed here in order of increasingly eutrophic status.

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INTRODUCTION

Tissue analyses of aquatic plants have been widely reported in the past (Schuette and Hoffman, 1921; Schuette and Alder, 1927, 1929; Harper and Daniel, 1934; Misra, 1938; Gorham, 1953; Anderson et al., 1965; Boyd, 1969b). Factors affecting these tissue levels have also been investigated. The extent to which tissue content reflects environmental concentrations has been evaluated in the field by Weatherly (1955) and under laboratory conditions by Gerloff (1966). Likewise, the influence of season upon these levels has been investigated in lakes: in a June-September study Gerloff (1969) reported nitrogen and phosphorus levels in plant tissue, and Caines (1965) monitored plant phosphorus levels before and after fertilizing a small lake.

Edwards and Owens (1960) and Owens and Edwards (1961, 1962) have reported on productivity studies of aquatic plants in streams, but until recently productivity determinations and tissue analyses have been conducted independently. Forsberg (1960) and Boyd (1969a) investigated both of these factors in lakes, and Stake (1967,

1968) studied a small polluted stream well colonized by emergent macrophytes.

In this study, streams of differing water quality were chosen in an attempt to evaluate the influence of eutrophication upon seasonal changes in standing crop and upon the nitrogen and phosphorus content in tissues of submerged macrophyte communities. An underlying objective was to test the feasibility of using these parameters as indicators of degree of eutrophication.

DESCRIPTION OF STUDY SITES

Three rivers in Michigan with varying nutrient levels were chosen for this study. Four 100 meter long stations, each supporting macrophyte communities considered representative of the stream type in which it was located, were established as follows: (1) the headwaters of the Jordan River, representing pristine water conditions; (2) the still unpolluted lower reaches of the Jordan River, flowing through an area of few farms and few cabins; (3) a site on the AuSable River, located in the recovery zone (Brege, 1969) of a sewage treatment plant for a community of 2,000, nine river km upstream; and (4) a site on the Red Cedar River, representing poor water quality conditions. In contrast to the three other sites, the Red Cedar is located in southern Michigan where population densities are high and soils have a relatively greater clay content. The water is colored, often turbid, and oxygen levels below 1 mg/liter are common in the summer months. Pertinent water parameters for these sites are given in Table 1. Location and configuration of study sites are presented in the Appendix, Figures A1-A4.

TABLE 1. Physical and chemical water parameters at study sites during growing season (collected 4/12, 5/3, 5/31, 6/26, 8/11, 9/4, 9/25/70).

River	Physical (m)			Chemical (mg/liter) [average (range)]			
	width	depth					
	most freq.	most freq.	seasonal fluct.	hardness	solids	NO_3-N	total phosphorus
upper Jordan	13-16	0.4-0.8	0.01	182 (164-195)	199 (187-210)	0.72 (.59-.84)	0.03 (.01-.05)
lower Jordan	12-15	0.6-1.0	0.05	182 (171-201)	210 (198-220)	0.55 (.29-.64)	0.04 (.01-.09)
AuSable	20-25	0.5-1.0	0.13	149 (132-166)	187 (155-239)	0.10 (.06-.23)	0.05 (.03-.08)
Red Cedar	15-18	1.0-1.5	1.00	334 (263-399)	551 (456-646)	1.19 (.20-2.21)	0.48 (.15-1.14)

METHODS

The boundary of a plant bed is often indistinct, and an estimation of bed size can be a decidedly subjective decision. Methods were used to give an unbiased estimate of the percent stream bottom occupied by a given species and also to minimize the number of sampling points required for a reliable estimate of standing crop.

Each study site was mapped using a plane-table, and total surface area was estimated with a compensating polar planimeter. Since, except for the AuSable, vegetation existed only along the shoreline, a boundary of the area to be sampled at each site was permanently established, and was defined as that line outside of which little plant growth would be likely to occur at any time during the growing season. The proportion of the site included in the sampling zone was then determined, and this constant was used to convert standing crop and cover estimates from a sampling zone basis to a total site basis. Percent cover within the sampling zone was estimated from the quotient of samples containing a given species and the total number of samples taken. Standing crop within colonized areas of the stream was estimated from only those samples containing a given species.

Heterogeneity of plant growth made a large number of samples desirable, yet minimum disturbance was needed to reduce bias for subsequent estimates. The number of sampling points, randomly located by means of a grid, was set at about 100, and a circular sample area of $0.02m^2$ was used. Since plant distribution was more homogeneous at the AuSable site, the area per sample was increased to $0.09m^2$, and the number of samples reduced to 30-36.

This aquatic macrophyte study was confined to submerged species. Therefore, the few scattered emergent species present (*Typha* sp., *Iris* sp., *Nasturtium* sp., sedges) were not collected at any site. Material collected was hand washed in tap water, oven dried at 80C for 3-5 days, and weighed to the nearest 0.01 g. Subsamples of each plant species were ground in a Wiley Mill until they were fine enough to pass through a #20 screen (no. mesh per inch). Weighed aliquots of each species were ashed at 550C for 75 minutes for estimates of dry organic weight.

Total phosphorus determinations were made spectrophotometrically by a modification of the vanadomolybdate method of Rickey and Avens (1955). A mixture of nitric and perchloric acids (3:1), to which 2.0 g/liter sodium bromide had been added, was used for digestion of the plant material. According to Lueck and Boltz (1956) sodium bromide reduces interferences from germanium, arsenic, and silicon.

For nitrogen analysis, additional grinding through a #40 screen was required. Aliquots were then analyzed in a Perkin-Elmer Elemental Analyzer. This instrument automatically measures the thermal conductivity of combustion products (CO_2, H_2O, nitrogen) and expresses the elements as percentages of dry weight.

RESULTS

Phosphorus

Per cent phosphorus in dried plant material for all species increased in May, decreased sharply in June, and could not be shown to change significantly during the remainder of the growing season. Differences in phosphorus content in plant tissue reflected the site differences in phosphorus enrichment of the water. Tissue levels for all species common to at least two sites, along with concentrations of phosphorus in the water, are given in Table 2. Phosphorus content of species not common to more than one site are listed in Appendix, Table A1. Estimates of concentrations in the water probably were not representative of averages for time periods at which plants were sampled since each estimate was obtained from a single water sample. However, judging from the average seasonal values of phosphorus concentrations in the streams (Table 1), levels rose progressively from the upper Jordan to the lower Jordan to the AuSable to the Red Cedar. Phosphorus content of the plant tissues from these sites generally increased in the same order. The estimates

TABLE 2. Percent phosphorus in oven dried plant tissue ($\bar{X} \pm 90\%$ C.I.) and phosphorus concentration (mg/liter) in water at four stream sites.

		River					
date	species/water	upper Jordan		lower Jordan		AuSable	Red Cedar
9/21/69	Potamogeton filiformis	.11± .02	<	.14± .02	<	.27± .04	Not
	P. crispus			.32± .28	<	.44± .07	Sampled
	Elodea canadensis	.39	>	.21± .00	<	.35± .17	
2/4/70	WATER	---		.03		.06	---
2/1	P. filiformis			.09± .02	<	.21± .03	Not
	P. crispus			.32± .28	<	.34± .15	Sampled
	E. canadensis			.21± .00	<	.35± .03	
5/3	WATER	.01		.03		.04	0.18
	P. filiformis	.54± .00	>	.50± .00	<	.54	No
	P. crispus			.48		.53± .02	Vege-
	E. canadensis	.38± .09	>	.24± .04	<	.51	tation
5/31	WATER	.05		.09		.07	.35
	P. filiformis	.22	<	.27± .03	<	.39± .06	No
	P. crispus			.34	<	.38± .04	Vege-
	E. canadensis	.32± .38	>	.27± .01			tation

6/27	WATER	.04		.04		.02		.27
	P. filiformis	.18	>	.16± .01	<	.23± .02		No
	P. crispus			.42± .29	>	.31± .25		Vege-
	E. canadensis	.32± .45	>	.29± .10	<	.40± .00		tation
7/29	WATER	.02		.01		.06		.47
7/23	P. filiformis	.25± .67	>	.21± .06	<	.22± .04		
	P. pectinatus							.56
	P. crispus			.51± .25	>	.45± .08	<	.94± .09
	E. candensis			.30± .06	<	.62		
	E. nuttalli							.90± .37
8/11	WATER	.03		.03		.06		.86
	P. filiformis	.14± .08	<	.18± .05	<	.23± .04		
	P. crispus			.37± .51	>	.28± .13	<	.77± .13
	E. canadensis	.28	>	.21± .09	<	.38± .16		
	Hippuris vulgaris	.14± .04	<	.24± .02				
9/22	WATER	.01		.01		.03		.15
	P. filiformis	.12± .06	<	.15± .03	<	.26± .06		
	P. crispus			.30± .25	<	.56± .23	<	1.21± .30
	E. canadensis	.23± .08	<	.24± .09	<	.35± .09		
	E. nuttalli							1.54± .38
	H. vulgaris	.12± .05	<	.24± .06				

which did not follow this order were usually obtained from a single tissue sample or from highly variable samples.

Variance at a given date and site depended upon the species involved: *Potamogeton filiformis* Pers. and *Hippuris vulgaris* L., both characterized by fleshy tissues, showed less variability than *Potamogeton crispus* L. and *Elodea canadensis* (Michx.) Planchon, whose supporting tissues more noticeably alter with physiological age.

Nitrogen

Percent total nitrogen in dried plant material was initially high in May, but decreased continually during the growing season at all sites. These estimates, along with nitrate and ammonia concentrations in the water, are given in Table 3 for all species common to more than one study site. Nitrogen levels in the tissues of *P. filiformis* were consistently highest in the AuSable, intermediate in the lower Jordan, and lowest in the upper Jordan. There were indications that contents of *P. crispus* followed this same trend. However, nitrate and ammonia concentrations of the water showed a reverse trend.

The ratio of nitrogen to phosphorus in the plant tissue could not be shown to change during the growing season at any of the sites. Although the ratio of nitrogen to phosphorus in the water varied widely between

TABLE 3. Percent nitrogen in oven dried plant tissue ($\overline{X} \pm 1$ SE,n) and NO_3-N/NH_3-N concentration (mg/liter) in water at four stream sites.

		River			
date	species/water	upper Jordan	lower Jordan	AuSable	Red Cedar
9/21/69	Potamogeton filiformis	1.38 ± .15(3)		2.68 ± .03(3)	
	P. crispus		2.74 ± .42(3)	< 3.03 ± .62(2)	< 5.21 (1)
	Elodea canadensis	2.17 (1)	< 2.19 ± .13	< 2.68 ± .39(3)	
	E. nuttalli				4.46 ± .36(3)
2/4/70	WATER		0.53/0.10	0.31/0.14	Not Sampled
	P. filiformis		1.71 ± .05(3)	< 1.75 ± .04(3)	
	P. crispus		1.97 ± .09(2)	< 2.44 ± .42(3)	
	E. canadensis	2.39 (1)	< 2.61 ± .13(3)	> 2.15 ± .02(2)	
5/3	WATER	0.73/0.19	0.29/0.15	0.08/0.22	1.84/0.55
	P. filiformis		2.70 ± .38(2)	< 3.59 (1)	No Vegetation
	P. crispus		2.66 (1)	< 3.52 ± .95(2)	
	E. canadensis	3.43 ± .13(2)	> 2.80 ± .13(6)	< 3.59 ± .01(2)	
5/31	WATER	0.84/1.21	0.55/0.10	0.09/0.02	0.86/1.21
	P. filiformis	2.67 (1)	< 2.98 ± .05(3)	< 4.06 ± .05(2)	No Vegetation
	P. crispus		3.97 (1)	> 3.82 ± .09(3)	
	E. canadensis	3.12 (1)	> 3.02 ± .03(3)	> 2.98 ± .06(3)	

6/26	WATER	0.65/0.18		0.55/0.03		0.06/0.02		0.93/0.63
	P. filiformis	2.25 (1)	<	2.51± .13(2)	<	2.76± .11(3)		No
	P. crispus			3.05± .91(2)	>	2.68± .02(2)		Vege-
	E. canadensis	3.70± .30(2)	>	2.25± .25(3)	<	3.24 (1)		tation
	Hippuris vulgaris	2.78 (1)	<	3.04 (1)				
7/19	WATER	0.69/0.01		0.57/0.02		0.07/0.04		1.32/0.37
	P. filiformis			2.23± .13(3)	<	3.03± .05(3)		No
	P. crispus			2.98± .16(2)	<	3.21± .33(2)		Vege-
	E. canadensis			2.85± .23(3)	<	4.05 (1)		tation
8/11	WATER	0.59/0.04		0.56/0.04		0.07/0.07		0.46/1.28
	P. filiformis	1.80± .23(2)	<	1.97± .02(3)				Not
	P. crispus			2.63± .20(2)	<	2.75± .07(2)		Sampled
	E. canadensis	3.53 (1)	>	2.43± .16(3)	<	3.69± .16(2)		
	H. vulgaris	1.96± .13(2)	<	2.69± .03(2)				
9/25	WATER	0.69/0.36		0.64/0.16		0.10/0.26		2.21/0.21
	P. filiformis	1.83± .04(2)	<	1.89± .11(2)	<	3.00± .19(2)		
	P. crispus			3.35 (1)	>	3.73± .19(2)	<	4.80± .13(2)
	E. canadensis	2.83± .17(2)	>	2.68± .38(2)	<	4.36± .48(2)		
	E. nuttalli							4.42± .10(2)
	H. vulgaris	2.13± .14(2)	<	2.87± .36(2)				

sites, this ratio remained constant in the tissues of a given species (see Table 4).

Standing crop

Species composition and standing crop estimates, calculated on an entire site basis, are presented in Figures 1-4. These estimates are functions of two factors: percent stream bottom colonized by aquatic plants and density within these colonized areas. At any given date standing crop differences between sites were attributed primarily to differences in the percentage of stream bottom colonized by plants. These differences in amount of cover, presented in Figure 5, appeared to be not as closely related to levels of enrichment as to other factors, such as stream configuration, flow rates, and turbidity. Specifically, the upper Jordan (pristine, but shallow, with areas of slow flowing water) supported a greater biomass than the lower reaches of the Jordan (deeper, with a fast flowing straight channel); the AuSable (third most eutrophic site) did support the greatest biomass, but the Red Cedar (extremely eutrophic and turbid) contained the least.

Since the establishment and growth of a plant community are influenced by factors other than nutrient availability, standing crop estimates based only upon colonized portions of the stream could tend to mask these other influences and better reflect enrichment levels.

TABLE 4. Seasonal ratio of nitrogen to phosphorus of species common to more than one site and of water, calculated from the mean values of each collection date. $\overline{X} \pm 1$ SE (n)

species/water	Stream			
	upper Jordan	lower Jordan	AuSable	Red Cedar
Potamogeton filiformis	13 ± 1 (5)	12 ± 2 (7)	10 ± 1 (7)	
P. crispus		8 ± 1 (8)	8 ± 1 (8)	4 (1)
Elodea canadensis	10 ± 1 (6)	11 ± 1 (8)	8 ± 1 (7)	
Hippuris vulgaris	14 ± 1 (4)	11 ± 0 (3)		
Water	38 ± 11 (6)	27 ± 9 (7)	2 ± 1 (7)	15 (1)

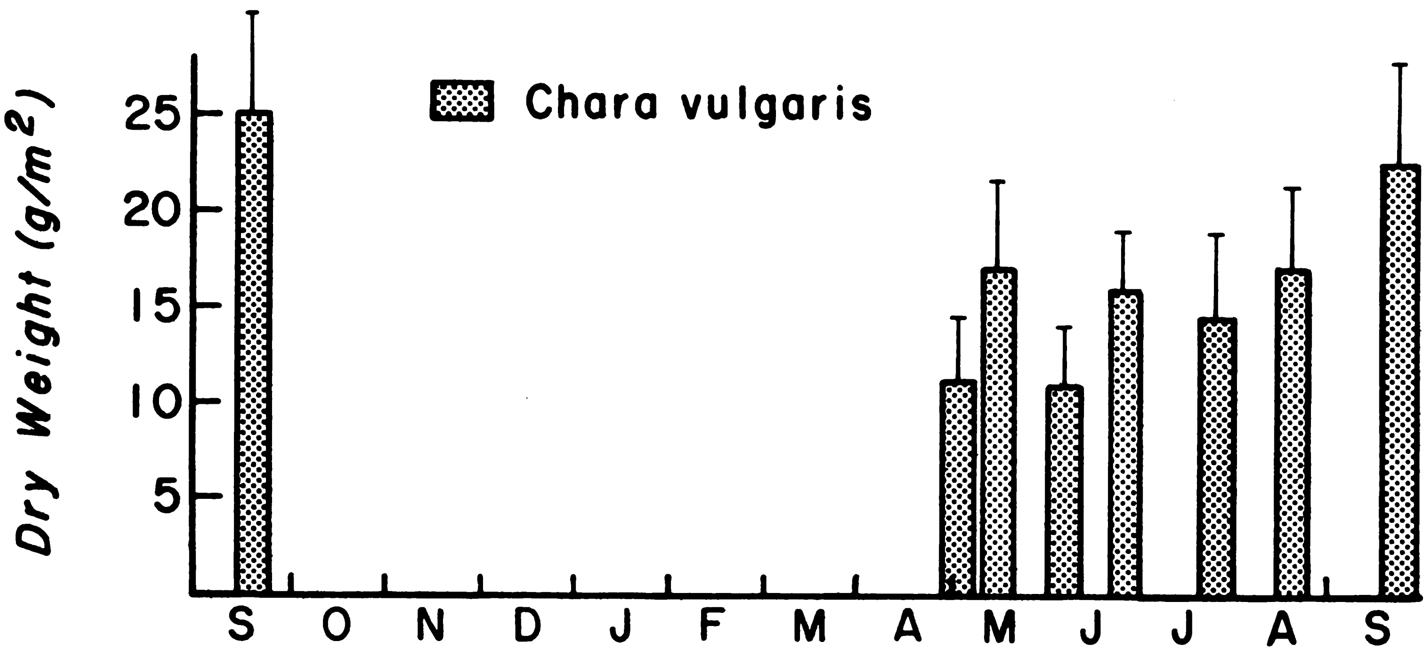

Figure 1. Species composition and dry weight standing crop for total study site in upper Jordan River. ($\bar{x}$ + 1 SE)

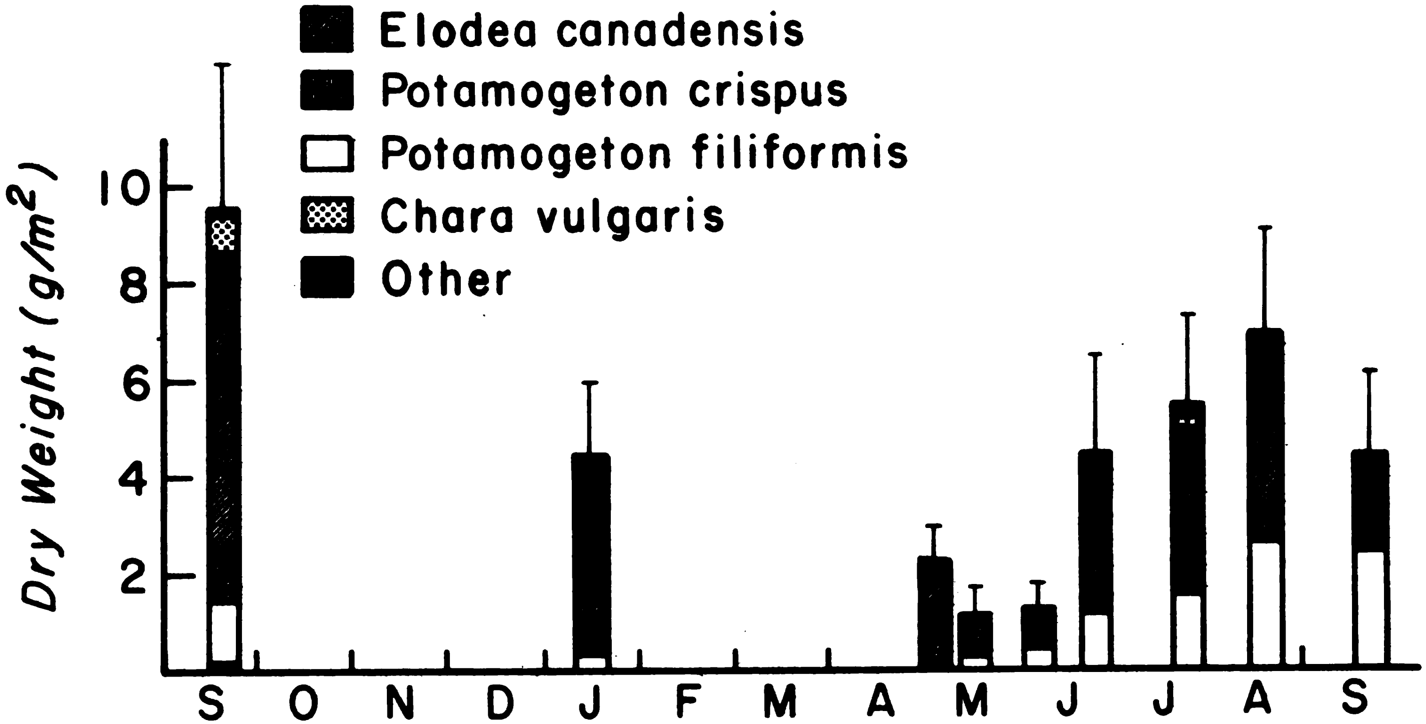

Figure 2. Species composition and dry weight standing crop for total study site in lower Jordan River. ($\bar{x}$ + 1 SE)

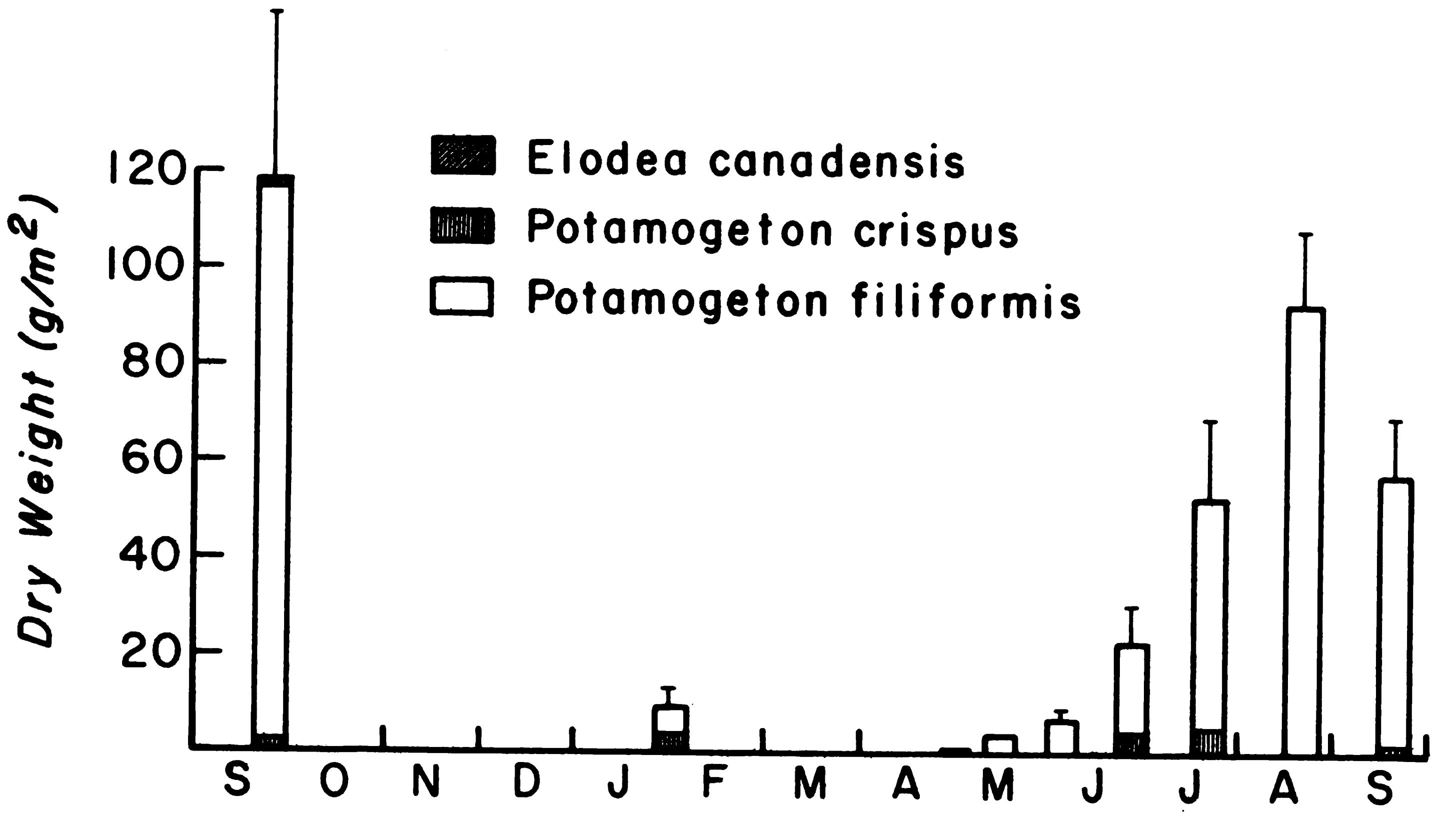

Figure 3. Species composition and dry weight standing crop for total study site in AuSable River. ($\bar{x}$ + 1 SE)

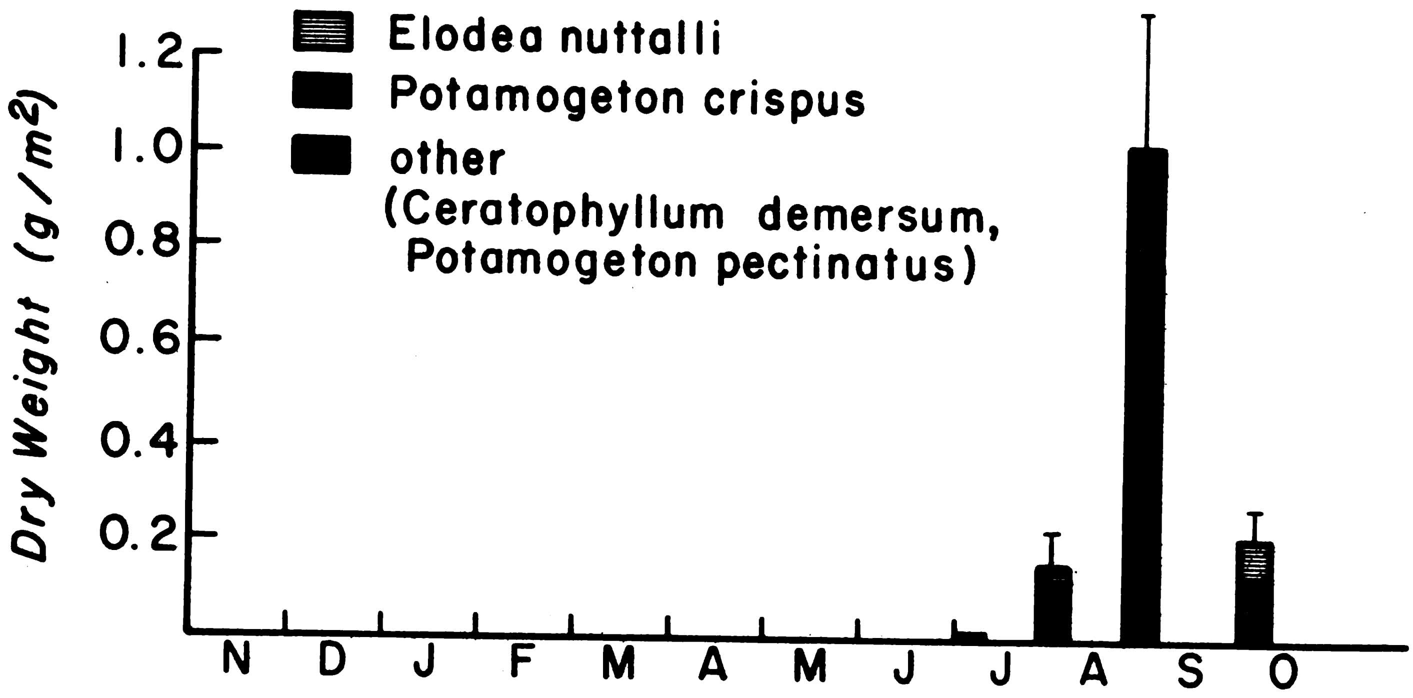

Figure 4. Species composition and dry weight standing crop for total study site in Red Cedar River. ($\bar{x}$ + 1 SE)

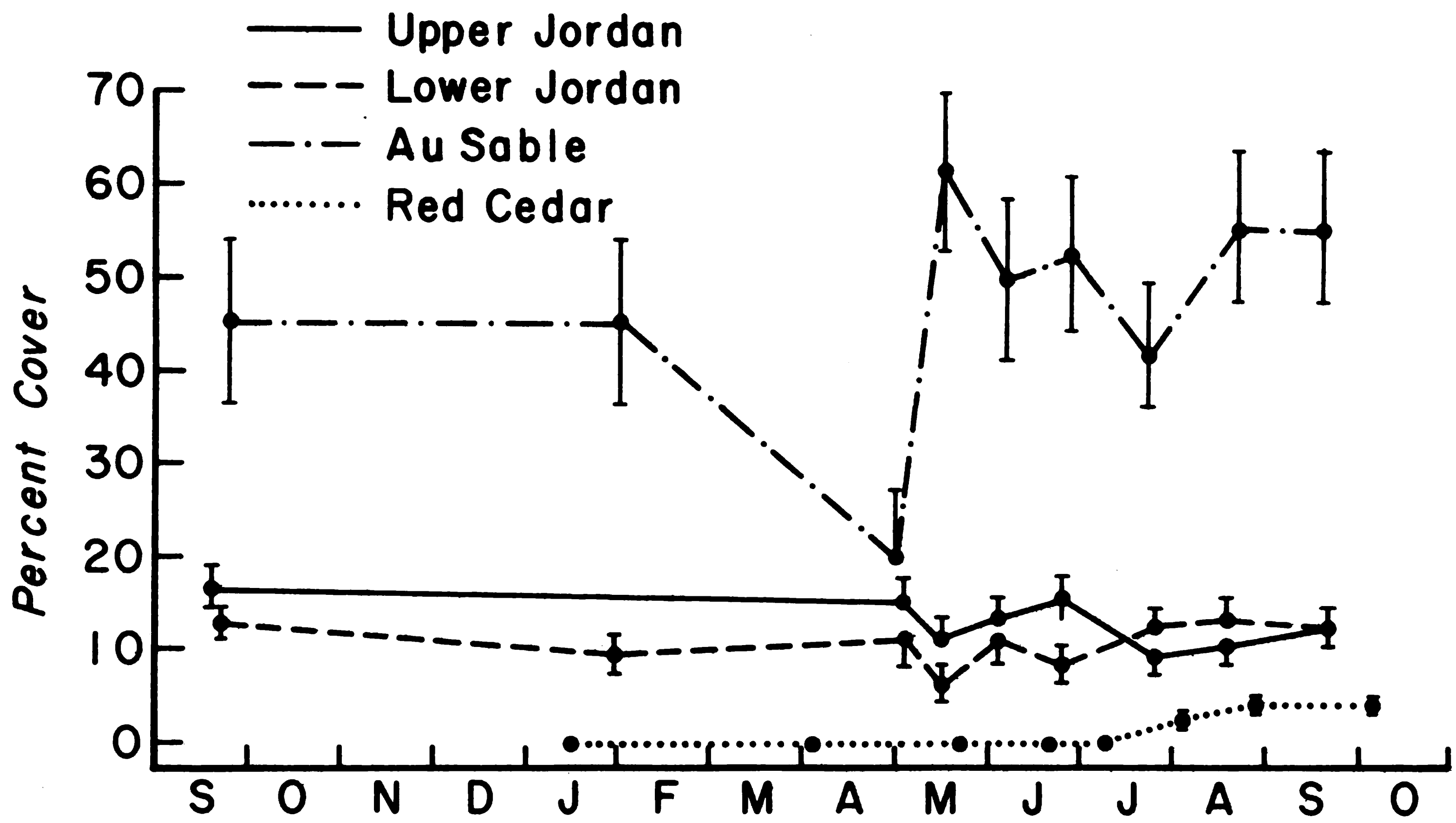

Figure 5. Percentage estimates of proportion of stream bottom colonized by submerged macrophyte communities in four study sites. ($\bar{x}$ ± 1 SD)

Therefore, estimates based only upon samples containing aquatic plants were calculated (see Figure 6). However, these values also appeared to be substantially influenced by factors other than eutrophication, although to a lesser extent than values computed on an entire site basis. The peripheral portions of the plant beds appeared to exist under marginal conditions resulting from increased flow rates and reduced available light.

After the onset of spring growth, percent cover remained more constant than plant density within beds. The relative stability of the two factors was quantified by correlating each with standing crop of the site as a whole. Table 5 illustrates that seasonal changes of plant density within a study site were consistently more closely related to density within beds than to changes in percentage of stream bottom supporting vegetation.

Seasonal fluctuations in the standing crop of organic plant material were calculated on the basis of percent deviation at a given date from the seasonal (May 1 to October 1) average. In this way only the relative stability of the plant communities was compared. Although biomass alone did not closely reflect nutrient levels, the degree of seasonal stability did appear to decrease with increased eutrophication (see Figure 7). The plant community in the upper Jordan site remained stable, that of the lower Jordan experienced minor fluctuations, the AuSable plant community showed great seasonal change, and

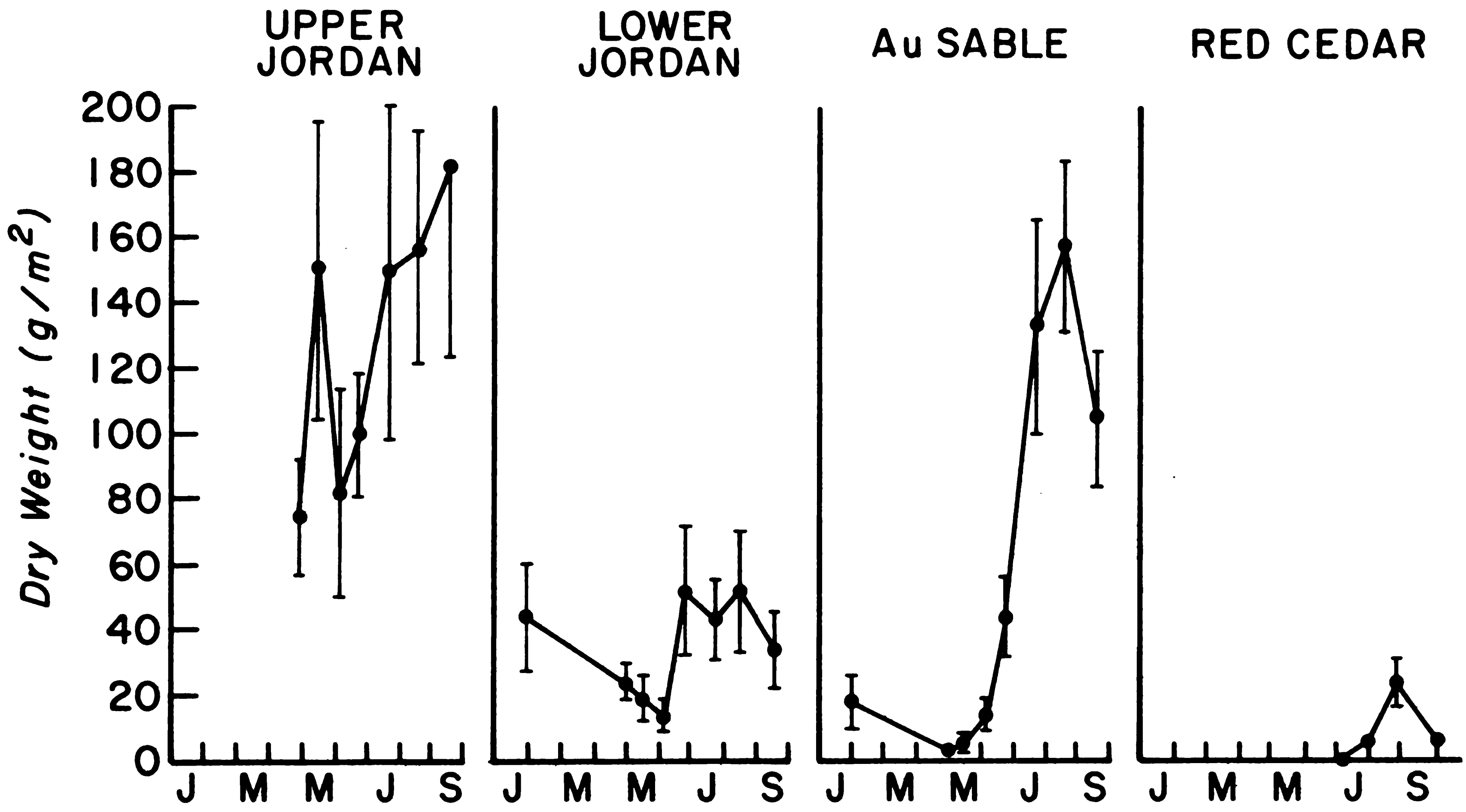

Figure 6. Submerged macrophyte dry weight standing crops for colonized portions of four stream sites. ($\bar{x} \pm 1$ SE)

TABLE 5. Correlation coefficients (r) of seasonal changes in dry weight standing crops to density within colonized areas and to percent stream bottom colonized with plants.

	River											
	upper Jordan			lower Jordan			AuSable			Red Cedar		
species	density within beds		cover	density within beds		cover	density within beds		cover	density within beds		cover
All combined	.75	>	.23	.96	>	.63	.98	>	.18	1.00	>	.60
Potamogeton filiformis	.89	>	.87	.94	>	.75	.97	>	.34			
P. crispus				.77	>	.68	.71	>	.44	1.00	=	1.00
Elodea canadensis				.97	>	.46	.74	>	.33			
E. nuttalli										.96	<	1.00
Chara vulgaris	.64	>	.36									

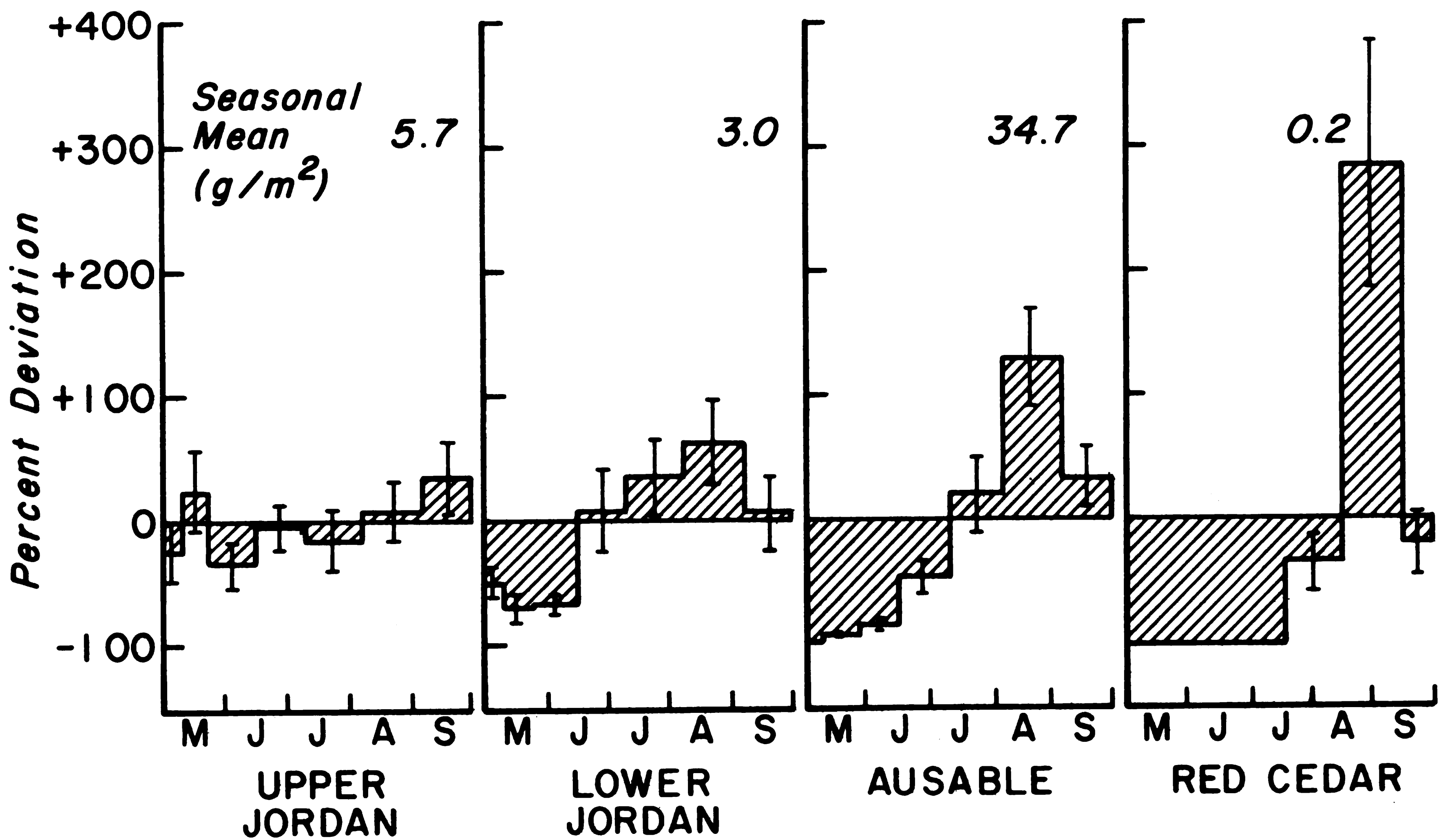

Figure 7. Percent deviation of standing crops of organic plant material from May 1 to October 1 average in plant communities of four stream sites. ($\bar{x} \pm 1$ SE)

the Red Cedar remained barren except for a brief period of growth late in summer.

Dry organic weights as percentages of dry weights for individual species were not sufficiently altered by changes in season or stream water quality to warrant comparison of sites. Values are included in Appendix, Table A2.

When comparing one site with another, differences in phosphorus standing crop (mg P/m^2) were a function primarily of macrophyte biomass rather than of phosphorus content of the plant tissue. Similarly, percent deviations in the phosphorus standing crop from a seasonal average were almost identical to the deviations in organic standing crop (Figure 7) with the exception that there was a minor dampening in these fluctuations due to high phosphorus content in spring when dry weight standing crop was low. There was no indication that the degree of dampening was a response to changes in eutrophication levels. Standing crop of phosphorus within plant tissue is presented in Appendix, Table A3.

DISCUSSION

Phosphorus content in plant tissue

Phosphorus content in a plant species is a function of physiological age and condition and of nutrient availability (Smith, 1962). In this study the phosphorus levels in tissue increased directly with total phosphorus concentration in the water, but this could not generally be shown with statistical reliability because of high variance. A great proportion of this variance is believed to result from variability in plant condition. Random sampling was required for a reliable estimate of standing crop of phosphorus. The disadvantage of this technique was that by not selectively sampling vegetation of a given physiological condition, the chances of detecting environmentally induced differences were reduced. Eliminating this variable would probably increase the reliability of using phosphorus content in plant tissue as an indicator of phosphorus levels in a stream.

Data in this study suggest that the most opportune time to apply an index of this type would be late in the growing season when tissue concentrations of the submerged aquatic plants are most stable. This relative stability has also been indicated in studies by Gerloff and Krombholz (1966) and Caines (1965). Stake (1968) suggested that this period of stability applies to submerged species more than to emergents, which generally have more extensive underground parts. Boyd (1968) indicated that edaphic factors influence growth of many species although the extent of dependency upon the substrate for mineral nutrients is unknown. Hillman (1961) reported that roots of the floating aquatic *Lemna minor* probably have little influence in mineral uptake. Considering these observations, it seems likely that the use of tissue analysis as an indicator of stream enrichment might most reliably be applied to floating species or submerged species with reduced roots systems.

Another consideration in the choice of species would be variability of mineral content within a given species. These data suggest that species with a greater proportion of fleshy tissue exhibit less variability than species with a high percentage of cellulose fiber. If this is true, use of a species with limp stems and leaves as an indicator would increase the chances of detecting small differences with statistical reliability.

For long range predictions of detrimental effects before they actually happen, comparative studies involving analysis of submerged aquatic plant tissue of a given physiological condition could yield beneficial results.

Nitrogen content in plant tissue

In this study percent nitrogen within plant tissue did not reflect nitrate or ammonia levels in the water. On the contrary, nitrogen content of the tissue seemed to be more closely correlated to phosphorus content. The ratio of nitrogen to phosphorus remained stable within the plants at all sites in spite of great variations of this ratio in the water. Similar nitrogen to phosphorus ratios in aquatic plant tissue were reported by Schuette and Alder (1929), Harper and Daniel (1939), Gerloff and Krombholz (1966), and Boyd (1968).

Since water analyses for organic nitrogen were not performed in this study, no conclusions can be drawn involving total nitrogen concentrations in the water. However, tissue analyses for total nitrogen appear to be a most unreliable indicator of nitrate or ammonia levels within the water. Tissue levels could be expected to better reflect water concentrations in macrophyte communities where nitrogen is a limiting factor, but luxury consumption of nitrogen was not demonstrated in this study.

Standing crop

Biomass is thought to be less affected by eutrophication than by other physical parameters, such as solar radiation (Owens and Edwards, 1961), stream configuration, depth, and flow rate (Butcher, 1933). By sampling the same 100 meter sections on each collection date the reliability of the biomass estimate, as representative of a given stream type, depended upon the subjective choice of a "typical" section to study. On the other hand, by studying the same section on a yearly basis, the chances for a more accurate estimate of the degree of seasonal fluctuation were increased.

Standing crop estimates based on an entire site basis need not closely reflect levels of enrichment because of physical parameters affecting establishment and growth of plant species. Estimates based only upon areas containing vegetation also appeared to be affected by stream geometry, although to a lesser extent. From gross appearances it seemed that flow rate, which prevented growth completely in midstream, inhibited growth at the fringes of the community. It is expected that other physical parameters would similarly affect colonization by a species. For these reasons I do not believe that, under uncontrolled conditions, comparative studies of standing crops alone can produce a useful index to eutrophication. However, when the data were analyzed on the basis of percent deviation from the seasonal average of each site, the indications were that degree of plant community fluctuation did more closely reflect levels of enrichment in a stream. The extent to which other parameters affected these values is unknown and would require further study.

An unresolved question was the influence of species interaction in these fluctuations. Must an index based upon degree of standing crop fluctuation necessarily be applied at the species level or can this reliably be accomplished on a community level? This study did not lend itself well to answering that question, since all the communities, except that of the lower Jordan, were essentially monospecific. However, a comparison of the lower Jordan and AuSable Rivers suggests that species interactions affect the seasonal stability of a plant community. The AuSable community was composed primarily of *Potamogeton filiformis*, while the lower Jordan was dominated by *P. filiformis* and *Elodea canadensis*. The estimates of percent deviation in organic biomass from the May 1 to October 1 average for these species (Figure 8) indicated that the seasonal fluctuation of *P. filiformis* was greater in the AuSable than in the less eutrophic lower Jordan. On a community level, however, fluctuations in the lower Jordan were less than in the AuSable more by reason of species interaction than by differences in fluctuation of the one species common to both streams. The increased stability resulted from seasonal differences in the growth cycle of the two species. Butcher (1933) also reported that *E. canadensis* overwintered longer than many *Potamogeton* species. Further investigation should be made into the importance of species interaction in

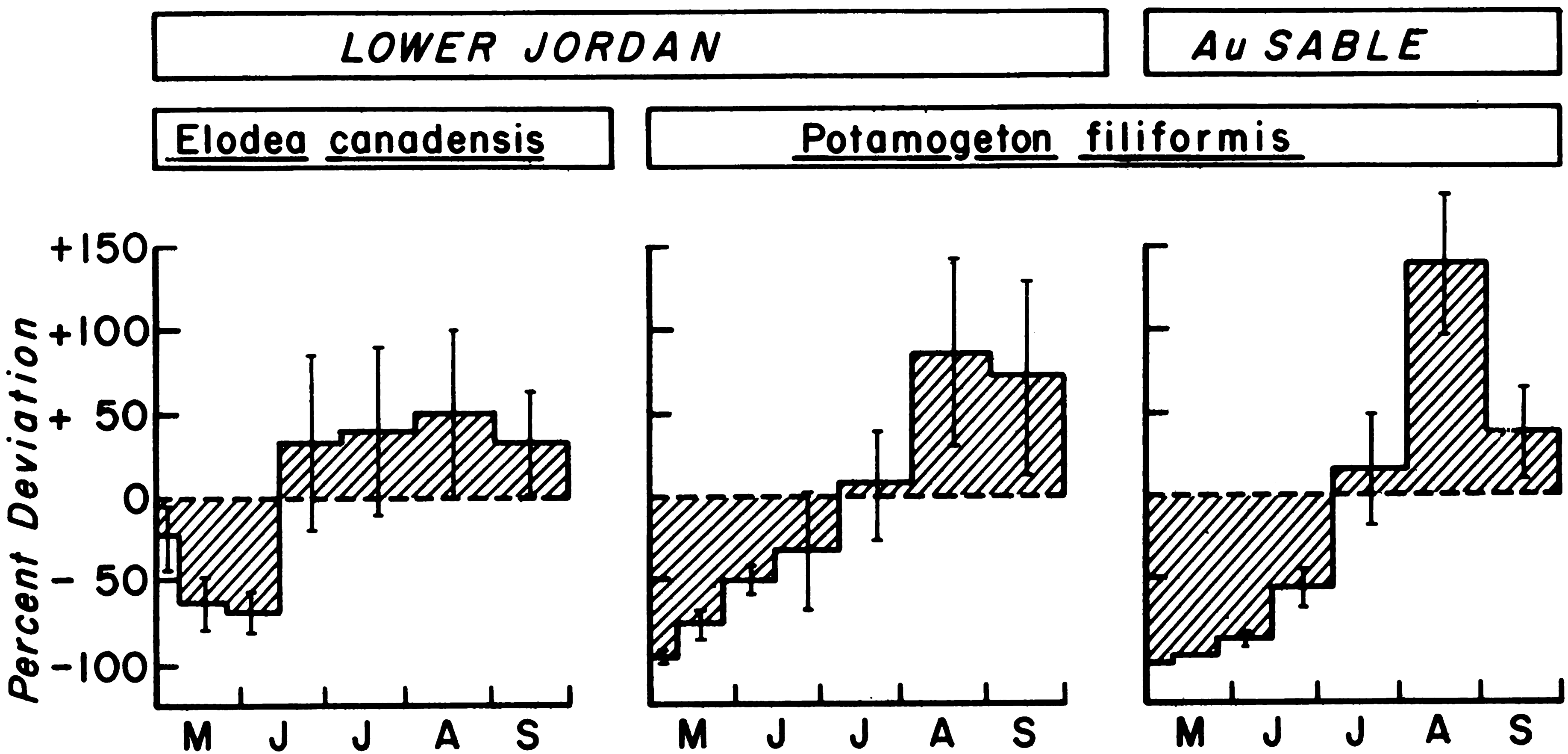

Figure 8. Percent deviation of standing crops of organic plant material from May 1 to October 1 average for selected species. ($\bar{x} \pm 1$ SE)

community stability. Possibly, at given levels of enrichment, a plant community would select for a species composition which would exhibit a predictable amount of seasonal fluctuation.

Few stream studies involving seasonal changes in submerged macrophyte biomass have been reported. Edwards and Owens (1960) reported a June-September increase of 220% in an unpolluted stream and (Owens and Edwards, 1962) a May-July increase of 500% further downstream where nutrient levels were higher. Stake (1967) studied a small enriched creek, primarily with emergent vegetation. There *Potamogeton natans*, though not a dominant species, increased 110% from June to July, and decreased thereafter. On the other hand, Owens and Edwards (1961) suggested that shading had a greater influence on standing crop than did enrichment levels. These studies do not appear to have included sufficient collection dates to obtain reliable estimates of seasonal averages. It is, therefore, difficult to make valid comparisons. They do, however, strongly suggest that any use of percent deviation from a seasonal mean as an index to water quality must, at a minimum, incorporate or be applied under given conditions of latitude, solar radiation, and local geographic factors.

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APPENDIX

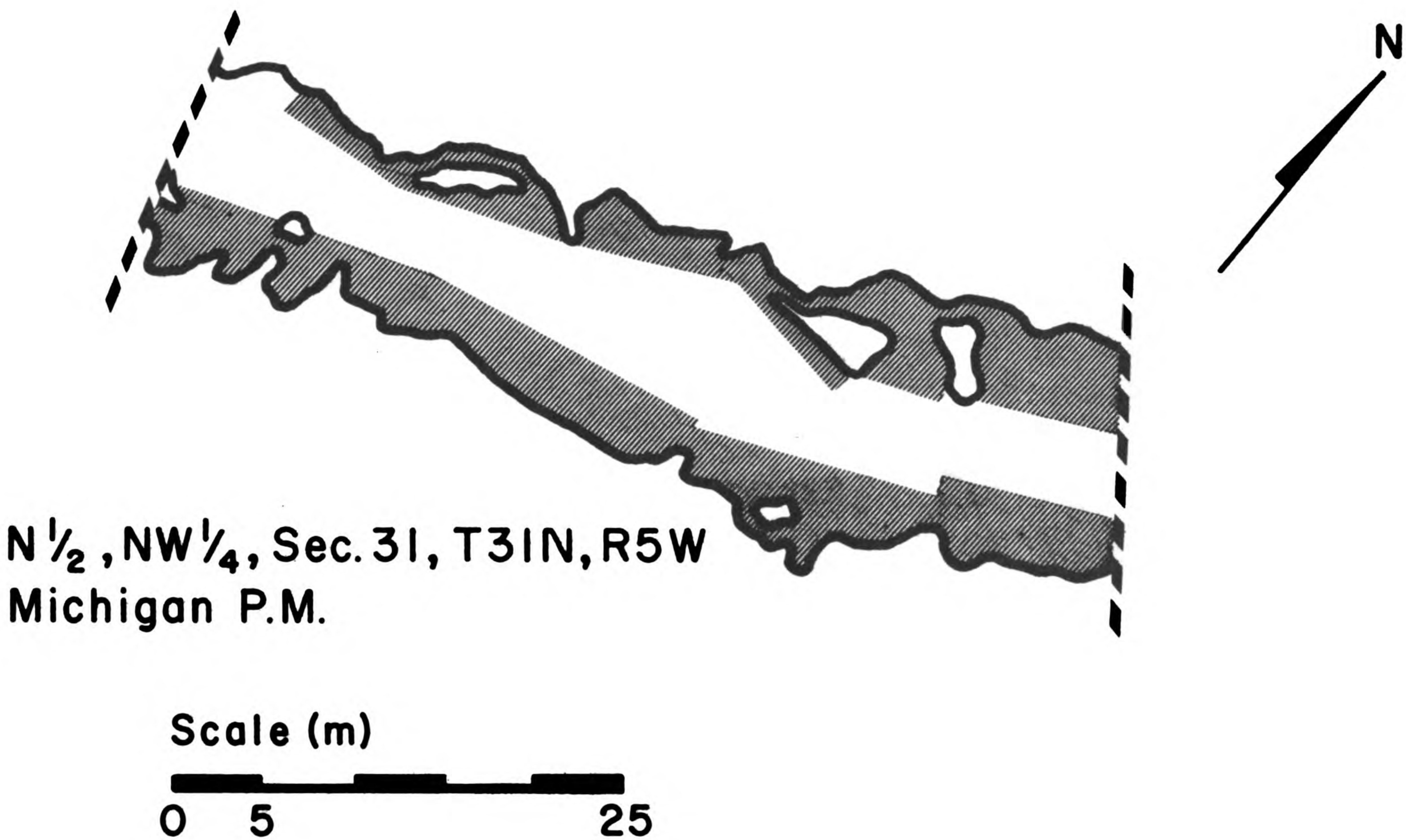

Figure A1. Scale map showing configuration, location, and sampling zones of upper Jordan River study site.

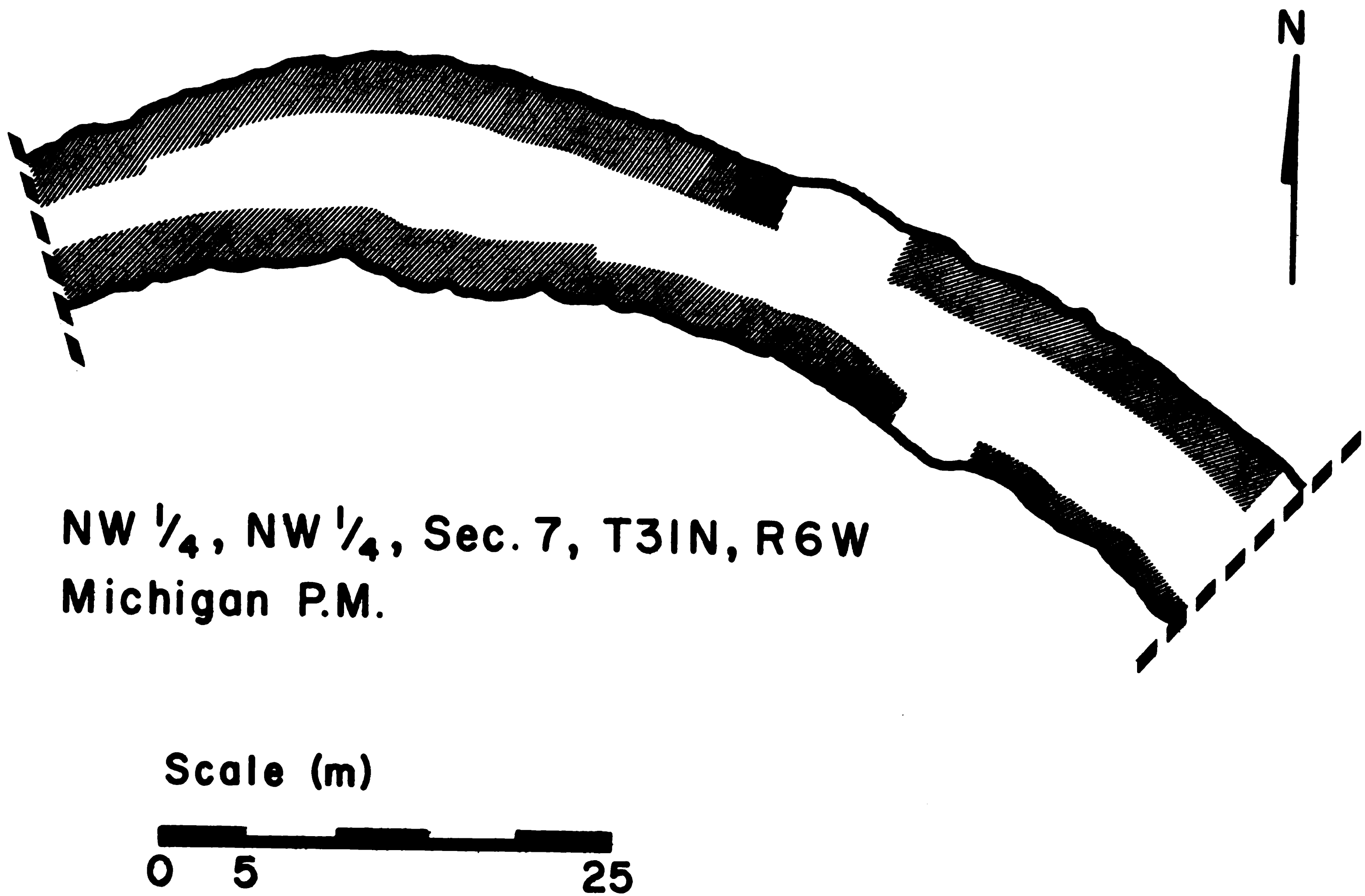

Figure A2. Scale map showing configuration, location, and sampling zones of lower Jordan River study site.

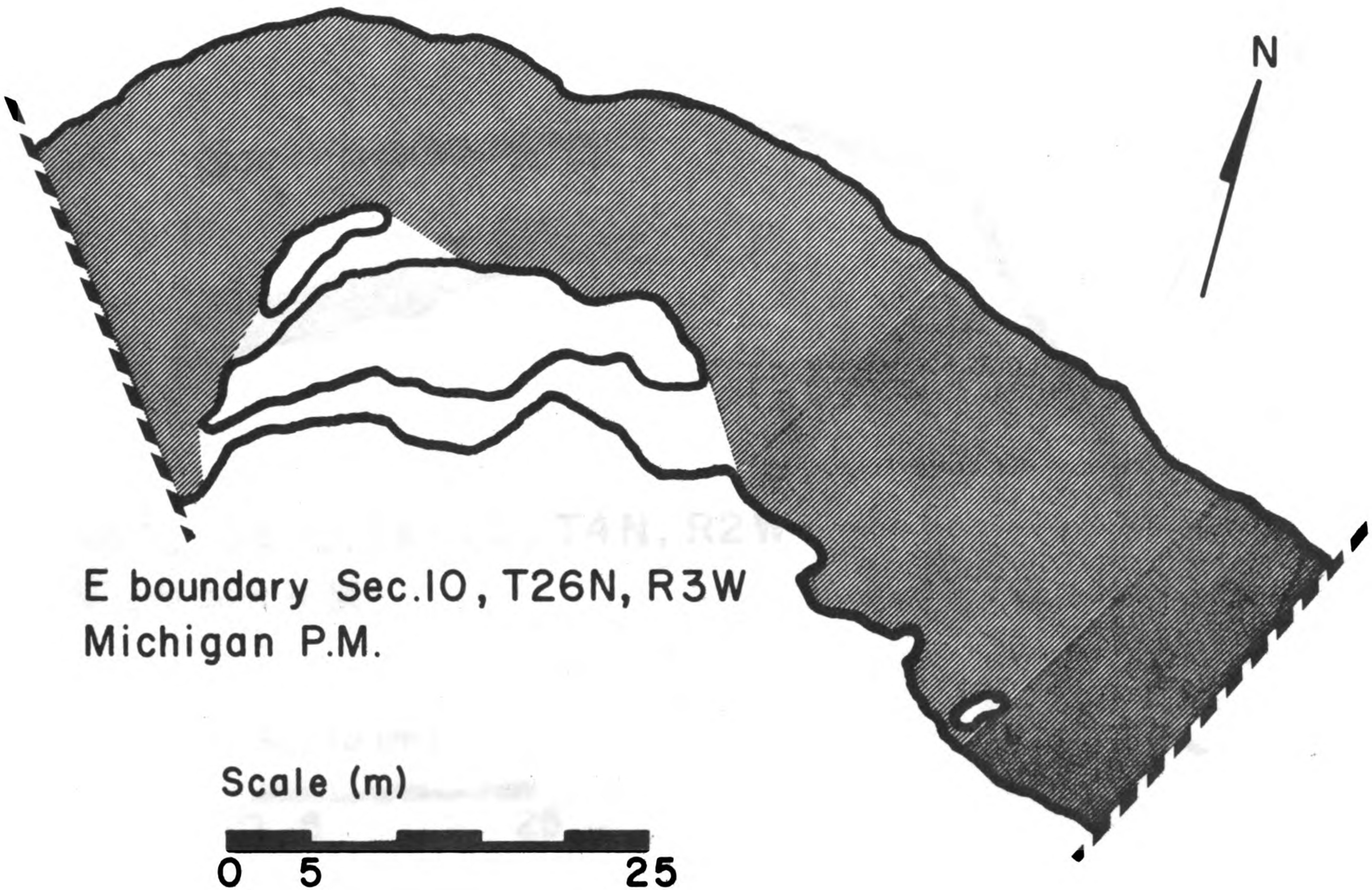

Figure A3. Scale map showing configuration, location, and sampling zone of AuSable River study site.

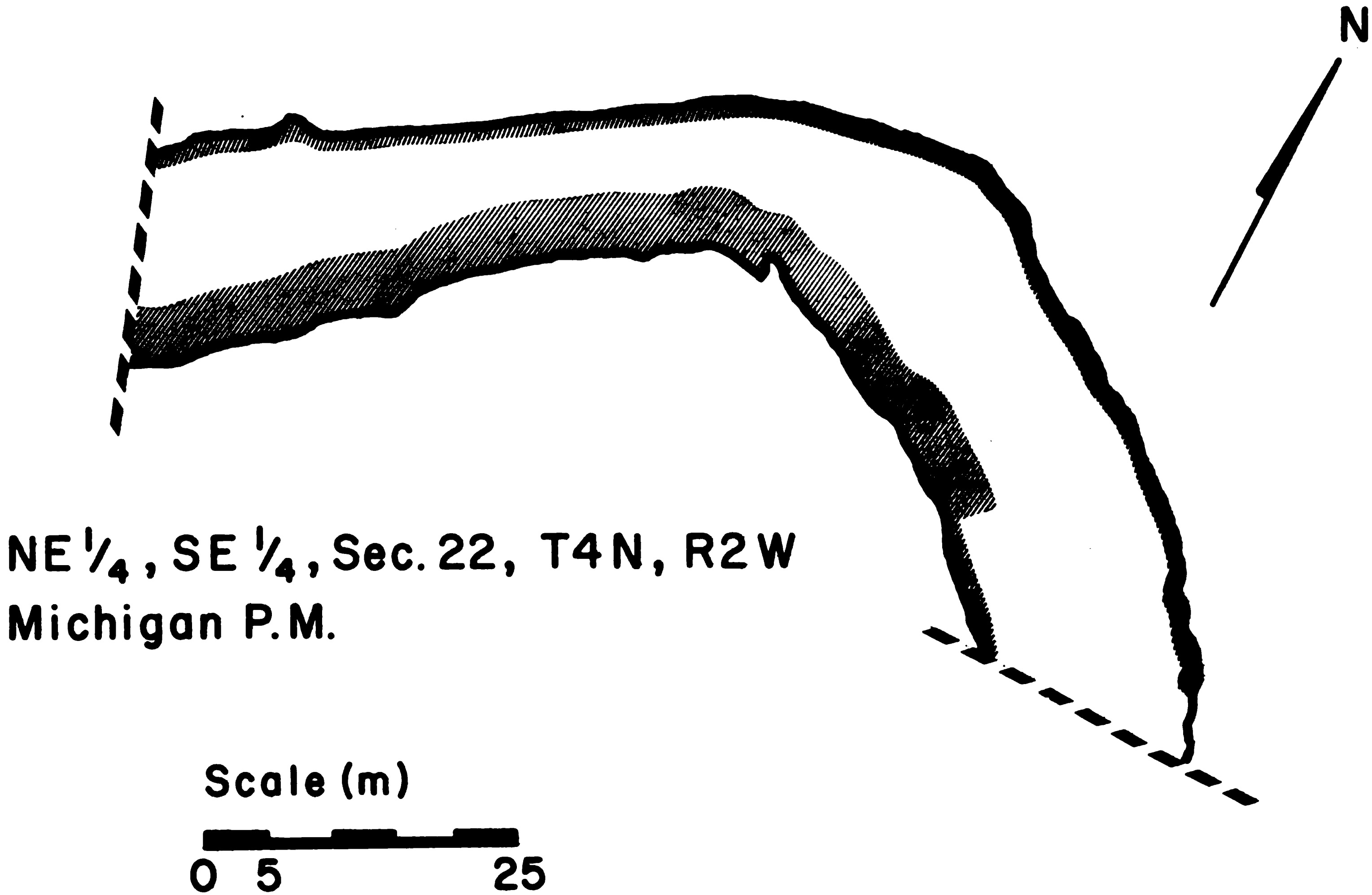

Figure A4. Scale map showing configuration, location, and sampling zones of Red Cedar River study site.

Statistical formulas

1. Estimate of mean and variance for standing crop within colonized areas, percent nitrogen, percent phosphorus, percent phosphorus, and percent ash-free of dried plant material were determined by conventional parametric statistics:

Where

x_i is the i^{th} estimate of parameter in question,

n is number of estimates taken,

$$\text{mean} = \Sigma x_i / n$$

$$\text{with variance} = \sum_{i=1}^{n} (\bar{x} - x_i)^2 / (n-1)$$

2. Standing crop of dried plant material for entire study site was estimated as follows:

Where

b is proportion of total site within sampling area,

N is total number of samples taken,

n is number of samples containing plant material

x_i is dry weight of i^{th} sample (including only those samples containing vegetation),

$p = n/N$

$$\text{mean} = bp\bar{x}$$

$$\text{with variance} = b^2 p \, [s_x^2 \; \bar{x}^2 (1-p)]/N$$

3. Standing crop of phosphorus was estimated as follows:

Where

$\bar{x}$ is estimate of mean dry weight standing crop within entire study site,

$\bar{y}$ is estimate of (mean percent phosphorus in dry plant material)/100

mean = $\overline{xy}$

with variance of the mean = $\bar{x}^2 s_{\bar{y}}^2 + \bar{y}^2 s_{\bar{x}}^2$

4. Percent river bottom colonized by plants was estimated according to the binomial distribution:

Where

b is proportion of total site within sampling zone

n number of samples containing plants

N total number of samples taken

p n/N

mean = bp

with variance = $b^2 p(1-p)/N$

TABLE A1. Percent phosphorus of oven dried plant tissue for species not common to more than one site. $\overline{X} \pm 90\%$ C.I.

species	river[a]	date: 9/21/69	5/3/70	6/5	6/26	7/23	8/23	9/20
Potamogeton pectinatus	D					.56		
Ceratophyllum demersum	D					1.17±.20	1.36±.30	1.32
Ranunculus sp.	B	.31±.80			.23±.03		.46±.15	.37
Chara vulgaris	A	.05±.01	.08±.03	.07±.01	.07±.01	.08±.02	.05±.01	.07±.02

[a] A = upper Jordan; B = lower Jordan; D = Red Cedar.

TABLE A2. Percent ash free weights of oven dried plant material at four stream sites. $\bar{X} \pm 1$ SE (n).

		River			
species	date	upper Jordan	lower Jordan	AuSable	Red Cedar
Potamogeton crispus	9/19/69		72±1(2)	75 (1)	
	2/1/70			76±3(3)	
	5/15			78±6(2)	
	6/5		84 (1)	82±2(3)	
	6/25		76 (1)	81±1(3)	
	7/23		86 (1)	78±2(3)	
	8/19		77±3(3)	76±2(3)	
	9/20		72 (1)	80±3(2)	
P. filiformis	9/19/69		78±2(3)	76±3(6)	
	2/1/70		61±4(4)	63±4(3)	
	5/2		72 (1)		
	5/15	83 (1)		82±0(3)	
	6/5		85 (1)	84±1(4)	
	6/25		81±1(3)	80±2(3)	
	7/23		80±3(3)	80±3(3)	
	8/19	84±0(3)	78±4(3)	85±2(3)	
	9/20	85±1(3)	79±3(3)	80±1(3)	
P. pectinatus	8/1				75 (1)
	8/28				70±1(3)
Hippuris vulgaris	6/25	82 (1)	71±1(2)		
	8/19	83±1(3)	73±3(3)		
	9/20	79±9(2)	73±2(3)		

Elodea canadensis	9/20/69	69 (1)	69±1(4)	71±4(2)	
	2/1/70		66±2(3)		
	5/2		64±3(5)		
	5/15		73±2(3)	47 (1)	
	6/5	82±2(2)	73±2(4)	66±0(2)	
	6/25	72±4(3)	70±0(2)		
	7/23		75±1(2)	76 (1)	
	8/19	76±1(2)	66±0(3)	77±2(3)	
	9/20	81±2(3)	74±2(3)	76±2(3)	
Elodea nuttalli	8/1				79±2(3)
	10/5				76±1(2)
Ceratophyllum demersum	8/1				72±4(2)
	8/28				74±4(2)
	10/5				84 (1)
Chara vulgaris	9/19/69	35±1(4)			
	5/3	38±2(3)	44 (1)		
	5/15	40±2(3)			
	6/6	35±0(3)			
	6/25	34±0(3)			
	7/23	34±2(3)	24 (1)		
	8/19	36±1(3)	35±2(2)		
	9/20	33±1(3)	33±2(3)		

TABLE A3. Standing crops of phosphorus (mg P/m^2) at four stream sites. $\overline{X} \pm 1$ SE.

	River			
date	upper Jordan	lower Jordan	AuSable	Red Cedar
9/21/69	13±3	19±4	328±82	
2/1/70		16±6	23±10	
5/3	9±3	6±1	4± 2	
5/15	14±4	4±1	13± 3	
6/5	7±2	3±1	26± 6	
6/26	11±2	12±4	57±14	
7/23	12±4	15±4	128±33	1.5±0.5
8/23	9±2	13±4	215±40	8.0±2.1
9/20	15±4	8±2	153±33	2.7±0.9