To the Graduate Council:

I am submitting herewith a thesis written by Janice McMahon Harmon entitled "Associations Between Site Characteristics and Plant Biomass and Starch Content of *Myriophyllum spicatum* L. in Melton Hill Reservoir." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

Clifford C. Amundsen, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

A

ASSOCIATIONS BETWEEN SITE CHARACTERISTICS AND PLANT BIOMASS AND STARCH CONTENT OF *MYRIOPHYLLUM SPICATUM* L. IN MELTON HILL RESERVOIR

A Thesis

Presented for the

Master of Science

Degree

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Janice McMahon Harmon

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ABSTRACT

The associations between site characteristics, consisting of both water column and sediment qualities, and total plant biomass and starch content of Myriophyllum spicatum L. was investigated.

Plant and sediment samples were collected monthly from May to September, 1979 in Melton Hill Reservoir near Oak Ridge, TN, U.S.A. Monthly water column data from each site consisted of surface temperature, conductivity and Secchi disk transparency. Sediment samples were analyzed for soil texture, NO_3, available P, available K, organic matter content and pH. Plant samples were analyzed for dry weight, ash content and starch content. Multivariate statistical analyses were used to associate biotic and site variables.

Site variables for two sites located above the Bull Run Steam Plant in the main channel of the reservoir, although statistically significantly different, tended to be similar. Site variables for two sites located below the Bull Run Steam Plant in the main channel of the reservoir, although statistically significantly different, tended to be similar. One site, located in an embayment outside the main channel of the reservoir, had site variables completely distinct from the main channel sites.

Plant biomass at each site was greatest in the shoots, secondly in the roots and lowest in the rhizomes. Seasonal patterns of growth were generally apparent for the shoots, less so for the roots but not apparent for the rhizomes. Root:shoot ratios indicated

that most of the plant growth occurred in the shoots. Starch content of plant samples collected at each site throughout the season was greatest in the rhizomes, roots and shoots, respectively. Rhizomes may function as organs for starch storage. Total biomass and total starch content were greatest at the embayment site.

Patterns revealed by canonical correlation analysis associated water surface temperature and Secchi disk transparency with biomass change and starch content in this study.

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I. INTRODUCTION

The weedy growth form of *Myriophyllum spicatum* L., a submersed rooted aquatic angiosperm, can seriously impinge upon the aesthetic and economic values of a water body (Smith et al., 1967). Problems typically caused by *M. spicatum* result from the large amounts of plant material that it produces near the water's surface (Grace and Wetzel, 1978). Attempts at eradication have proven futile and expensive (Harmon and Amundsen, in press). Control, not eradication, of *M. spicatum* has become the focus for researchers and waterway managers.

Mechanical harvesting of the above-sediment plant material has been one of the major available control techniques for this aquatic plant (Harmon and Amundsen, in press). A main drawback to extensive use of this technique originates from *M. spicatum*'s ability to successfully resprout from its root crowns. It has proven necessary to harvest several times per growing season to keep an area free of the plant stands. Subsequent years' growth has not been appreciably affected by prior seasons of harvesting (Nichols, 1971). It is necessary to negatively influence the roots and rhizomes of *M. spicatum* before mechanical harvesting can have a lasting effect on regrowth of the plant.

The role of the rooted organs of submersed aquatic vascular plants has been thought to range from merely providing anchorage (Den Hartog and Segal, 1964) to functioning in capacities similar to terrestrial vascular rooted organs (Grace and Wetzel, 1978; Bristow, 1975; Sculthorpe, 1967). Very little information exists on the below-sediment biomass of submersed aquatic vascular plants (Ozimek, 1976). Even less has been reported on the role of rooted organs in storing carbon in the form of starch (Titus and Adams, 1979).

Above-sediment *M. spicatum* productivity has been linked directly to water column temperature (Young, 1973) and indirectly to sediment characteristics (Forest, 1977; Reed, 1977; Schiemer and Prosser, 1976). Reed (1977) states that maximum density of growth occurs in areas of fine organic ooze with a muck or sandy-muck base, diminishing to nearly total absence on pure sand. This implies that nutrient poor sediments inhibit *M. spicatum* growth and that *M. spicatum* roots are important in absorbing nutrients for plant growth.

This study was designed to investigate the relationship between site characteristics, consisting of both water column and sediment physical and chemical variables, and *M. spicatum* biomass and starch content. The insights into morphology, physiology and biomass change revealed in this study should allow increased management control of *M. spicatum*.

II. STUDY AREA

The study was conducted in Melton Hill Reservoir, a multipurpose impoundment of the Tennessee Valley Authority (TVA) system. Melton Hill dam is located on the Clinch River, 75.2 river kilometers (RK) below Norris dam (Figure 1). The reservoir lies within the Appalachian Valley subregion of the Valley and Ridge province (TVA, 1966).

The reservoir was impounded in May, 1963. The length is 71 km with a shoreline length of 232 km and surface area of 2,315 ha, at normal maximum pool with an elevation of 242 m above sea level. The reservoir collects from an area of 8,658 km^2. Mean reservoir depth is 6.4 m. Retention time at normal maximum pool is 12.4 days.

The bedrock underlying the reservoir is predominantly cherty dolomite with thin beds of shale and sandstone (TVA, 1966). Slopes and ridges along the shoreline consist of Tolbert-Colbert soil associations which have a silty loam texture. River terraces consist of Sequatchie soils which were derived from alluvium originating from sandstone and shale. These soils have a coarse loamy texture. Floodplain and upland drainages consist of Lindside soils originating from young alluvium washed from limestone uplands and have silty loam to clay loam textures (Baxter, 1972 as cited in Young, 1973).

There were two distinct types of shoreline landscape: steep slopes or flat low lands. Vegetation was dominated by mixed hardwood

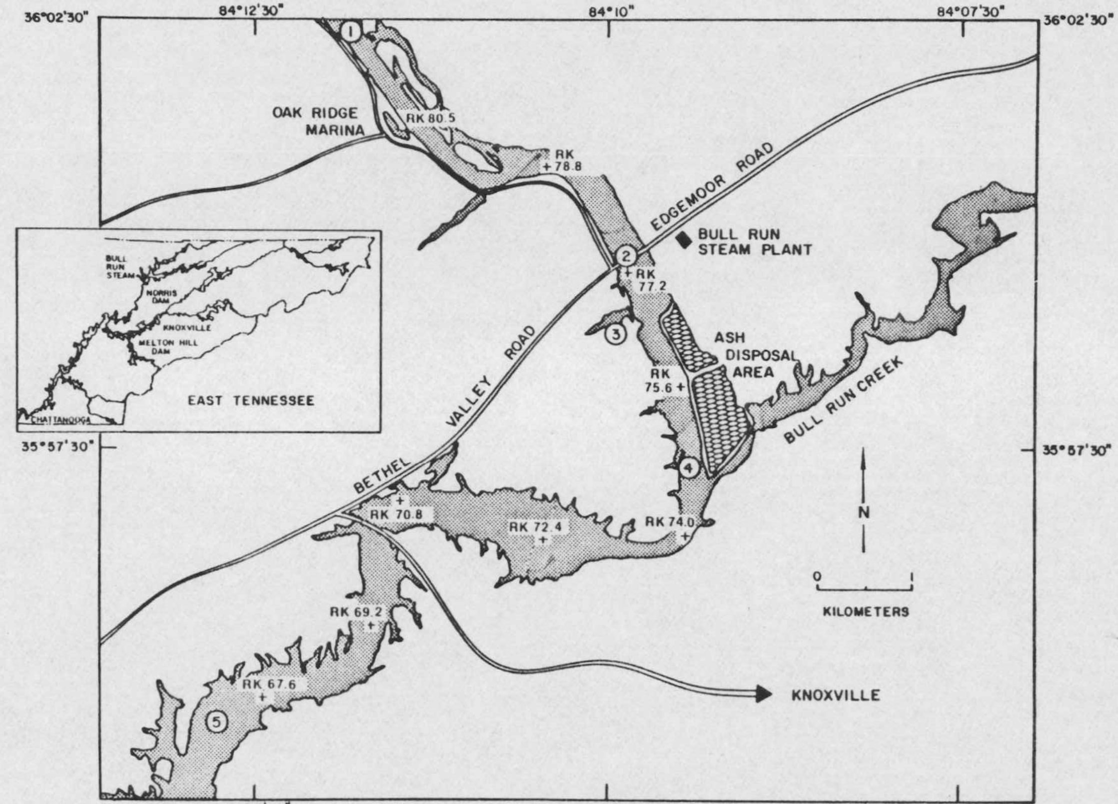

Figure 1. Map of the study area showing _M. spicatum_ sampling sites in Melton Hill Reservoir.

forests on the steep slopes and pasture land grasses on the low lands. Shoreline low lands were used mainly for grazing cattle but also for a few home sites. Virtually all steep slopes were forested.

Rainfall in this area during summer months has averaged: 12.2 cm in May, 11.2 cm in June, 13.5 cm in July, 10.2 cm in August and 8.6 cm in September for the past 15 years (Figure 2).

Bull Run Steam Plant is located at Clinch RK 77.2, and discharges heated water into the reservoir (Figure 1). This creates a thermal plume that usually extends downstream from the discharge canal along the west bank of the reservoir. Additional heated water enters the reservoir in the vicinity of the thermal plume from the flyash disposal area and Bull Run Creek. The size, depth, and dispersal patterns of the complex thermal plume are extremely variable. Fluctuating cold water output from Norris Dam, changing water elevations in Melton Hill Reservoir, and changing water temperature output from the Bull Run Steam Plant discharge canal cause this variation (Young, 1973). When the water output from Norris Dam is low, the heated effluent discharge into Melton Hill Reservoir from the steam plant often flows upstream in surface layers (Young, 1973).

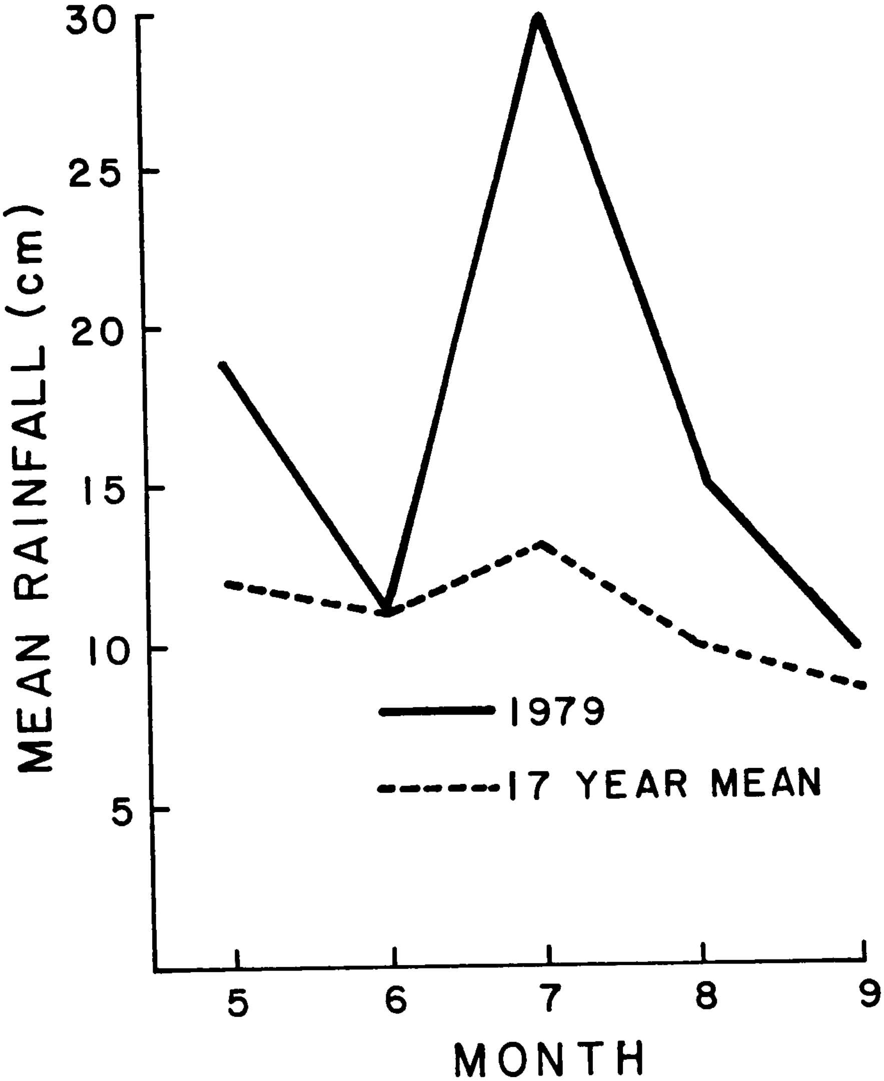

Figure 2. Mean rainfall at Bull Run Steam Plant.

Source: TVA Division of Natural Resources.

III. METHODS

Description of Sites and Plant Growth Form

Five study sites were selected in Melton Hill Reservoir between RK 65.2 and RK 82.0 (Figure 1). Sites 1, 2, 4 and 5 were in the main reservoir channel. Site 3 was located in an embayment of a small stream. The embayment was cut off from the main channel of the reservoir by a road, except for a culvert under the road which allowed water exchange.

M. spicatum stands in the main channel were elliptical in shape with the long axis parallel to the shoreline. The ends of the stands were orientated either upstream or downstream with respect to the current in the reservoir. Stand width was determined by the width of the littoral zone (the shallow interface zone between the dry land and the deeper open water) at each site. However, growth in the shallowest areas was limited by the winter water draw-down elevations imposed by TVA (Goldsby et al., 1978). The *M. spicatum* stand at site 3 was amorphous in shape. The littoral zone at this site was formed after impoundment by the flooding of a shallow cove-shaped area.

By late August the *M. spicatum* stands, except for those at sites 1 and 5, had formed dense canopies of leaves and stems at the water's surface. These canopies rose and fell with varying water elevations. At the sediment surface, stems formed relatively widely spaced clusters that emerged from their root crowns below. Rhizomes linked the clustered stems together. Sometimes rhizomes extended between clusters. Adventitious roots originated at nodes along the rhizomes. Roots and rhizomes were found in the loose sediment layer (ranging from approximately 1-6 cm in depth) overlying a compact hard layer of sediment.

Field Procedures

Samples of *M. spicatum* and sediment from the five sites were collected monthly from May through September, 1979. Standing crop plant samples were harvested in 0.31 m^2 plots with the use of SCUBA (self-contained underwater breathing apparatus). Whole-plant samples were collected, also with the use of SCUBA, by locating the base of a cluster of stems, digging down into the sediment by hand and knife and collecting the roots and rhizomes attached to the clustered stems. It was fairly easy to collect most of the roots and rhizomes attached to the clustered stems. Three standing crop and three whole-plant samples were sampled at both the upstream and downstream ends of each site. Extremely poor visibility, due to both normal water column turbidity and greatly increased turbidity created by the diver's movements along the bottom, made a defined sampling pattern impossible. All samples were collected from the same bottom contour (240.6 m above mean sea level). On each sample date, water elevation was obtained from TVA. Then at each site, sampling locations were determined through the use of a calibrated rod. Contour sampling was used to eliminate the effects of water depth and water elevation fluctuation. Four sediment samples from each site, two from both the upstream and downstream ends of a site, were collected monthly using a Ponar grab sampler.

In the field, plant and sediment samples were sealed in plastic bags and kept in plastic coolers until returned to the laboratory. Water surface temperature (1.5 m) and conductivity were measured monthly at each site with a YSI Model 33 S-C-T meter. Secchi disk transparency readings were also taken monthly at each site.

Laboratory Procedures

Plant and sediment samples were stored at 4.4 C. Plant samples were separated into three segments: 1) shoots, composed of leaves and stems, 2) rhizomes and 3) roots (Figure 3). Each segment was then rinsed in tap water, dried at 100 C for at least 24 hours and weighed. Dried plant matter was ground using a Wiley mill with a 20 mesh screen. Ground plant matter (250 mg) of each segment of each sample was analyzed for starch content after Allen (1974). Perchloric acid was used to extract the starch. The starch was then measured colorimetrically, using a Spectronic 20 spectrophotometer, after forming the blue complex with iodine.

Approximately 0.5 g of the ground root and rhizome segments and 1.0 g of the ground shoot segment for each plant sample were combusted at 500 C for three hours to obtain percent ash content (Allen, 1974).

Sediment samples were air dried, ground with mortar and pestle and sieved through a 2 mm screen. Organic matter (OM) was determined by Walkley-Black wet oxidation (Hesse, 1971) using a 77% recovery factor (Jackson, 1958). Sediment texture was determined gravimetrically using a modified hydrometer technique originally developed

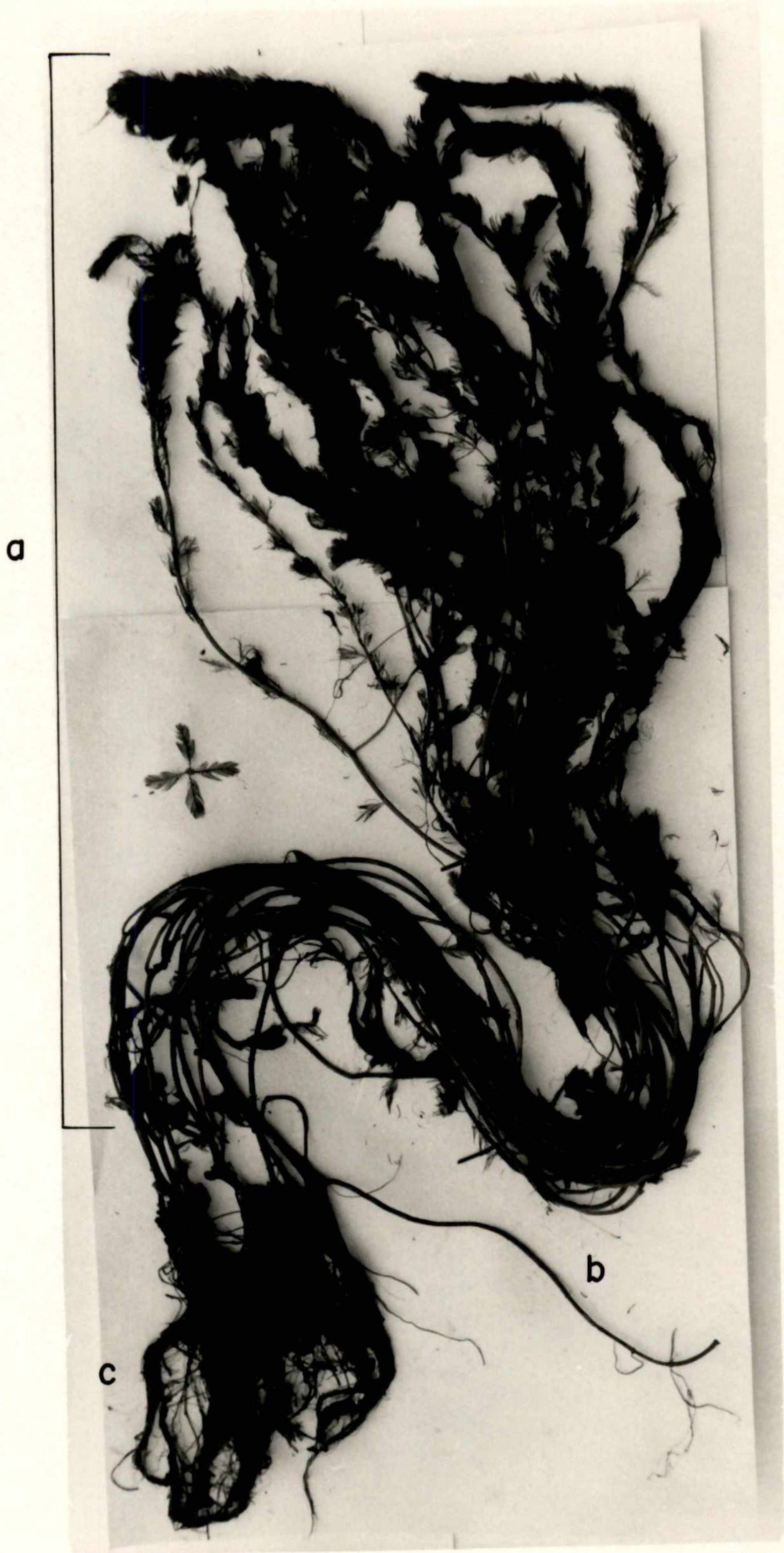

Figure 3. Myriophyllum spicatum: a) shoots, b) rhizome and c) roots.

by Day (1953). Analysis of sediment pH, available phosphorous (P), and available potassium (K) were determined by The University of Tennessee Soil Testing Laboratory in Nashville, Tennessee using their standard techniques (Univ. of TN Soil Testing Laboratory, Revised Oct., 1977). Sediment nitrate (NO_3) was determined through the use of a NO_3 ion electrode (Bremner et al., 1968; Myers and Paul, 1968; and Pedrazzini et al., 1979).

Anatomical Study Procedures

Microtomed cross sections of *M. spicatum* stems and rhizomes were cut, fixed in glutaraldehyde and photographed.

Data Analysis

Any missing data were replaced by an average value for that variable on a subsite by month basis.

Spearman's correlation analysis was performed on site variable data. Site variables consisted of: 1) sediment characteristics: percent sand, percent silt, percent clay, pH, percent OM, available P (ppm), available K (ppm) and NO_3 (ppm); and 2) water column characteristics: surface temperature (1.5 m depth), conductivity (μmhos) and Secchi disk transparency (m).

Factor analysis was applied to the raw site variable data to obtain units (factors) of correlated site variables between which there would be relatively little correlation. Factor analysis is a multivariable statistical technique. Its aim is the explanation of relationships among several difficult-to-interpret, correlated variables in terms of a few conceptually meaningful, relatively independent factors (Kleinbaum and Kupper, 1978). The single most distinctive characteristic of factor analysis is its data-reduction capability. Given an array of correlation coefficients for a set of variables, factor-analytic techniques can determine underlying patterns of relationships. The data may then be "rearranged" or "reduced" to a smaller set of factors or components. These factors may be taken as source variables accounting for the observed interrelations in the data (Nie et al., 1975).

Discriminant analysis, a multivariable statistical technique, was applied to the factor scores of the site variables in order to characterize the differences between sites. The mathematical objective of discriminant analysis is to weight and linearly combine the discriminating variables (in this case, the factor scores of the site variables) in a way that the groups (in this case, the sites) are forced to be as statistically distinct as possible (Nie et al., 1975). These linear combinations are called discriminant functions. Evaluation at group means (group centroids) provide graphical display of the relationship between groups along the first two discriminant functions.

Nested analysis of variance (ANOVA) and Duncan's multiple range test were performed on each site variable to compare with results of the discriminant analysis.

Root and rhizome production were determined by 1) establishing root:shoot (rt:st) ratios and rhizome:shoot (rz:st) ratios of the whole-plant samples, 2) comparing the standing crop per m^2 with the shoot weights of the whole-plant samples collected by cluster, and 3) calculating the root and rhizome production per m^2.

In order to establish associations between the site variables and biotic variables, canonical correlation analysis was applied to these two sets of variables. Biotic variables consisted of: standing crop ash-free weight (g/m^2), rhizome ash-free weight (g/m^2), root ash-free weight (g/m^2), shoot percent ash, rhizome percent ash, root percent ash, shoot percent starch, rhizome percent starch and root percent starch.

Canonical correlation analysis is a multivariate correlation technique that takes as its basic input, two sets of variables, each of which can be given theoretical meaning as a set. The strategy of canonical correlation analysis is to derive a linear combination from each set of variables so that the correlation between the two linear combinations is maximized (Nie et al., 1975). There are two sources of potential error in using this analytic technique: 1) spurious correlations can occur between the two sets of variables and 2) canonical correlations may or may not exist in reality (Pimental, 1979).

Nested ANOVA and Duncan's multiple range test were also performed on the biotic variables from each site.

IV. RESULTS

Site Variables

Texture analysis of sediment samples helped to define the characteristics of each site. Percent sand at each site varied little through the season (Figure 4, Tables I and A-1). Sites 5 and 4 had the greatest percentages of sand (≈60.0%) and site 3 had the least percentage of sand (≈22.0%). Sites 1 and 2 were intermediate, containing approximately 27.0% and 32.0% sand, respectively. Percent silt also varied little through the season (Figure 4, Tables I and A-2). Sites 1, 2 and 3 had the greatest percentages of silt (≈63.0%, 55.0% and 60.0%, respectively), and sites 4 and 5 had the least silt (≈36.0%). Clay content also varied little through the season (Figure 4, Tables I and A-3). Site 3, the embayment, had the greatest percentage of clay (averaging 20.0%). Clay content was intermediate and not significantly different between sites 1 and 2 (averaging 10.5% and 10.1%, respectively). Sites 4 and 5 were characteristically low in percent clay (averaging 5.9% and 4.7%, respectively).

OM content of a soil has been used to indicate the nutrient status of soils (Boyd, 1970). The cation exchange capacity of soils increases with increasing soil OM. Each of the five sites was significantly different in OM content (Figure 5, Tables I and A-4). OM content was positively correlated with percent clay, percent silt and available K while negatively correlated with percent sand

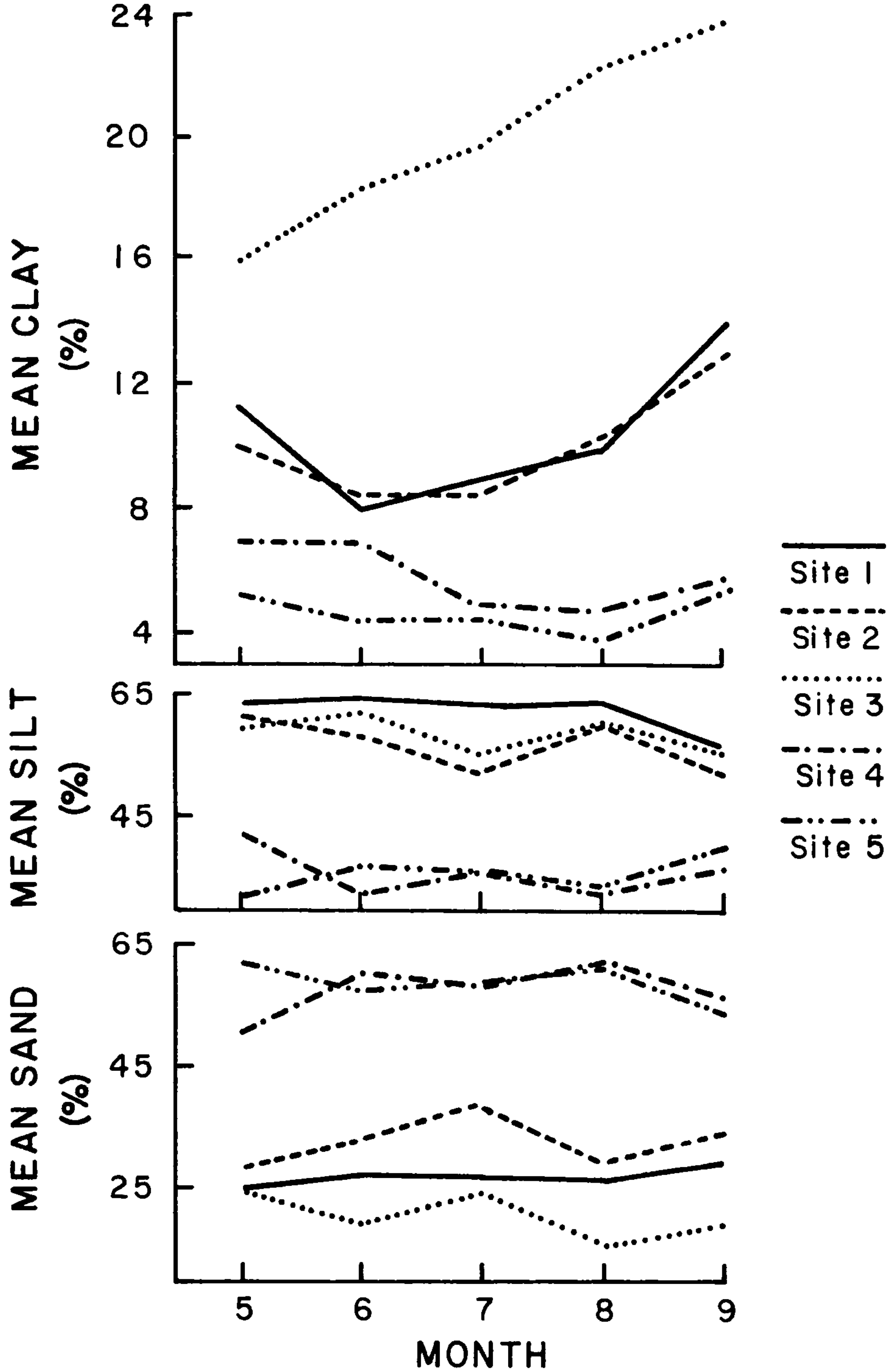

Figure 4. Sediment textural characteristics for each site and sampling time (N=4).

Table I. Nested analysis of variance and Duncan's multiple range test (mrt) on site variables with data combined from all sampled months.

Site Variables	Nested Analysis of Variance: Site	Nested Analysis of Variance: Site * Subsite		Duncan's MRT Ranks
Clay	**	**	(5.48%)[a]	5 4 2 1[b] 3[c]
Sand	**	**	(7.30%)	3 1 2 4 5
Silt	**	**	(7.07%)	5 4 2 3 1
OM	**	*	(0.59%)	5 4 1 2 3
pH	**	**	(4.91%)	1 2 4 3 5
NO_3	**			1 2 5 4 3
K	**	**	(5.18%)	5 4 2 1 3
P	**	**	(8.40%)	3 4 5 2 1
Water surface temperature	**			1 5 2 4 3
Conductivity	**			1 3 2 5 4
Secchi disk transparency	**			3 4 2 5 1

**Significant at the α=.01 level.

*Significant at the α=.05 level.

[a]Percent of total variance.

[b]Underlined groups are not significantly different.

[c]Groups listed in order of increasing value.

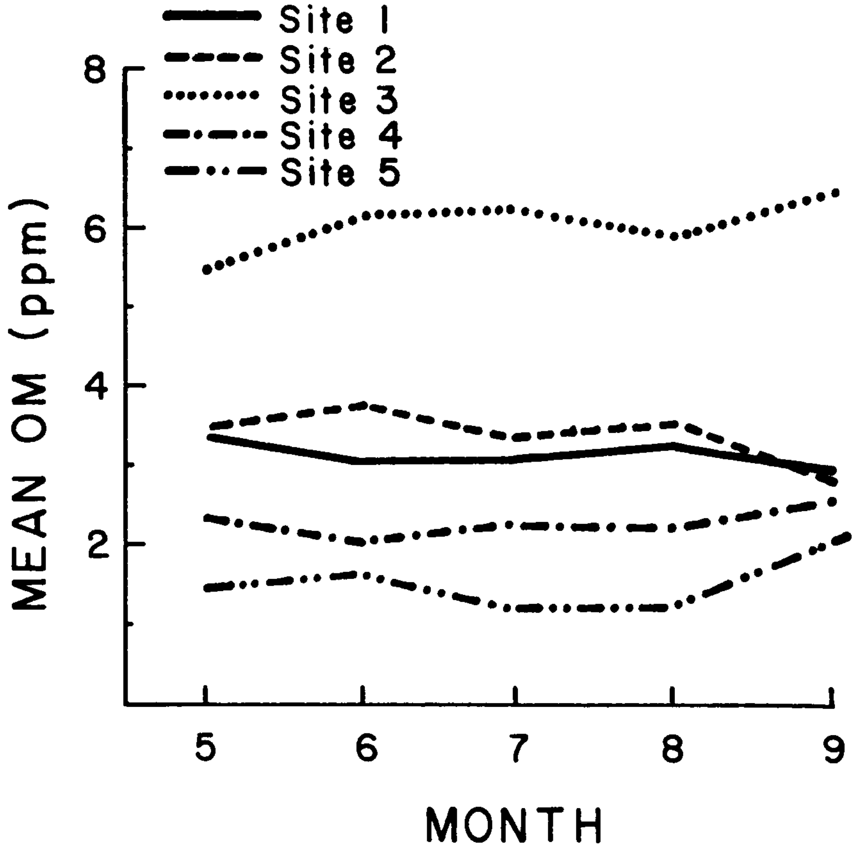

Figure 5. Mean sediment organic matter content for each site and sampling time (N=4).

(Table II). The greatest percentage of OM was found at site 3 (averaged 6.1%), intermediate levels existed at sites 1 and 2 (averaged 3.2% and 3.5%, respectively) and lowest percentages were at sites 4 and 5 (averaged 2.3% and 1.5%, respectively).

Sediment NO_3 increased at all sites through the season (Figure 6, Tables I and A-5). Increased sediment NO_3 was positively correlated with increased water surface temperature and pH while negatively correlated with available P and Secchi disk transparency (Table II). Sediment NO_3 was greatest at site 3, rising from 27 ppm in May to 56 ppm in September. Site 4 was also high in sediment NO_3, rising from 14 ppm in May to 39 ppm in September. Sediment NO_3 content rose more slowly for sites 1, 2 and 5. Water surface temperatures were lower at these sites. Site 5 had intermediate NO_3 values, rising from 16 ppm in May to 34 ppm in September. Sediment NO_3 was not significantly different between sites 1 and 2, but was low when compared to the other sites. Values rose from about 10 ppm in May to approximately 21 ppm in September.

Available P in the sediment was greater at sites 1, 2 and 5 than at sites 3 and 4. For these three sites, it generally rose from May to June, and then declined for the remainder of the season (Figure 6, Tables I and A-6). Increased available sediment P was positively correlated with Secchi disk transparency while negatively correlated with sediment NO_3, pH and water surface temperature (Table II). Among the three sites with the greatest amount of available P, site 1 had the most, site 2 was intermediate and site 5 had the least amount of available P. Available P in the sediment

Table II. Spearman correlation coefficients among site variables.

	Sediment Variables (N=100)								Water Column Variables (N=25)		
Site Variables	Sand	Silt	Clay	pH	Available P	Available K	NO_3	OM	Water Surface Temperature	Conductivity	Secchi Disk Transparency
Sand	1.00 0	-0.95 **	-0.86 **	0.35 *	NS	-0.71 **	NS	-0.84 **	NS	0.38 **	NS
Silt		1.00 0	0.72 **	-0.45 **	NS	0.60 **	NS	0.75 **	NS	-0.34 *	NS
Clay			1.00 0	-0.32 *	NS	0.80 **	NS	0.84 **	0.35 *	NS	-0.33 *
pH				1.00 0	-0.67 **	-0.29 *	0.62 *	NS	0.38 **	NS	NS
Available P					1.00 0	NS	-0.74 **	NS	-0.67 **	NS	0.41 **
Available K						1.00 0	NS	0.75 **	0.36 *	NS	-0.38 **
NO_3							1.00 0	NS	0.72 **	NS	-0.48 **
OM								1.00 0	0.39 **	-0.32 *	NS
Water surface temperature									1.00 0	NS	-0.66 **
Conductivity										1.00 0	NS
Secchi disk transparency											1.00 0

**Significant at the α=.01 level. *Significant at the α=.05 level. NS=Not significant.

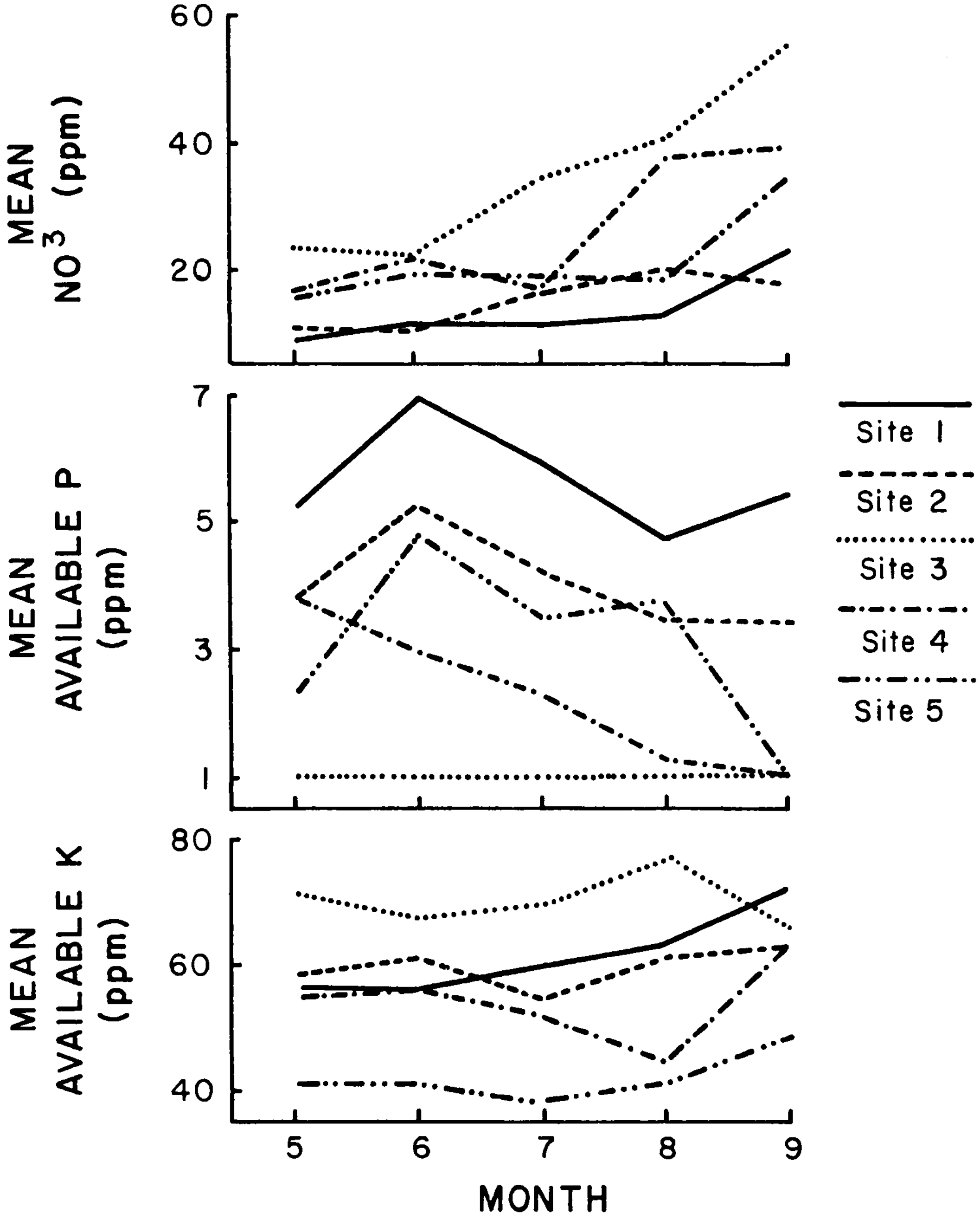

Figure 6. Mean sediment nutrients for each site and sampling time (N=4).

dropped linearly at site 4 from 3.8 ppm in May to 1.0 ppm in September. Site 3 had 1.0 ppm available P in the sediment from May through September.

Available K in the sediment varied from site to site (Figure 6, Tables I and A-7) and was positively correlated with percent clay, OM content and percent silt, while negatively correlated with percent sand (Table II). Site 3, the embayment, had the most available K in the sediment with values ranging from 66.3 ppm to 77.5 ppm. Sites 1 and 2 did not have significantly different available K values. They ranged from about 5.8 ppm to approximately 6.8 ppm available K. Available K in the sediment at site 4 dropped sharply from June (56.3 ppm) to August (45.0 ppm) and then rose sharply in September (63.8 ppm). Available K in the sediment at site 5 remained near the same level (40.0 ppm) from May through August, but rose in September (49.0 ppm).

Sediment pH values were significantly different among all sites (Tables I and III). Values generally remained constant throughout the season, ranging from 7.0 at site 1 to 7.5 at site 5. Sediment pH was positively correlated with sediment NO_3 while negatively correlated with sediment available P (Table II).

Water surface temperature generally increased at all sites as the season progressed (Figure 7, Tables I and A-8). However, the increase was more constant and linear and temperatures were higher for sites 3 and 4 than for sites 1, 2 and 5. Water surface temperatures fluctuated at sites 1, 2 and 5. Site 1 was the coldest site followed by sites 5 and 2. Site 3, the embayment, was the warmest site.

Table III. Mean sediment pH and standard deviations* for each site and sampling time (N=4).

Month	Site				
	1	2	3	4	5
5	7.0 (0.0)*	7.2 (0.1)	7.4 (0.1)	7.3 (0.1)	7.5 (0.1)
6	7.0 (0.1)	7.1 (0.1)	7.3 (0.0)	7.2 (0.1)	7.4 (0.0)
7	6.9 (0.1)	6.9 (0.1)	7.3 (0.1)	7.2 (0.0)	7.4 (0.1)
8	6.9 (0.0)	7.0 (0.1)	7.4 (0.1)	7.4 (0.1)	7.5 (0.1)
9	7.0 (0.2)	7.0 (0.0)	7.4 (0.1)	7.4 (0.1)	7.5 (0.0)

*Standard deviations listed within parentheses.

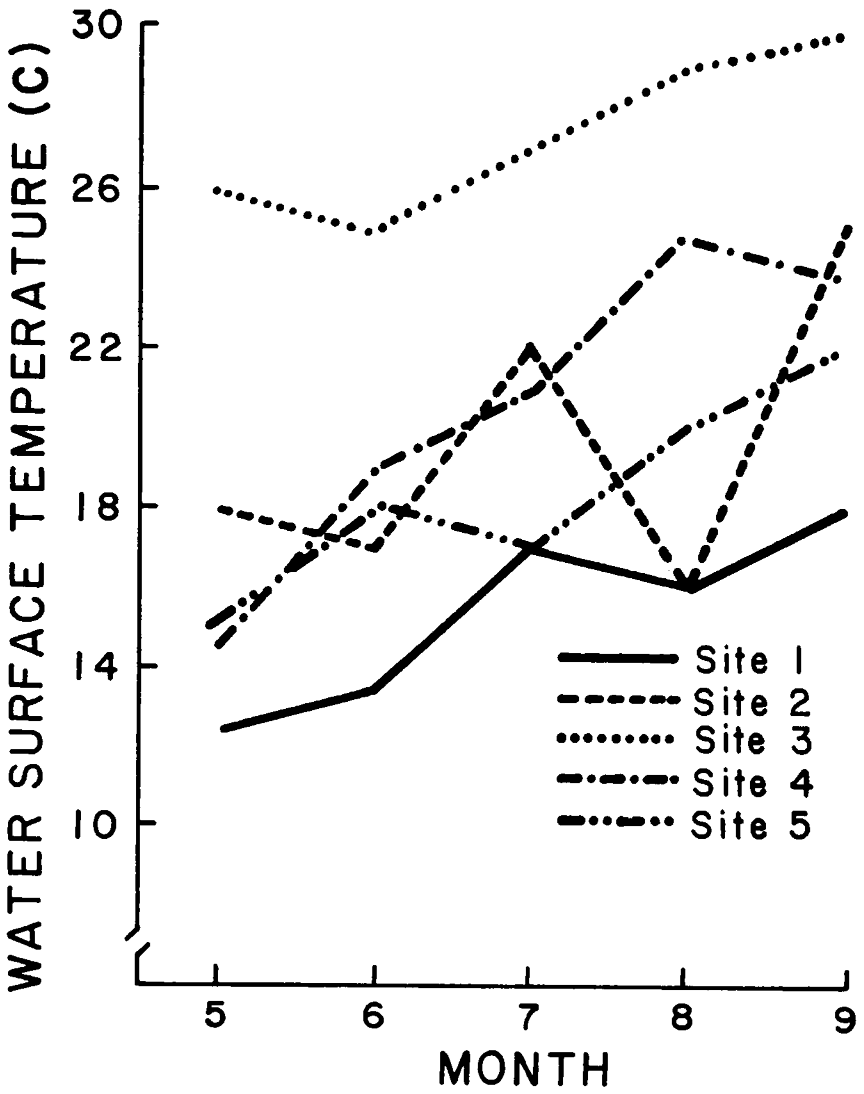

Figure 7. Water surface temperature for each site and sampling time (N=1).

Water column conductivity (Figure 8 and Table A-9) for the main channel sites (1, 2, 4 and 5) decreased through June and July (to an average of 143 μmhos) during heavy rainfall (Figure 2, page 6), and then returned to near May values during August and September (an average of 223 μmhos). Conductivity values were relatively low at site 3, the embayment, except during July, the month of heaviest rainfall. July conductivity values at site 3 greatly surpassed any conductivity value of the main channel sites.

Secchi disk transparency steadily declined with the seasonal decrease of solar radiation (Figures 9 and 10). Main channel sites showed a drop in Secchi disk transparency (increase in turbidity) during July which reflected the high rainfall and decreased solar radiation of that month.

Since many of the site variables were highly correlated with one another (Table II), factor analysis was used to obtain sets of correlated site variables (factors) (Tables IV and A-11).

Characterization and separation of each site based on factor analysis scores of site variable values was revealed through the use of discriminant analysis (Figure 11). The overall test of the discriminant analysis was significant at $P<.001$ (D.F.=32,510). Pairwise tests indicated significant differences between each combination of sites at a multivariate significance level of $P<.001$ (D.F.=8,138). Sites 1 and 2, located in the main channel of the reservoir and upstream from the discharge of Bull Run Steam Plant, although significantly different, were most similar to one another. Sites 4 and 5, located in the main channel of the reservoir and downstream from the discharge

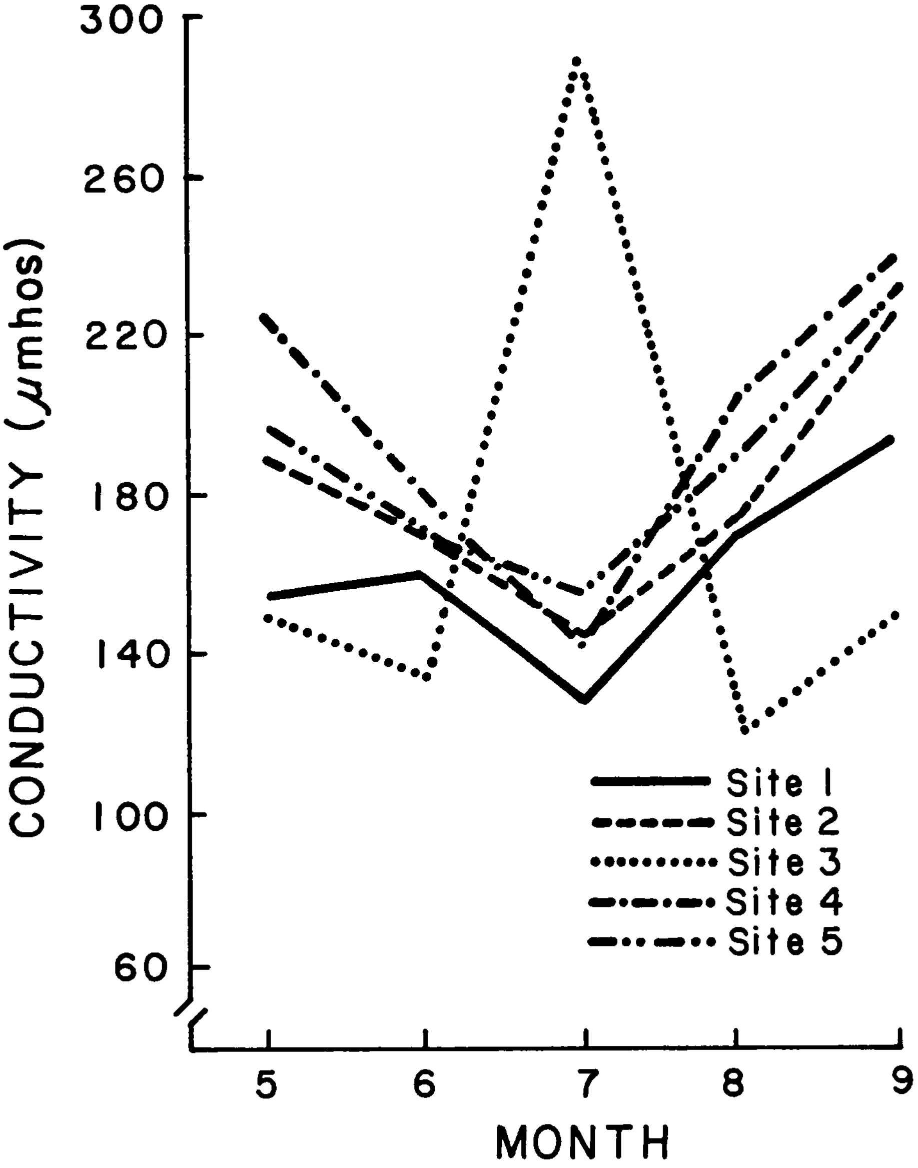

Figure 8. Conductivity for each site and sampling time (N=1).

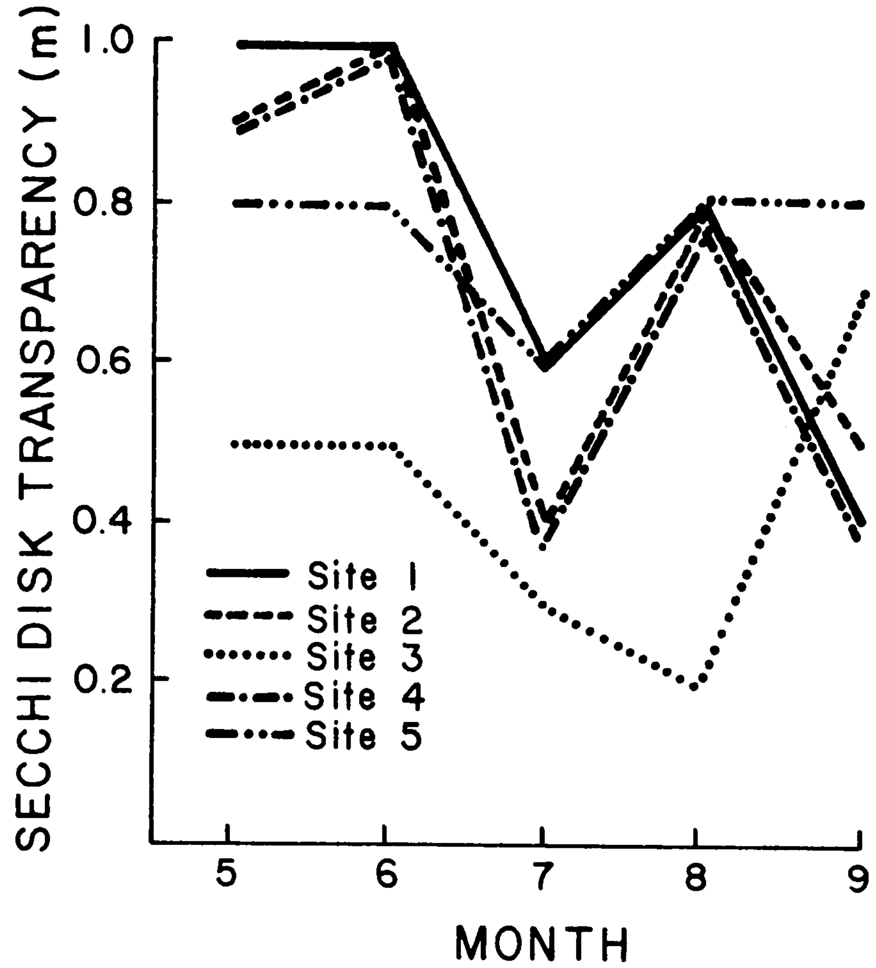

Figure 9. Secchi disk transparency for each site and sampling time (N=1).

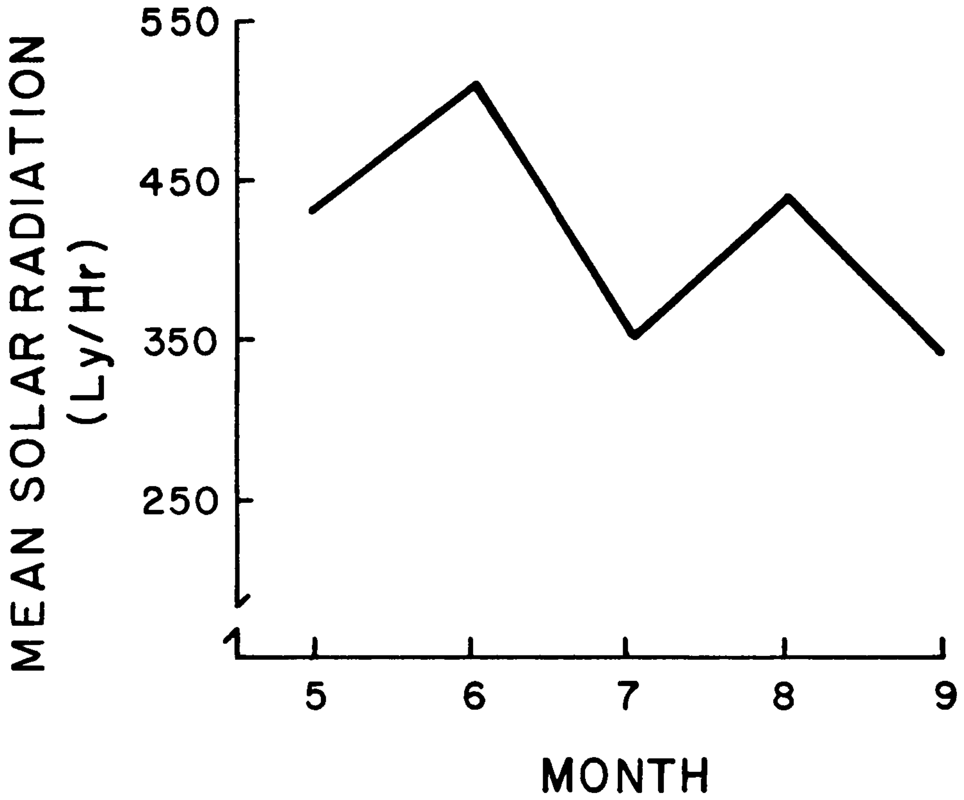

Figure 10. Mean solar radiation at Bull Run Steam Plant, 1979.

Source: TVA meteorological data.

Table IV. Site variable groupings resulting from factor analysis.

Factor 1	Factor 2	Factor 3[a]	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
-Sand[b]	pH	Month	Conductivity	Secchi disk trans-parency	K	P	Water surface temperature	NO_3
Clay	-P							
OM	NO_3							
K								

[a]Factor 3 was eliminated during discriminant analysis and canonical correlation due to the statistical nature of those analyses.

[b]Site variables are listed in order of importance.

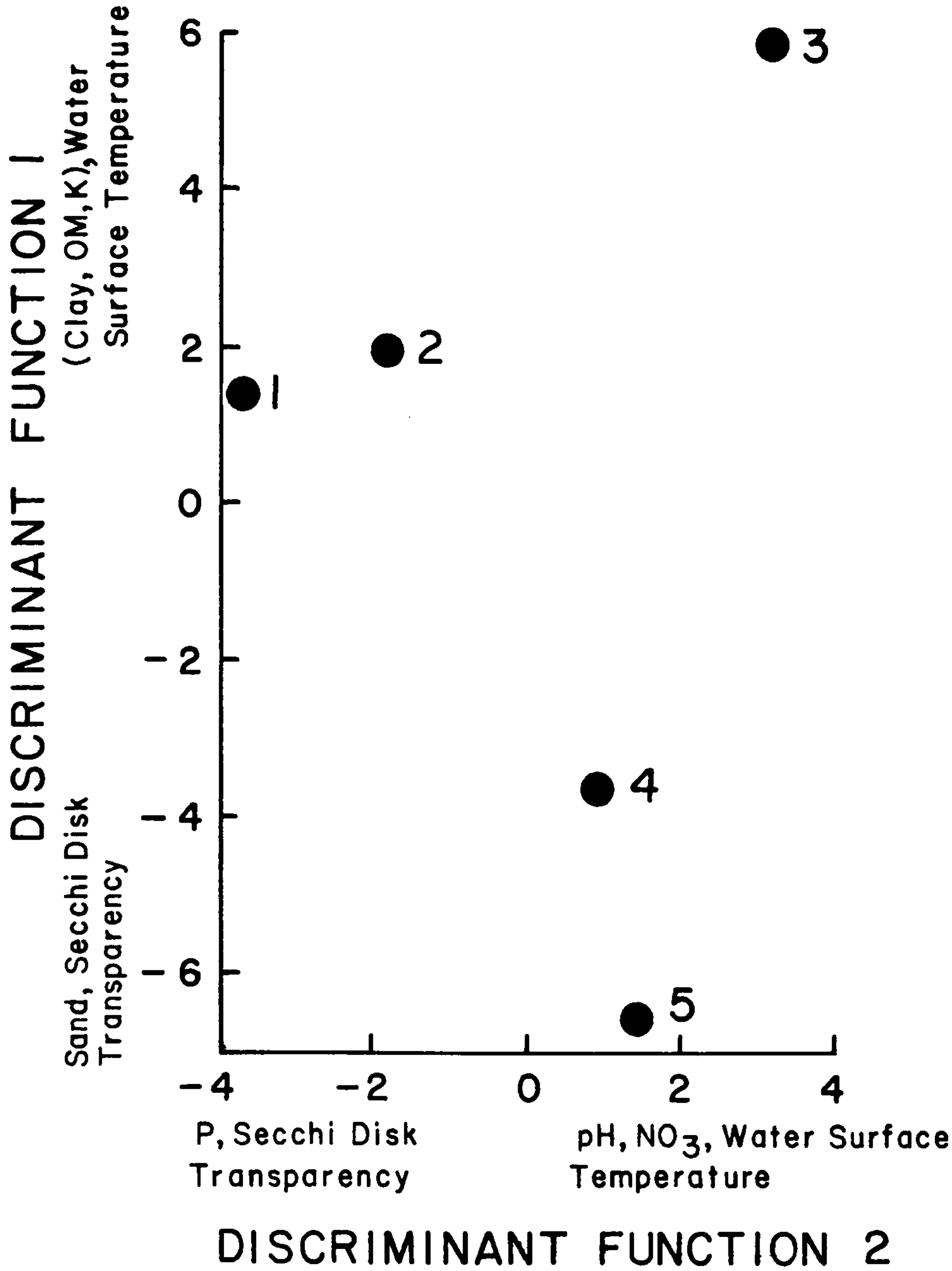

Figure 11. Discriminant analysis separating the five sites by site variables. Points represent group centroids. Site variable position on a discriminant function indicates a high value of that site variable on that discriminant function.

of Bull Run Steam Plant, although significantly different, were most similar to one another. Site 3, located in the embayment outside the main channel of the reservoir, was distinctly different from the other four sites.

Discriminant analysis characterized sites 1 and 2 as having: a) more clay, availabke K, OM and available P, and less NO_3 in their sediments, and b) lower water surface temperatures than sites 4 and 5. Sites 4 and 5 were characterized as having: a) more sand and NO_3, higher pH and less available P in their sediments, and b) higher water surface temperatures than sites 1 and 2. Site 3 was characterized as having: a) the most clay, available K, OM and NO_3, the least available P and similar pH levels with sites 4 and 5 in its sediment, and b) the highest water surface temperatures and lowest Secchi disk transparency when compared to the other four sites.

The characterization and separation of sites produced through discriminant analysis were confirmed by nested ANOVA and Duncan's multiple range tests (Table V).

Biotic Variables

Biomass. Plant biomass at each site was greatest in the shoots, second most in the roots and lowest in the rhizomes (Figures 12 and 13, Tables A-12 and A-13). Seasonal patterns in growth among all sites were apparent for the shoots, less so for the roots and not apparent for the rhizomes.

Standing crop at each site was generally greater in September than in May (Figure 12). Shoot biomass at sites 3 and 4 generally

Table V. Nested analysis of variance and Duncan's multiple range test (mrt) on biotic variables with data combined from all sampled months.

Site Variables	Nested Analysis of Variance: Site	Site * Subsite		Duncan's MRT Ranks
Standing crop ash-free weight g/m^2	**			1 5[b] 2 4 3[c]
Rhizome ash-free weight g/m^2	**			1 5 2 3 4
Root ash-free weight g/m^2	**			1 5 2 4 3
Shoot % ash	**			3 4 5 1 2
Rhizome % ash	**			3 5 4 2 1
Root % ash	**	**	(14.76%)[a]	3 5 2 4 1
Shoot % starch	**	*	(1.84%)	1 2 5 4 3
Rhizome % starch	**			1 5 2 4 3
Root % starch	**			1 4 2 5 3

**Significant at the α=.01 level.

*Significant at the α=.05 level.

[a]Percent of total variance

[b]Underlined groups are not significantly different.

[c]Groups listed in order of increasing value.

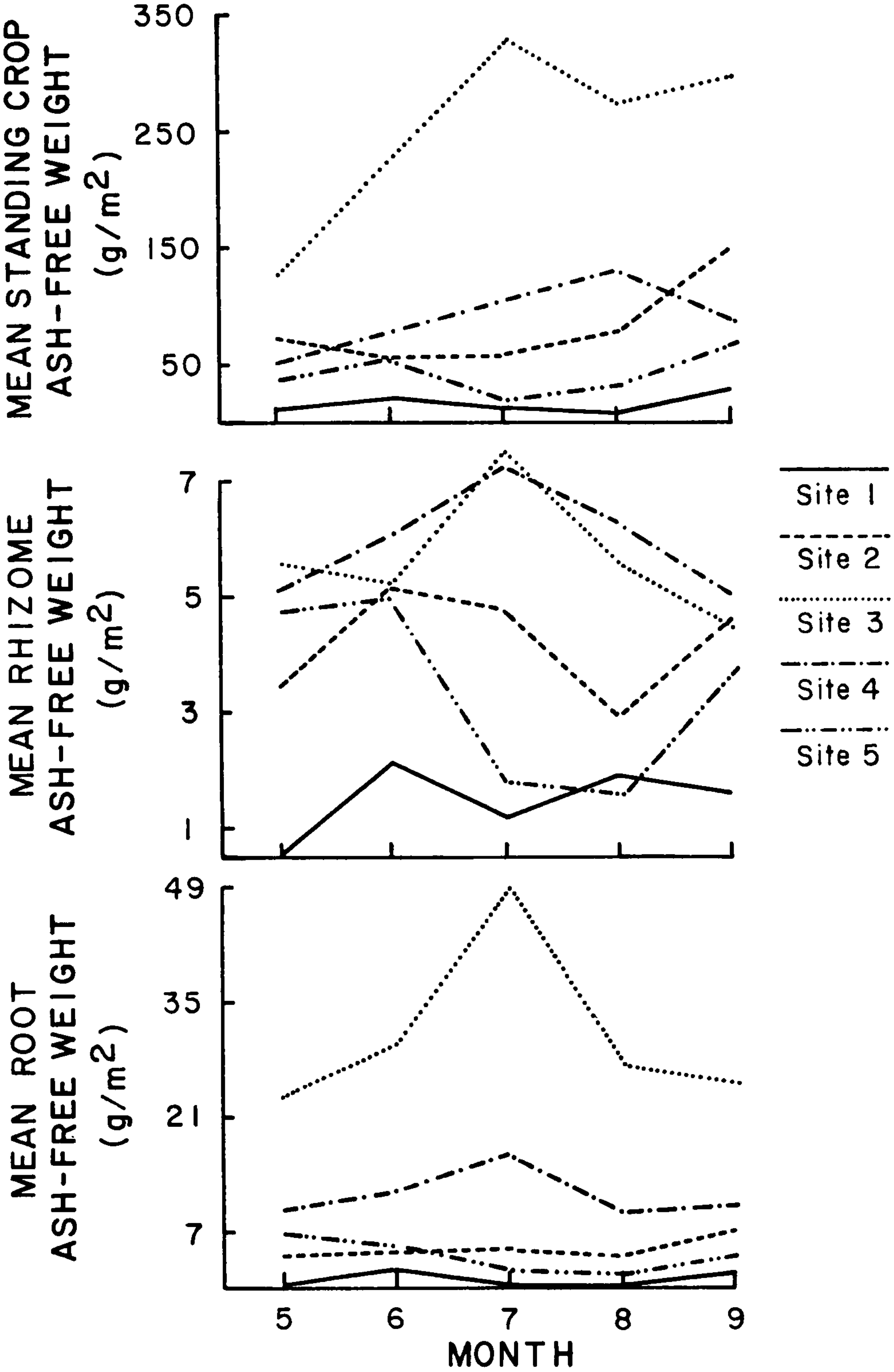

Figure 12. Mean ash-free weight of each plant segment for each site and sampling time (N=6).

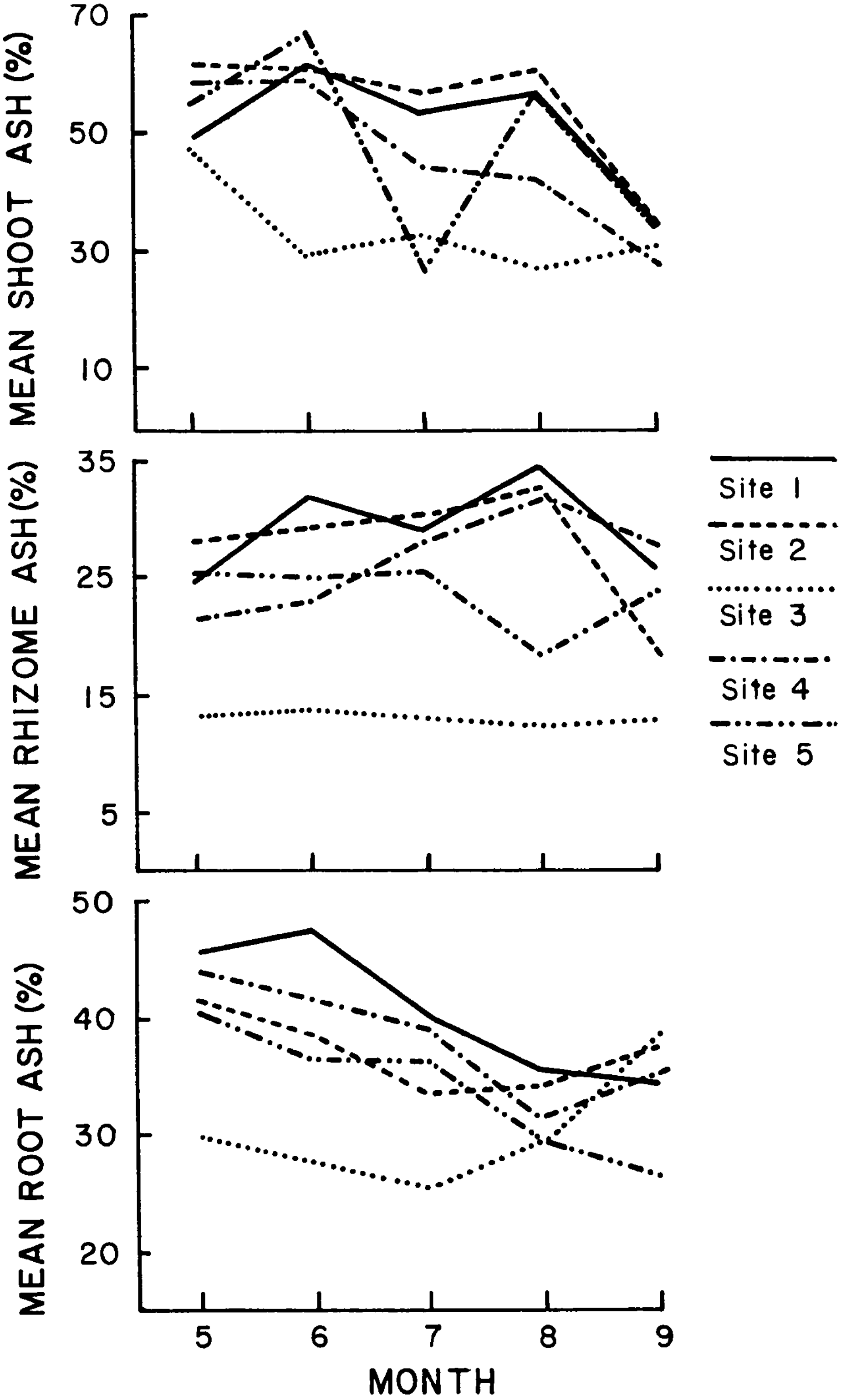

Figure 13. Mean ash content of each plant segment for each site and sampling time (N=6).

followed the May to September pattern of standing crop development described for 1972 in Melton Hill Reservoir (Stanley et al., 1976). Site 3 had the greatest standing crop. It rose linearly from May [(124.99 g/m^2 ash-free weight, 0.19 rt:st ratio, 0.05 rz:st ratio) (Figures 14 and 15 and Tables V and A-14)] to July (336.92 g/m^2 ash-free weight, 0.14 rt:st ratio, 0.02 rz:st ratio), ending the season in September with 299.12 g/m^2 ash-free weight, 0.09 rt:st ratio and 0.02 rz:st ratio. Sites 4 and 2 had the second highest standing crops, respectively, through the season (Table V). Site 4 steadily increased in standing crop from May (51.71 g/m^2 ash-free weight, 0.19 rt:st ratio, 0.10 rz:st ratio) to August, then dropped a bit in September, ending the season with 86.85 g/m^2 ash-free weight, 0.12 rt:st ratio and 0.06 rz:st ratio. Standing crop at site 2 dropped slightly in June from what it had been in May (72.90 g/m^2 ash-free weight, 0.06 rt:st ratio, 0.05 rz:st ratio), but gradually increased through the following months to September (152.28 g/m^2 ash-free weight, 0.05 rt:st ratio, 0.03 rz:st ratio). Sites 1 and 5 had the lowest standing crops through the season (Table V). Standing crop at site 1 barely changed from May (11.67 g/m^2 ash-free weight, 0.05 rt:st ratio, 0.04 rz:st ratio) to September (30.53 g/m^2 ash-free weight, 0.07 rt:st ratio, 0.05 rz:st ratio). Standing crop at site 5 rose slightly in June from what it had been in May (42.59 g/m^2 ash-free weight, 0.16 rt:st ratio, 0.11 rz:st ratio) dropped substantially in July (20.82 g/m^2 ash-free weight, 0.12 rt:st ratio, 0.09 rz:st ratio), then gradually increased through September (68.51 g/m^2 ash-free weight, 0.06 rt:st ratio, 0.06 rz:st ratio).

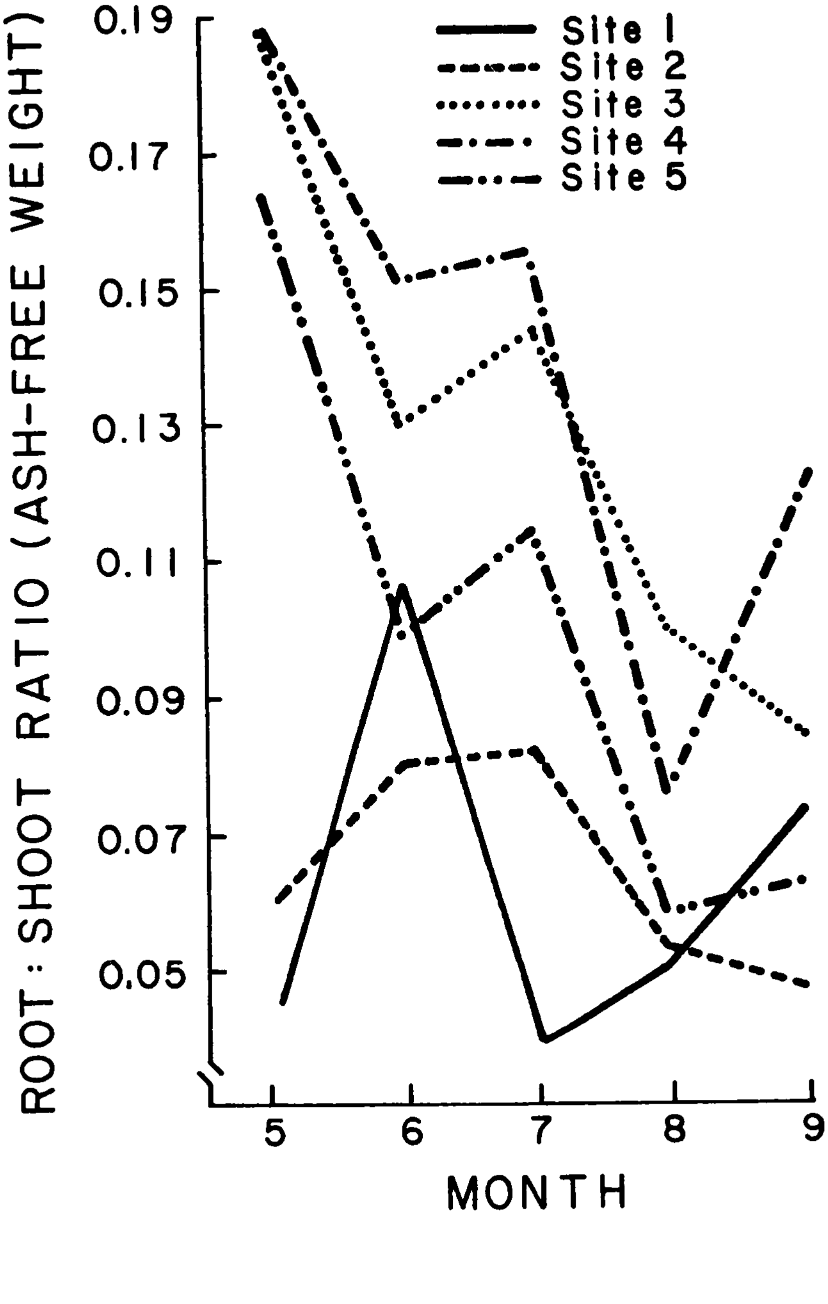

Figure 14. Mean root:shoot ratios for each site and sampling time (N=6).

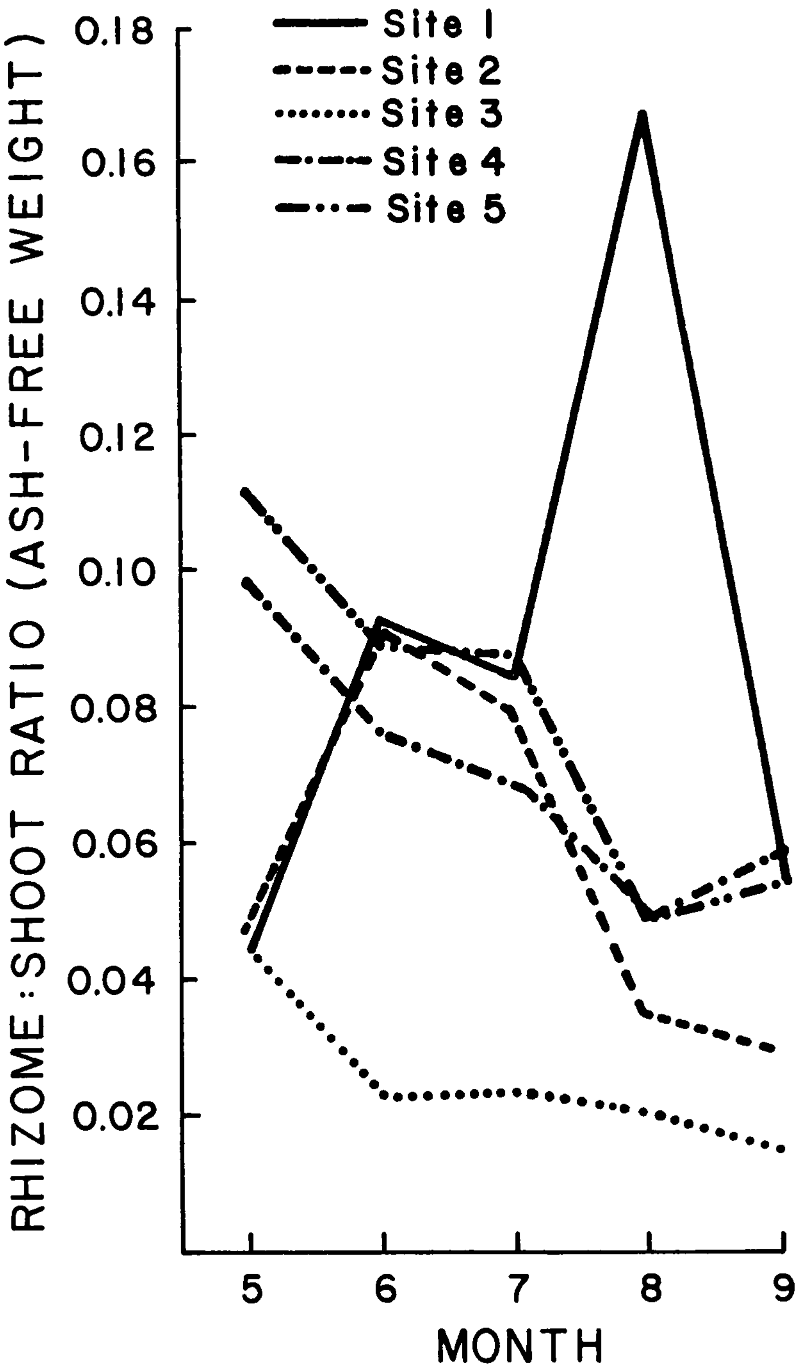

Figure 15. Mean rhizome:shoot ratios for each site and sampling time (N=6).

Rhizome biomass changes are easiest followed by studying Figures 12 and 15 and Table A-12. Variables not measured in this study, such as weekly water current speed and fluctuations, seasonal stem buoyancy and seasonal sediment deposition, would perhaps have helped to explain rhizome formation and seasonal biomass variation.

Root biomass was lowest at sites 1, 5 and 2, respectively, throughout the season (Table V). Little change in root biomass from May (averaged 3.97 g/m^2 ash-free weight) to September (averaged 4.64 g/m^2 ash-free weight) occurred at these sites. However, differences did occur in rt:st ratios (Figure 14). Site 5 usually had higher rt:st ratios through the season than sites 1 and 2. Root biomass was greatest at site 3. It rose linearly from May (23.50 g/m^2 ash-free weight) to July (48.66 g/m^2 ash-free weight) then dropped substantially through September (25.54 g/m^2 ash-free weight). Site 4 had the second greatest root biomass through the season. It gradually increased from May (9.75 g/m^2 ash-free weight) through July (16.47 g/m^2 ash-free weight), dropped during August, but leveled out in September (10.60 g/m^2 ash-free weight).

Starch content. Starch content of plant samples collected at all sites throughout the season was greatest in the rhizomes and then generally greater in the roots than in the shoots (Figure 16 and Table A-15). Throughout the season, site 3 had more starch in each plant segment than any of the other sites.

Shoot starch content was quite low at sites 1, 2, 4 and 5 with little variation from May (averaged 0.26% starch) through September

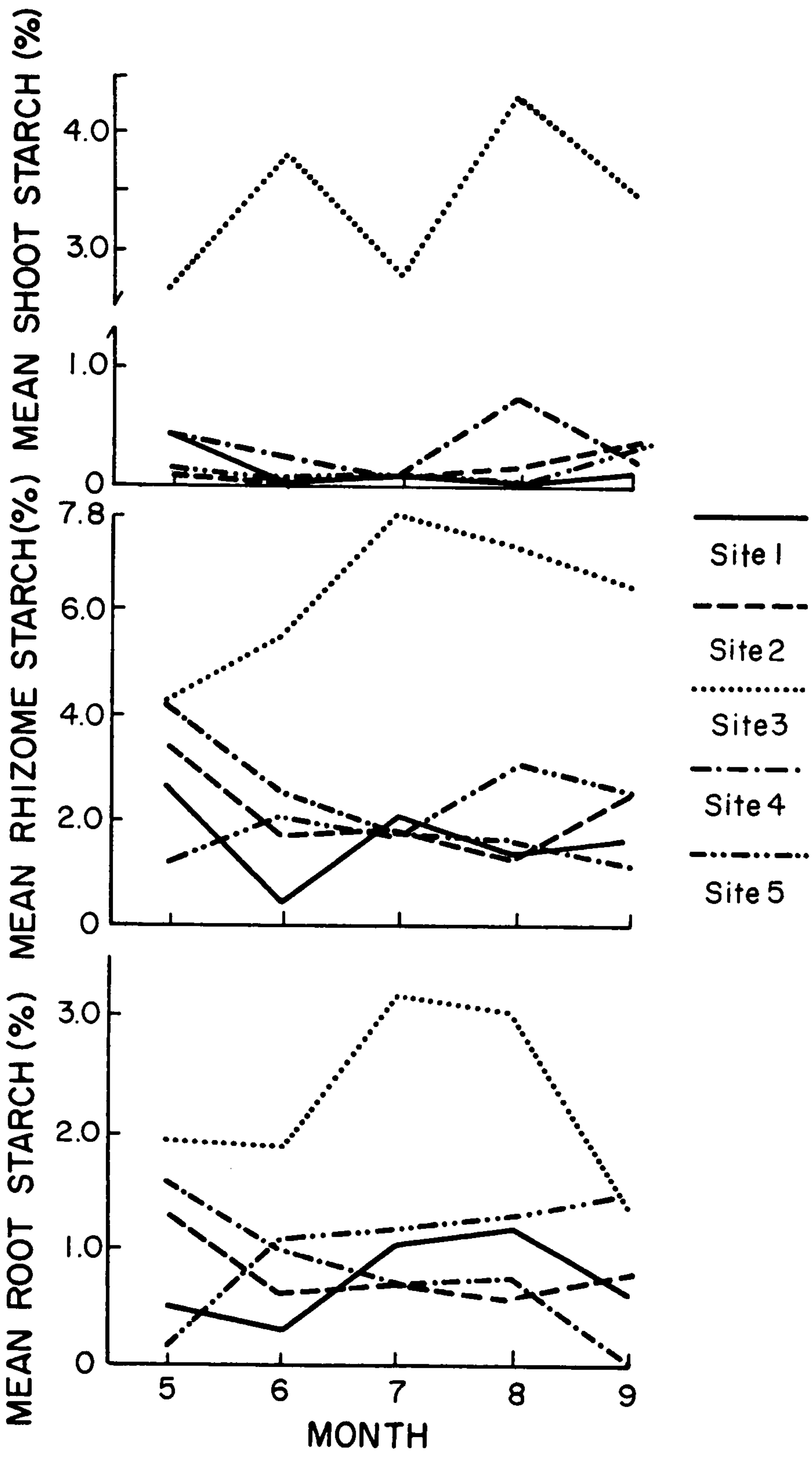

Figure 16. Mean starch content of each plant segment for each site and sampling time (N=6).

(averaged 0.26% starch). Shoot starch content at site 3, however, was relatively great. It rose substantially from May (2.65% starch) to June (3.77% starch), dropped sharply in July (2.73% starch), peaked in August (4.27% starch) and dropped again in September (3.47% starch). The dip in shoot starch content during July at site 3 coincides with that month's low solar radiation and Secchi disk transparency.

Rhizome starch content for sites 1, 2 and 4, although varying through the season, generally decreased from May (averaged 3.52% starch) to September (averaged 1.83% starch). Rhizome starch content also varied at site 5, but basically increased from May (1.23% starch) to September (2.58% starch). Rhizome starch content at site 3 rose steeply from May (4.36% starch) to July (7.82% starch) then dropped gradually through September (6.70% starch).

Root starch content at sites 1 and 5, although varying through the season, generally increased from May (averaged 0.33% starch) through September (averaged 1.04% starch). Root starch content at sites 2 and 4, generally decreased from May (averaged 1.44% starch) to September (averaged 0.41% starch). Root starch content at site 3 remained at the same level during May and June (1.90% starch), rose in July (3.12% starch), maintained that level in August but dropped sharply in September (1.37% starch).

Associations Between Site and Biotic Variables

Different patterns of associations between site and biotic variables at each site were detected through the use of canonical correlation analysis (Table A-16). Table VI summarizes these

Table VI. Summarized canonical correlation analysis.

Site	Ash-free weight (g/m^2) Standing crop	Ash-free weight (g/m^2) Rhizomes	Ash-free weight (g/m^2) Roots	% Ash Shoots	% Ash Rhizomes	% Ash Roots	% Starch Shoots	% Starch Rhizomes	% Starch Roots
1	+Water surface temperature $+NO_3$ -Secchi disk transparency	+Water surface temperature	+Water surface temperature	-Water surface temperature $-NO_3$ +Secchi disk transparency		-Water surface temperature $-NO_3$ +Secchi disk transparency	-Water surface temperature -pH	+Water surface temperature -P	+Water surface temperature -pH
2	+Conductivity +Water surface temperature +Clay	+Water surface temperature +P	+Water surface temperature	+Conductivity -Water surface temperature -Clay, +OH +Secchi disk transparency	-Conductivity -Water surface temperature -Clay, +OH	$-NO_3$ +Clay, -OH	+Conductivity $+NO_3$ +Water surface temperature	+Conductivity $-NO_3$ +Water surface temperature	
3	+Clay $+NO_3$ +Water surface temperature	+Conductivity	-Secchi disk transparency +Conductivity	-OH +Conductivity		+Water surface temperature +Secchi disk transparency -Conductivity	-Conductivity		-Secchi disk transparency
4	+Water surface temperature $+NO_3$, -P, +pH -Conductivity	-Conductivity	+Secchi disk transparency -Conductivity	+Secchi disk transparency -Water surface temperature +P $-NO_3$, +P, -pH	+Water surface temperature $+NO_3$, -P, +pH	-Water surface temperature $-NO_3$, +P, -pH	-K	$-NO_3$, +P, -pH -Water surface temperature	+P -Secchi disk transparency -Water surface temperature $-NO_3$, +P, -pH
5	+Secchi disk transparency +Water surface temperature $+NO_3$, -P, +pH +Conductivity +OH, +K	+Secchi disk transparency	+Secchi disk transparency -Water surface temperature	+Secchi disk transparency $-NO_3$, +P, -pH		-Water surface temperature -Secchi disk transparency $-NO_3$, +P, -pH	$+NO_3$, -P, +pH +OH, +K +Conductivity	+Secchi disk transparency +Water surface temperature	+Water surface temperature

*Site variables are listed in order of importance. Sign indicates negative or positive correlation.

associations. Site variables correlated with biomass change and starch content are organized below by site.

Site 1. Biomass change was correlated most with water surface temperature. Other site variables correlated with standing crop were sediment NO_3 and Secchi disk transparency.

Total plant starch content was correlated most with water surface temperature. Shoot and root percent starch were also correlated with pH. Rhizome percent starch was also correlated with sediment available P.

Site 2. Biomass change was correlated most with water surface temperature. Other site variables correlated with standing crop were conductivity and sediment clay content. Rhizome biomass was also correlated with sediment available P.

Shoot and rhizome starch content were correlated with conductivity, sediment NO_3 and water surface temperature. Root starch content was not correlated with any measured site variables.

Site 3. Biomass change in each plant segment was correlated with different site variables. Standing crop was correlated with sediment percent clay and NO_3, and water surface temperature. Rhizome biomass was correlated with conductivity. Root biomass was correlated with water column characteristics, Secchi disk transparency and conductivity.

Shoot starch content was correlated with conductivity. Rhizome starch content was not correlated with any of the measured site variables. Root starch content was correlated with Secchi disk transparency.

Site 4. Biomass change appears to be mainly correlated with water column site variables. Standing crop was correlated with water surface temperature, sediment NO_3, available P and pH, and conductivity. Rhizome biomass was correlated with conductivity. Root biomass was correlated with Secchi disk transparency and conductivity.

Total plant starch content was correlated with a combination of sediment and water column site variables. Shoot starch content was correlated with sediment available K. Rhizome starch content was correlated with sediment NO_3, available P and pH, and water surface temperature. Root starch content was correlated with Secchi disk transparency, water surface temperature, and sediment available P, NO_3, and pH.

Site 5. Biomass change was correlated most with Secchi disk transparency. Other site variables correlated with standing crop were water surface temperature, sediment NO_3, available P and pH, and conductivity. Root biomass was also correlated with water surface temperature.

Shoot starch content was correlated with a combination of sediment and water column site variables. Shoot starch content was correlated with sediment NO_3, available P, pH and OM, and conductivity. Rhizome and root starch contents were correlated with water column site variables. Rhizome starch content was correlated with Secchi disk transparency and water surface temperature. Root starch content was correlated with water surface temperature.

Anatomical Characteristics

Rhizome and stem cross sections revealed identical arrangement of vascular tissues and over all structure of these plant segments (Figures 17 and 18). The presence of a greater abundance of starch bodies in the rhizome sections pointed to a possible functional difference between *M. spicatum* stems and rhizomes.

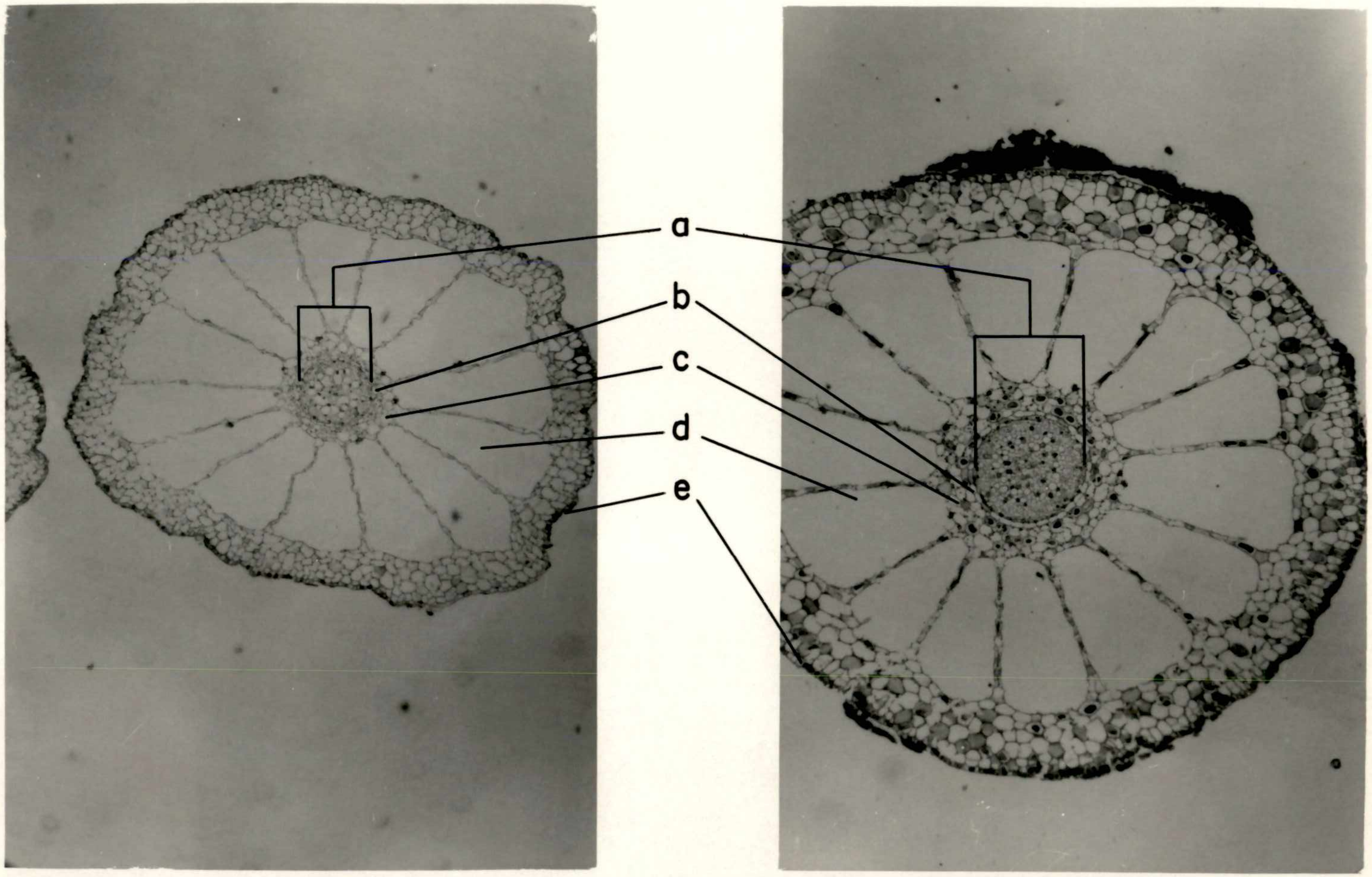

Figure 17. The stem cross section (left, 18.75X) and rhizome cross section (right, 18.75X) of _M. spicatum_. Center stele (a), casparian strip (b), parenchyma (c), aerenchyma (d) and epidermal (e) cells are arranged identically in each cross section. The rhizome cross section shows part of a dark exudate that typically surrounded all rhizomes sampled. Rhizome segments were also typically firmer than stem segments.

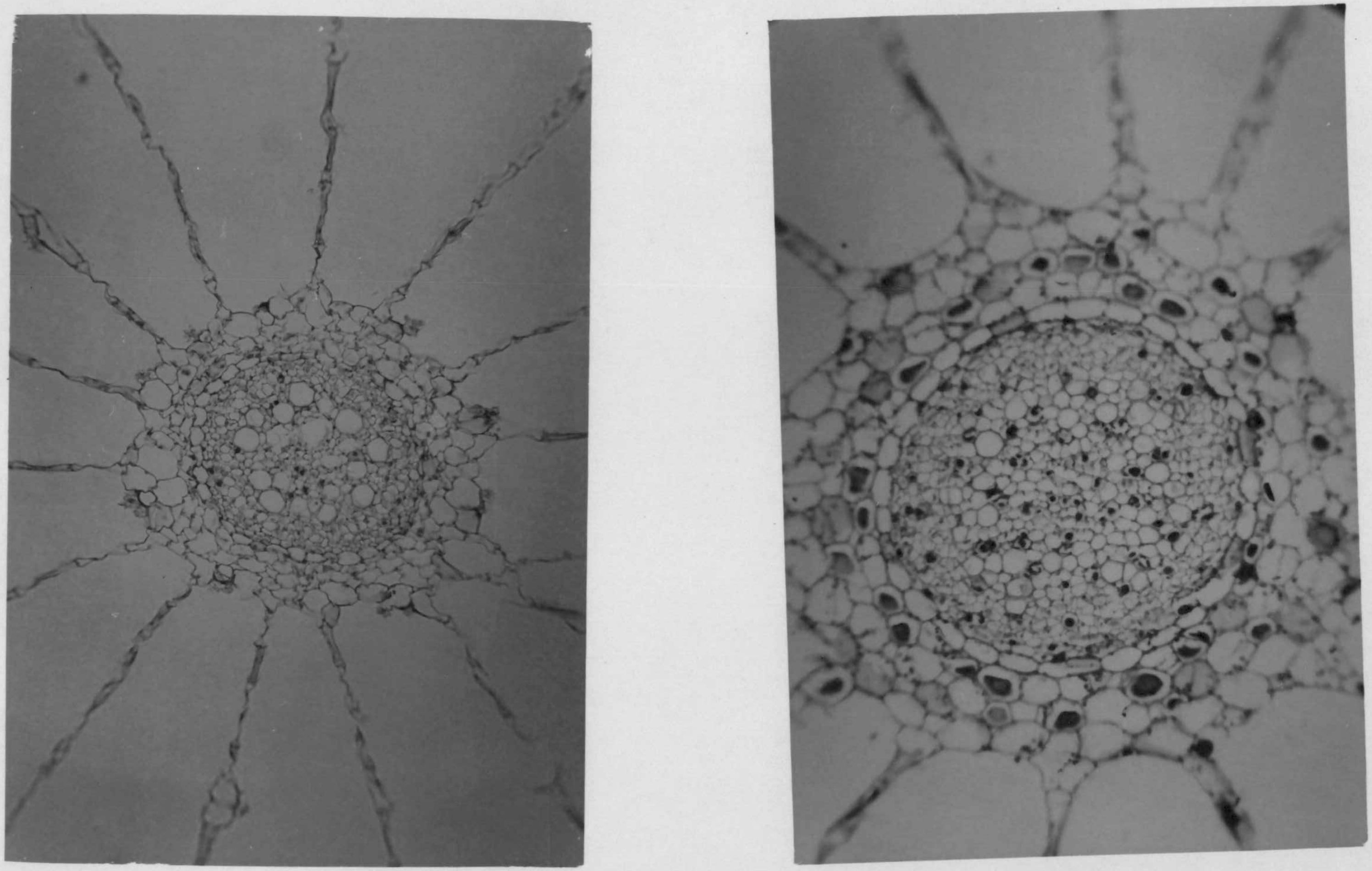

Figure 18. Close-ups of the stem stele (left, 62.5X) and rhizome stele (right, 62.5X) of M. spicatum. Parenchyma cells with dark centers or an overall darkened appearance contain starch bodies.

V. DISCUSSION

Biomass

Seasonal plant biomass varied considerably from site to site. Shoot and root biomass of main channel sites were significantly lower than shoot and root biomass of the embayment site. Rhizome biomass did not appear to follow any specific growth pattern. From anatomical evidence, rhizomes appear to be buried stem sections. Root:shoot ratios at sites 3, 4 and 5 followed a seasonal pattern with the majority of growth taking place in the shoots. Root:shoot ratios for sites 1 and 2 did not follow the seasonal pattern exhibited by the other sites. Shoot biomass and root biomass were particularly low and slow to increase at site 1. Seasonal rt:st ratios for sites 3, 4 and 5 were roughly comparable with rt:st ratios reported by Titus and Adams (1979) in Lake Wingra, Wisconsin and Nicholson and Best (1974) in Chautauqua Lake, New York. Sites 1 and 2 generally had lower rt:st ratios than those found by these authors.

Water column variables appeared to have the greatest effect on biomass change (Table VI). Among these variables, water surface temperature (and presumably entire water column temperatures) appeared to play the largest role in affecting plant growth both seasonally and spatially. Sites 3 and 4 were the warmest and had the greatest biomass values. Sites 1 and 5 were the coldest sites and had the lowest biomass values.

Secchi disk transparency was another important water column variable appearing to affect plant biomass change (Table VI). However, it was difficult to separate its effect on plant biomass change from the effect of water surface temperature. Also, conductivity and Secchi disk transparency were highly interrelated. For the main channel reservoir sites, as rainfall increased, both conductivity and Secchi disk transparency decreased. For site 3, the embayment, as rainfall increased, conductivity increased but Secchi disk transparency decreased. The light compensation point of M. spicatum is very low (Grace and Wetzel, 1978). Even so, it was felt from field observations that standing crop biomass at each site was negatively influenced in July by decreased water column light penetration. Unusually high rainfall (Figure 2, page 6) was recorded for this month, making the reservoir very turbid. Similar observations were made by employees of TVA concerning M. spicatum growth in other TVA reservoirs (Dennis, 1980, personal communication).

Sediment site variables, composed of texture and nutrient characteristics, varied from site to site. From this study it can be hypothesized that these characteristics were not the major determining factors affecting site biomass change for M. spicatum.

M. spicatum is capable of obtaining its nutrients from the sediment via root absorption. The primary source of P is generally by uptake from sediments through adventitious roots, while some uptake through shoot epidermis occurs depending on availability (Barko and Smart, 1980; Best and Mantai, 1978; Bole and Allan, 1978;

Peverly and Brittain, 1978; DeMarte and Hartman, 1974; Lie et al., 1974; Bristow and Whitcombe, 1971).

The sediment at site 3, the embayment, had the least amount of available P through the season. However, biomass at this site was significantly high throughout the season. Standing crop increased dramatically from May through July, dropping a bit in August but increasing again in September. The August and September standing crop values reflect more the lowered Secchi disk transparency in July and August and seasonal decreases in solar radiation (Figure 10, page 27) than the consistently low level of available P in the sediment of this site. Sediment available P existed in larger amounts at sites 1, 2, 4 and 5. By inference, P was not at growth limiting levels for these sites. The general decline in amount of sediment available P at sites 1, 2, 4 and 5 suggest active biological uptake. Further study of this phenomena could quantify the role _M. spicatum_ has in removing sediment P from Melton Hill Reservoir.

Ammonia (NH_4) is the primary form of nitrogen absorbed by _M. spicatum_ (Nichols and Keeney, 1976). However, NO_3 is also absorbed and utilized by the plants (Best and Mantai, 1978; Nichols and Keeney, 1976). Both forms of nitrogen can be absorbed and translocated from the roots to the shoots. Absorption also takes place through foliar tissues (Best and Mantai, 1978; Nichols and Keeney, 1976; Toetz, 1974). Vast stores of NH_4 are available in sediments (Gehler, 1969 as cited in Toetz, 1974). NO_3 in the sediment at each site increased through the season, suggesting biological activity. Nitrogen was most likely not a growth limiting nutrient at these sites.

Sediment cations have been shown to be absorbed by the roots of M. exalbescens Fernald and translocated to its shoots (DeMarte and Hartman, 1974). Perhaps M. spicatum obtains its K requirements from the sediment via root absorption. It is also probable that adequate amounts of K were present at each site, considering both sediment and water column available K (Figure 6, page 20; Table VII), to supply plant needs. Anderson et al. (1966) reported near constant levels of K (1,500 ppm) in tissues of M. spicatum from waters containing 5 ppm to 180 ppm K.

Tissue nutrient concentrations were not measured in this study. However, after taking into consideration: 1) the ability of M. spicatum to uptake and store luxury amounts of nutrients (Kimball and Baker, 1980; Gerloff and Krombholtz, 1966), 2) the sediment nutrients available at each site, and 3) the estimated water column nutrients available for foliar uptake (Table VII), it is reasonable to hypothesize that nutrient limiting conditions did not continuously exist at any site. Thus, it appears that water surface temperature (and water column temperature as a whole) and Secchi disk transparency had the greatest effects on plant biomass for each site in this study.

Starch Content

Without data for an entire year, it is difficult to assign particular significance to the May through September levels of whole-plant starch content found in this study. M. spicatum, at one site in Lake Wingra, Wisconsin in both 1974 and 1975, showed distinct seasonal above- and below-sediment total nonstructural carbohydrate content

Table VII. Water column nutrients (ppm) at RK 78.2, the skimmer wall of Bull Run Steam Plant, Melton Hill Reservoir.

Year	Month	NO_2, NO_3	NH_3	P-Total	K-Total
1977	5	0.59	0.08	0.03	----
	6	----	----	----	----
	7	0.61	0.03	0.02	2.00
	8	0.72	0.02	0.03	----
	9	----	0.03	----	----
1978	5	0.62	0.08	0.10	----
	6	0.63	0.01	0.01	1.10
	7	1.00	0.03	0.01	----
	8	0.12	0.02	0.01	----
	9	0.49	0.06	0.02	1.80
			NH_3, NH_4		
1979	5	----	----	----	----
	6	----	----	----	----
	7	----	----	----	----
	8	0.65	0.02	----	----
	9	----	----	----	----

---- = Data not available.

Source: TVA, Water Quality & Ecology Branch.

patterns (Titus and Adams, 1979). This was not the case in plants sampled from Melton Hill Reservoir. These differences might be explained by the dissimilarities in climatic regimes between the two locations, and/or by the lack of an entire year's data from Melton Hill Reservoir.

The rhizomes from each site contained greater percentages of starch than in their respective shoots or roots. In addition, cross sections of *M. spicatum* stems and rhizomes revealed more starch bodies located in the rhizome sections than in the stem sections (Figure 18). From these facts, it is hypothesized that *M. spicatum* rhizomes are used for starch storage. Titus and Adams (1979) claim *M. spicatum* has no conspicuous total nonstructural carbohydrate storage organs. The findings in this study dispute their opinion.

Site 3, the embayment, had relatively high percentages of starch in all plant segments. Site 3 presented an ideal location for *M. spicatum* growth in Melton Hill Reservoir. Main channel reservoir sites were not ideal for *M. spicatum* growth.

Conclusions

The sites in this study of Melton Hill Reservoir were significantly different in water column and sediment characteristics. *M. spicatum* stand biomass values reflected the quality of site characteristics among the sites. Stand biomass values were most associated with water temperature and depth of light penetration. Sediment textural and nutrient characteristics appeared not to vary enough to cause significant differences in stand biomass values that were found at the studied sites.

The embayment outside the main channel of the reservoir allowed for optimal M. spicatum growth in comparison to the main channel sites. However, the warm water discharged from Bull Run Steam Plant appeared to have had a positive effect upon the main channel for increased plant growth. This was reflected in the higher stand biomass values found at the site located directly below the Steam Plant.

No seasonal trend was found in whole-plant starch content. Rhizome starch content was usually greater than shoot or root starch content. Rhizomes appear to be organs for starch storage. Study of rhizome and stem anatomy suggests that rhizomes are buried stem sections.

Management Implications

Mechanical harvesting exists as one of the major techniques available for controlling unwanted and excessive M. spicatum growth (Harmon and Amundsen, in press). A primary drawback to this control method arises from the plant's highly successful ability to resprout from its root crowns. If the plant was less successful in resprouting, mechanical harvesting would become a more useful control technique.

M. spicatum's ability to resprout from root crowns after above-sediment biomass harvesting may be directly related to its level of stored carbon in the form of starch. If further study proves this to be correct, mechanical harvesting would be more effective if timed to take place when and where root and rhizome starch reserves were low.

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LITERATURE CITED

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APPENDIX

Table A-1. Mean sediment percent sand and standard deviations* for each site and sampling time (N=4).

Month	Site 1	Site 2	Site 3	Site 4	Site 5
5	25.0 (2.7)*	28.3 (3.6)	24.5 (13.2)	50.3 (1.9)	62.0 (1.1)
6	27.8 (0.3)	32.8 (4.7)	19.5 (6.6)	60.0 (1.1)	57.8 (8.5)
7	27.3 (4.1)	38.8 (1.4)	24.8 (12.9)	58.3 (5.2)	58.5 (4.9)
8	26.0 (0.0)	29.5 (4.9)	16.8 (6.3)	61.5 (1.6)	62.0 (3.3)
9	29.0 (11.5)	34.3 (6.9)	20.3 (12.3)	56.5 (0.0)	54.0 (0.6)

*Standard deviations listed within parentheses.

Table A-2. Mean sediment percent silt and standard deviations* for each site and sampling time (N=4).

Month	Site				
	1	2	3	4	5
5	63.8 (2.5)*	61.8 (2.5)	59.5 (10.4)	42.8 (3.6)	32.8 (0.3)
6	64.3 (0.3)	58.8 (4.1)	62.3 (3.6)	33.0 (2.2)	37.8 (7.4)
7	63.8 (4.1)	52.8 (1.9)	55.5 (11.5)	36.8 (4.1)	37.0 (3.8)
8	64.0 (0.6)	60.3 (4.1)	61.0 (3.3)	33.8 (1.4)	34.3 (3.0)
9	57.0 (12.1)	52.8 (9.0)	56.0 (6.0)	37.8 (0.3)	40.5 (0.6)

*Standard deviations listed within parentheses.

Table A-3. Mean sediment percent clay and standard deviations* for each site and sampling time (N=4).

Month	Site				
	1	2	3	4	5
5	11.3 (0.3)*	10.0 (1.1)	16.0 (2.7)	7.0 (1.6)	5.3 (0.8)
6	8.0 (0.0)	8.5 (0.6)	18.3 (3.0)	7.0 (1.1)	4.5 (1.1)
7	9.0 (0.0)	8.5 (0.6)	19.8 (1.4)	5.0 (1.1)	4.5 (1.1)
8	10.0 (0.5)	10.3 (0.8)	22.3 (3.0)	4.8 (0.3)	3.8 (0.3)
9	14.0 (0.6)	13.0 (2.2)	23.8 (6.3)	5.8 (0.3)	5.5 (0.0)

*Standard deviations listed within parentheses.

Table A-4. Mean sediment OM (ppm) and standard deviations* for each site and sampling time (N=4).

Month	Site 1	Site 2	Site 3	Site 4	Site 5
5	3.4 (0.2)*	3.5 (0.0)	5.5 (1.2)	2.4 (0.3)	1.5 (0.3)
6	3.1 (0.1)	3.8 (0.1)	6.2 (0.2)	2.1 (0.3)	1.7 (0.1)
7	3.1 (0.3)	3.4 (0.2)	6.3 (0.2)	2.3 (0.2)	1.3 (0.2)
8	3.3 (0.3)	3.6 (0.1)	6.0 (0.1)	2.3 (0.2)	1.3 (0.0)
9	3.0 (0.8)	2.9 (0.8)	6.5 (0.2)	2.6 (0.1)	2.1 (0.2)

*Standard deviations listed within parentheses.

Table A-5. Mean sediment NO_3 (ppm) and standard deviations* for each site and sampling time (N=4).

	Site				
Month	1	2	3	4	5
5	8.9 (1.5)*	10.6 (0.6)	23.9 (1.2)	16.9 (2.1)	15.8 (1.6)
6	11.6 (2.8)	10.3 (2.1)	22.7 (0.2)	21.8 (3.0)	19.9 (0.4)
7	11.9 (3.4)	16.1 (1.3)	34.5 (1.1)	18.3 (1.4)	19.6 (1.9)
8	13.1 (1.0)	20.5 (1.6)	40.8 (9.6)	37.8 (3.0)	18.8 (1.9)
9	23.6 (14.7)	18.2 (8.1)	55.5 (13.2)	39.7 (4.2)	34.8 (3.8)

*Standard deviations listed within parentheses.

Table A-6. Mean sediment available P (ppm) and standard deviations* for each site and sampling time (N=4).

Month	Site				
	1	2	3	4	5
5	5.3 (0.3)*	3.8 (1.4)	1.0 (0.0)	3.8 (3.0)	2.3 (1.4)
6	7.0 (0.0)	5.3 (0.8)	1.0 (0.0)	3.0 (2.2)	4.8 (1.4)
7	6.0 (0.6)	4.3 (1.9)	1.0 (0.0)	2.3 (0.3)	3.5 (1.1)
8	4.8 (0.8)	3.5 (0.6)	1.0 (0.0)	1.3 (0.3)	3.8 (0.3)
9	5.5 (0.6)	3.5 (0.6)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)

*Standard deviations listed within parentheses.

Table A-7. Mean sediment available K (ppm) and standard deviations* for each site and sampling time (N=4).

Month	Site				
	1	2	3	4	5
5	56.3 (4.1)*	58.8 (4.1)	71.3 (1.4)	56.3 (4.1)	41.3 (4.1)
6	56.3 (4.1)	61.3 (12.3)	67.5 (8.2)	56.3 (12.3)	41.3 (1.4)
7	60.0 (5.5)	55.0 (5.5)	70.0 (5.5)	52.5 (5.5)	38.8 (4.1)
8	63.8 (4.1)	61.3 (1.4)	77.5 (8.2)	45.0 (2.7)	41.3 (1.4)
9	72.5 (5.5)	63.8 (4.1)	66.3 (4.1)	63.8 (9.6)	49.0 (4.4)

*Standard deviations listed within parentheses.

Table A-8. Water surface (1.5 m below surface) temperature (C) for each site and sampling time (N=1).

Month	Site 1	2	3	4	5
5	12.5	18.0	26.0	14.5	15.0
6	13.5	17.0	25.0	19.0	18.0
7	17.0	22.0	27.0	21.0	17.0
8	16.0	16.0	29.0	25.0	20.0
9	18.0	25.0	30.0	24.0	22.0

Table A-9. Conductivity (μmhos) for each site and sampling time (N=1).

Month	Site 1	2	3	4	5
5	155	190	150	225	195
6	160	170	135	180	170
7	128	145	290	142	155
8	170	175	120	205	190
9	195	225	150	240	230

Table A-10. Secchi disk transparency (m) for each site and sampling time (N=1).

	Site				
Month	1	2	3	4	5
5	1.0	0.9	0.5	0.9	0.8
6	1.0	1.0	0.5	1.0	0.8
7	0.6	0.4	0.3	0.4	0.6
8	0.8	0.8	0.2	0.8	0.8
9	0.4	0.5	0.7	0.4	0.8

Table A-11. Rotated factor pattern resulting from factor analysis.

Site Variables	Factors								
	1	2	3	4	5	6	7	8	9
Sand	-0.94[a]	0.21	-0.01	0.13	-0.03	-0.10	-0.04	0.09	0.03
Clay	0.91	0.10	0.10	-0.05	0.20	0.06	-0.01	0.15	0.10
pH	-0.15	0.97	-0.05	0.11	0.03	-0.09	-0.07	0.06	0.04
P	-0.12	-0.66	-0.11	-0.11	-0.22	-0.00	0.67	-0.15	-0.08
K	0.66	-0.15	0.09	0.04	0.21	0.70	-0.01	0.06	0.03
NO_3	0.26	0.57	0.47	0.09	0.13	0.06	-0.13	0.16	0.56
OM	0.90	0.12	-0.03	-0.07	0.16	0.13	-0.18	0.19	0.09
Water surface temperature	0.35	0.41	0.33	0.03	0.40	0.09	-0.22	0.61	0.13
Conductivity	-0.13	0.13	0.11	0.98	-0.01	0.02	-0.04	0.01	0.02
Secchi disk transparency	-0.22	-0.09	-0.23	0.01	-0.93	-0.10	0.09	-0.10	-0.04
Month	-0.01	-0.00	0.97	0.11	0.20	0.04	-0.04	0.07	0.06

[a]Underlined factor scores indicate important site variable(s) for that factor.

Table A-12. Mean standing crop, rhizome and root ash-free weights (g/m^2) and standard deviations for each site and sampling time (N=6).

Site	Month	Standing Crop	SD	Rhizome	SD	Root	SD
1	5	11.67	5.17	0.51	0.28	0.52	0.31
	6	23.12	19.44	2.14	2.05	2.48	2.57
	7	14.41	3.88	1.22	0.55	0.55	0.28
	8	11.46	7.44	1.94	1.58	0.58	0.49
	9	30.53	15.35	1.66	2.06	2.26	2.38
2	5	72.90	31.57	3.47	1.29	4.43	1.64
	6	57.15	14.44	5.20	1.79	4.62	1.47
	7	60.88	18.64	4.82	1.35	5.02	1.54
	8	81.60	48.40	2.94	1.36	4.39	2.02
	9	152.28	72.29	4.70	2.31	7.30	3.85
3	5	124.99	87.76	5.60	4.60	23.50	19.00
	6	229.10	156.67	5.22	3.00	29.90	17.76
	7	336.92	117.75	7.82	2.28	48.66	16.62
	8	274.66	112.82	5.66	2.35	27.69	12.66
	9	299.12	92.39	4.52	1.10	25.54	7.37
4	5	51.71	12.24	5.12	1.23	9.75	2.77
	6	79.16	17.98	6.06	1.34	11.96	2.26
	7	106.19	23.92	7.26	1.98	16.47	4.35
	8	129.48	48.77	6.31	2.88	9.86	3.96
	9	86.85	21.23	5.07	1.47	10.60	2.09
5	5	42.59	15.24	4.75	0.85	6.96	1.52
	6	56.35	19.21	4.99	1.28	5.58	1.30
	7	20.82	13.68	1.82	1.30	2.40	1.79
	8	33.26	21.84	1.62	0.95	1.96	1.19
	9	68.51	16.97	3.75	1.03	4.36	1.13

Table A-13. Mean shoot, rhizome and root percent ash contents and standard deviations for each site and sampling time (N=6).

Site	Month	Shoot	SD	Rhizome	SD	Root	SD
1	5	49.35	5.47	24.70	0.00	45.75	6.06
	6	61.93	14.75	31.73	4.39	47.58	6.28
	7	53.80	13.67	29.10	4.53	40.33	7.36
	8	57.15	8.75	34.37	2.76	35.60	1.93
	9	35.60	16.31	25.80	5.68	34.75	9.24
2	5	62.17	2.06	28.02	4.31	41.60	2.85
	6	61.23	4.18	29.38	4.35	38.63	6.28
	7	57.05	3.50	30.18	5.77	33.88	3.92
	8	60.57	7.85	32.87	6.16	34.47	5.76
	9	34.23	2.21	18.82	7.52	37.83	17.30
3	5	47.67	13.24	13.53	1.19	30.03	6.17
	6	29.40	10.90	14.00	1.66	27.92	10.86
	7	32.93	7.39	13.43	2.32	25.50	7.42
	8	27.22	9.19	12.72	1.98	29.50	10.75
	9	31.02	7.68	13.23	1.87	39.07	6.50
4	5	58.92	5.40	21.63	9.27	44.20	3.84
	6	59.37	1.62	23.13	3.50	41.58	3.19
	7	44.32	2.17	28.20	5.30	39.00	5.83
	8	42.18	2.78	31.95	4.61	31.43	1.83
	9	28.17	1.11	27.68	4.61	35.75	7.35
5	5	58.92	5.40	21.63	9.27	44.20	3.84
	6	59.37	1.62	23.13	3.50	41.58	3.19
	7	44.32	2.17	28.20	5.03	39.00	5.83
	8	42.18	2.78	31.95	4.61	31.43	1.83
	9	28.17	1.11	27.68	4.61	35.75	7.35

Table A-14. Mean root:shoot and rhizome:shoot ratios (ash-free weight) for each site and sampling time (N=6).

Site	Ratio	Month				
		5	6	7	8	9
1	Root:Shoot	0.05	0.11	0.04	0.05	0.07
	Rhizome:Shoot	0.04	0.09	0.09	0.17	0.05
2	Root:Shoot	0.06	0.08	0.08	0.05	0.05
	Rhizome:Shoot	0.05	0.09	0.08	0.04	0.03
3	Root:Shoot	0.19	0.13	0.14	0.10	0.09
	Rhizome:Root	0.05	0.02	0.02	0.02	0.02
4	Root:Shoot	0.19	0.15	0.16	0.08	0.12
	Rhizome:Shoot	0.10	0.08	0.07	0.05	0.06
5	Root:Shoot	0.16	0.10	0.12	0.06	0.06
	Rhizome:Shoot	0.11	0.09	0.09	0.05	0.06

Table A-15. Mean shoot, rhizome and root percent starch contents and standard deviations for each site and sampling time (N=6).

Site	Month	Shoot	SD	Rhizome	SD	Root	SD
1	5	0.42	0.28	2.70	0.68	0.50	0.42
	6	0.03	0.08	0.41	0.22	0.27	0.14
	7	0.08	0.10	3.37	1.30	1.03	0.20
	8	0.00	0.00	1.47	0.08	1.17	0.27
	9	0.12	0.12	1.70	0.81	0.63	0.44
2	5	0.08	0.08	3.53	0.62	1.30	0.24
	6	0.00	0.00	1.77	0.48	0.62	0.18
	7	0.07	0.10	1.90	0.51	0.68	0.23
	8	0.17	0.21	1.37	0.41	0.60	0.16
	9	0.35	0.22	2.60	0.77	0.77	0.16
3	5	2.65	0.45	4.36	0.67	1.93	0.58
	6	3.77	1.82	5.60	0.85	1.88	0.65
	7	2.73	0.85	7.82	1.20	3.12	1.02
	8	4.27	1.87	7.45	1.18	3.03	1.14
	9	3.47	1.73	6.70	2.48	1.37	0.61
4	5	0.40	0.16	4.33	1.83	1.58	0.61
	6	0.23	0.10	2.70	1.60	0.98	0.41
	7	0.10	0.09	1.77	0.86	0.62	0.31
	8	0.73	0.34	1.70	0.59	0.75	0.29
	9	0.23	0.20	1.18	0.89	0.05	0.08
5	5	0.13	0.12	1.23	0.98	0.16	0.01
	6	0.08	0.10	2.17	0.36	1.05	0.40
	7	0.13	0.12	1.78	0.31	1.17	0.37
	8	0.02	0.04	3.15	0.72	1.28	0.25
	9	0.32	0.18	2.58	1.06	1.45	0.52

Table A-16. Summarized canonical correlation analysis between biotic and site variables.[a]

Site	Biotic variables	Statistics[b] A	B	C	D	E	F	Site variables[c] Factor 1	Factor 2	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
1	Standing crop ash-free weight g/m²	2	0.60	35.52%	0.77	0.00	1.39		10.63(NO_3)[d]		-9.48			18.31	
	Rhizome ash-free weight g/m²	1	0.76	45.26%	0.87	0.00	-1.83							-12.83	
	Root ash-free weight g/m²	1					1.70		6.28(NO_3)					12.83	
	Shoot % ash	2	0.68	42.99%	0.83	0.00	0.97		-8.47(NO_3)		6.96			-12.84	
	Rhizome % ash	No correlation with site variables													
	Root % ash	1	0.76	47.45%	0.87	0.00	1.02		-11.26(P)		6.52			-14.47	
	Shoot % starch	1	0.78	50.07%	0.88	0.00	0.46		-16.28(pH)					-25.13	
	Rhizome % starch	1					-0.35		-16.28(P)					-25.13	
	Root % starch	1					-0.72		16.28(pH)					-25.13	
2	Standing crop ash-free weight g/m²	1	0.85	49.87%	0.92	0.00	0.82	0.54(Clay)		1.69				0.99	0.57
	Rhizome ash-free weight g/m²	1					-1.15						-0.73	-0.99	
	Root ash-free weight g/m²	2	0.63	36.79%	0.79	0.01	2.47							0.64	
	Shoot % ash	1	0.91	61.19%	0.95	0.00	0.71	0.24(Clay)		0.68	0.14			-0.54	
	Rhizome % ash	1					0.37	0.24 "		-0.68				-0.54	
	Root % ash	1					-0.19	0.24 "							0.49
	Shoot % starch	1	0.81	43.98%	0.90	0.00	0.97			1.21				0.09	0.59
	Rhizome % starch	1					0.23		-0.72(NO_3)	1.21				0.09	
	Root % starch	No correlation with site variables													
3	Standing crop ash-free weight g/m²	2	0.72	35.30%	0.85	0.00	1.39	2.66(Clay)	2.12(NO_3)					1.26	
	Rhizome ash-free weight g/m²	1	0.85	41.65%	0.92	0.00	-2.44			-1.60					
	Root ash-free weight g/m²	2					-2.52			-1.60	2.06				
	Shoot % ash	1	0.69	44.04%	0.83	0.00	-0.59	1.76(OM)		-1.13					
	Rhizome % ash	No correlation with site variables													
	Root % ash	2	0.58	37.42%	0.76	0.02	0.72			-1.13	1.69			2.00	
	Shoot % starch	1	0.73	50.99%	0.86	0.00	0.23			-0.36					
	Rhizome % starch	No correlation with site variables													
	Root % starch	1					0.96				-1.54				
4	Standing crop ash-free weight g/m²	1	0.92	47.51%	0.96	0.00	1.65		0.79	-0.44				1.15	
	Rhizome ash-free weight g/m²	1					-1.17			0.44					
	Root ash-free weight g/m²	2	0.79	41.09%	0.89	0.00	-2.02			0.22	-0.67				
	Shoot % ash	1	0.97	65.10%	0.98	0.00	0.91		-0.23		1.08		0.55	-0.79	
	Rhizome % ash	1					-0.12		-0.54					-0.79	
	Root % ash	1					0.06		-0.54					-0.79	
	Shoot % starch	1	0.88	43.60%	0.94	0.00	0.35					-0.76			
	Rhizome % starch	2	0.75	37.54%	0.87	0.00	-0.32		1.20					1.07	
	Root % starch	1					0.99		-0.39		-0.85		1.13	-0.66	
5	Standing crop ash-free weight g/m²	1	0.93	42.44%	0.96	0.00	1.25	0.89(OM,K)	2.90	0.90	7.96			5.67	
	Rhizome ash-free weight g/m²	3	0.55	25.12%	0.74	0.01	3.26				2.09				
	Root ash-free weight g/m²	2	0.71	32.45%	0.84	0.00	2.14				3.50			-1.31	
	Shoot % ash	1	0.95	49.27%	0.97	0.00	0.98		-3.56		11.12				
	Rhizome % ash	No correlation with site variables													
	Root % ash	2	0.84	36.89%	0.84	0.00	0.85		-1.38		-2.88			-3.19	
	Shoot % starch	1	0.86	57.96%	0.93	0.00	0.60	0.53(OM,K)	2.60	0.39					
	Rhizome % starch	1					0.61				5.81			4.86	
	Root % starch	1					0.49							4.86	

Table A-16. Continued.

[a]Only high site variable coefficients are reported here. Correlation signs were checked against raw data and when necessary, changed to correspond to the sign of the correlation between the raw biotic and site variables.

[b]A=Canonical variate, B=Eigenvalue, C=Amount of variation explained by the canonical variate, D=Canonical correlation, E=P<, F=Standardized coefficients of biotic variables in canonical variate.

[c]Standardized coefficients of site variables in canonical variate.

[d]Denotes the site variable(s) responsible for that Factor score.

VITA

Janice McMahon Harmon was born in Evanston, Illinois on December 5, 1949. She attended grammar schools in Des Plains and Deerfield, Illinois and was graduated from Hudson High School, Hudson, Ohio in June 1968. The following September she entered Hiram College, Hiram, Ohio. She transferred the following year to the University of Dayton, Dayton, Ohio, and in April 1972 she received a Bachelor of Arts degree in Psychology.

The next four years she held various jobs ranging from helping to start and run a town weekly newspaper in Brockton, Massachusetts to working as a corporate paralegal in a Cincinnati, Ohio law firm.

In March 1976 she entered Miami University, Oxford, Ohio for an intensive year of botany, chemistry and math courses. In the fall of 1977 she began study toward a Master of Science degree at The University of Tennessee, Knoxville.

She is married to Mark E. Harmon.