ECOLOGICAL STUDIES OF THE HAMILTON MARSHES
PROGRESS REPORT FOR THE PERIOD
JUNE, 1974 - JANUARY, 1975

BY

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INTRODUCTION AND ACKNOWLEDGEMENTS

The Hamilton Marshes are an invaluable asset of the people of Hamilton Township and surrounding areas. We hope that our studies of the marshes will demonstrate their unique qualities and that the data will be used in the wise management of this resource.

This report summarizes our research for the period April, 1974 to January, 1975. This is a preliminary report but we believe that our final conclusions will not be altered after the termination of our ongoing research projects. Several studies have been completed and several continue at present. We have completed our analysis of the vegetation of the marshes as well as the primary productivity studies. A separate study of wild rice has been completed. This report also contains papers on the ecology of two other marsh species that have been studied as independent research projects by two Rider College students. Water chemistry, nutrient cycling, and mud algae studies will continue until June, 1975. Detritus and litter decomposition studies will continue until October, 1975. Incomplete results of those studies are presented in this report.

We would like to thank the many people who have encouraged us during our investigations. Mr. Gerald Hererra, Mr. Richard Klockner, and Mr. Haig Kasabach have been especially helpful in coordinating our activities with the Hamilton Township Environmental Commission and in permitting us to use the facilities of the Hamilton Township Sewage Treatment Plant as a base of many of our field operations.

Financial support for our work has been provided by the Hamilton Township Environmental Commission, the National Geographic Society, The Society of the Sigma Xi, and a Rider College Grant-in-Aid.

Special thanks go to Penelope Simpson who designed and spent long hours making the nylon bags that were used in our litter decomposition experiment. To our wives, Penny and Jan, also go our thanks for their patience during many of the long days and vacationless weekends. We would also like to thank our student assistants: Paula Bozowski, Herbert Grover, Barry Kline, Thomas Leslie, Richard McClellan, and David West.

BACKGROUND INFORMATION

The Hamilton Marshes occupy approximately 500 Hectares of tidal and nontidal land adjacent to the Delaware River near Trenton, N. J. We estimate that there are approximately 260 Hectares of tidal marshland. The marsh is bordered on the north by a highly developed section of Hamilton Township. On the western boundary is the Delaware and Raritan Canal. Except for the Canal side, the natural border of the marsh is a steep hill-side that extends almost entirely around the marsh. In most places, residental developments occur directly on the hill-sides that overlook the marshes. The marshes are impacted by a number of facilities. The most important are: DeLorenzo land fill, Hamilton Township Sewage Treatment Plant, Ocean Spray Cranberry Company, Yardville Sanitary Landfill, Yates Industrial, and Bordentown Reformatory Sewage Treatment Plant, (Walton and Patrick, 1973). In addition several, large storm-drains discharge runoff water.

Our studies were initiated in the summer of 1973. The original purpose was to quantify the interelationships of the plants and animals that are found in the marshes. In the course of our work it became apparent that the marshes were extremely valuable and ecologically interesting. Endangered birds spend several months in the marshes, there is great potential for utilization of the area for environmental education, the marshes are valuable as a sink for water during peak flow periods after heavy rainfall, and perhaps most importantly, we believed that the marshes serve a valuable function in the processing and storage of nutrients. It was obvious to us that it was necessary to document the ecological and social significance of the marshlands. As a result, our research was expanded to include important functional aspects of the marshes. This report summarizes our research to date.

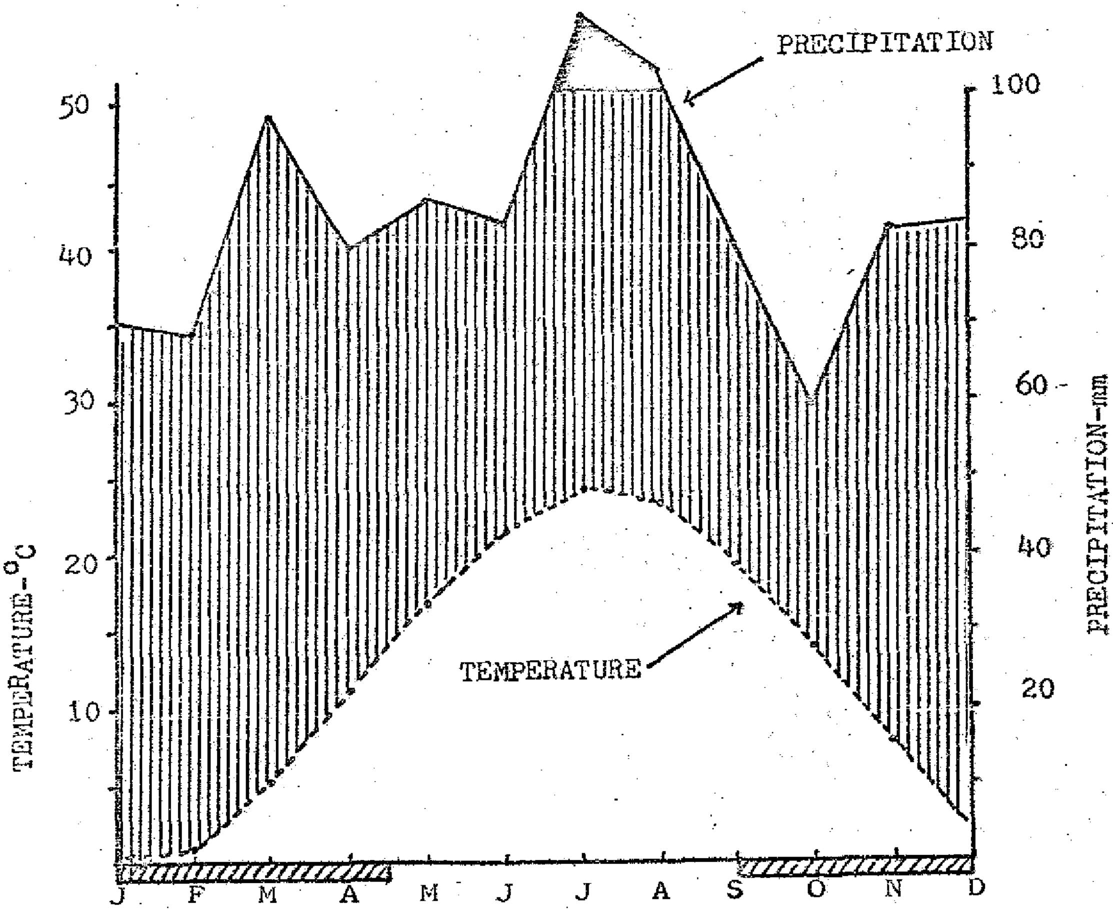
CLIMATE

Trenton has a typical temperate climate (Walter and Lieth, 1960) with a cold but not long winter (Figure 1).

Precipitation averages 1020 mm annually and it is fairly evenly distributed with a maximum in July and a minimum in October. The average temperature is 12.1°C and the growing season lasts from mid-April until late September. Within the Hamilton Marshes, water supply is always adequate and temperature, along with photoperiod, seem to be the most important factors in controlling biological activities of organisms.

Figure 1. Climatic diagram for Trenton, N.J. The mean annual temperature and precipitation are shown next to the climatic station name. Because the precipitation curve is always above the temperature curve, the climate is interpreted as not having a dry season. Along the abscissa are plotted the months of the year (January - December) and a shaded area which shows the number of months during which there is a chance of temperatures that fall below 0°C. Trenton has a Type VI climate according to the system of Walter and Lieth (1960). Precipitation above 100 mm per month is plotted on the scale of 1:3 (10°C:30mm ppt.).

TRENTON 12.1°C 1020 mm



SOILS

Introduction

The U.S. Department of Agriculture Soil Conservation Service (Markley, 1971) classifies all substrates within the Hamilton Marshes as tidal marsh soils. They are highly organic silt flat soils that are flooded twice daily. The Soil Conservation Service describes the soils as "brownish" with "an average thickness of about three feet". In places the soil might be as thick as 10 feet or as shallow as one foot. "Below the layers of silt are sand and gravel and, in some places, clay". Little other technical data is provided by the Soil Conservation Service, primarily because the soils are of minimal economic value.

We have collected substrate samples throughout the marsh (Figure 2 and Table 1), and have or will perform various analyses on them. To date, we have determined organic matter, nitrate nitrogen, and ammonium nitrogen for an entire set of samples. The samples will also be analyzed for phosphorous, magnesium, calcium, potassium, and sodium.

Methods

Soil cores were taken with a Weldco light duty gravity type core sampler. A preliminary study showed that the instrument provided a sample which covered most of the rooting zone of the vegetation - approximately the upper 50 cm.

Figure 2. Schematic diagram of the Hamilton Marshes. The pattern of water movement into and out of the marsh is shown at the lower right.

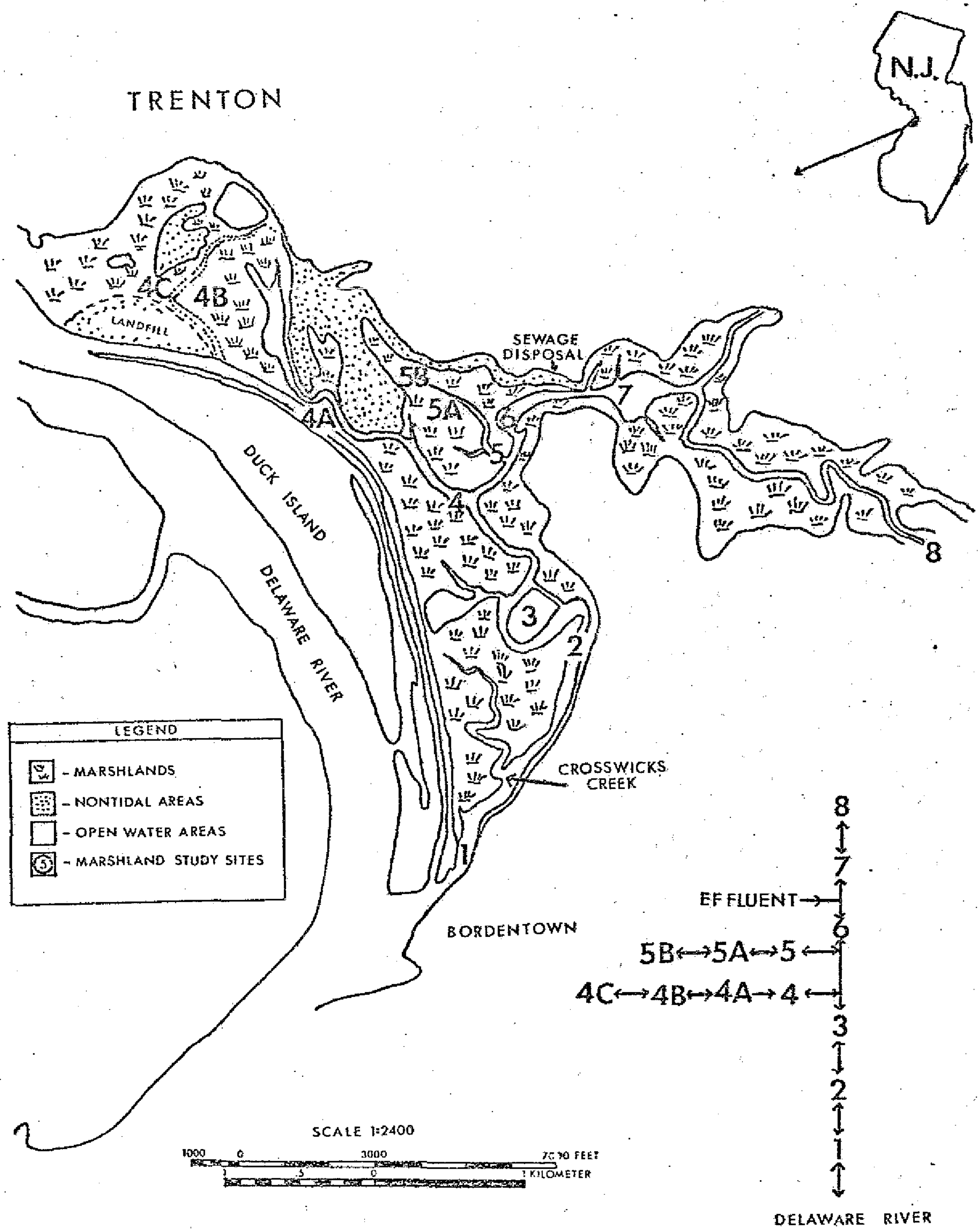

TRENTON
N.J.
4C
4B
LANDFILL
4A
5B
5A
5
SEWAGE
DISPOSAL
7
8
DUCK ISLAND
DELAWARE RIVER
4
3
2
1
CROSSWICKS
CREEK
BORDENTOWN
LEGEND
- MARSHLANDS
- NONTIDAL AREAS
- OPEN WATER AREAS
- MARSHLAND STUDY SITES
SCALE 1:2400
1 KILOMETER
EFFLUENT
5B↔5A↔5
4C↔4B↔4A→4
DELAWARE RIVER

Table 1

This table shows which experiments were performed (+) at each of the sites. See Figure 2 for the location of the sites.

EXPERIMENT

	PRIMARY PRODUCTION	WATER CHEMISTRY	DETRITUS	LITTER DECOMPOSITION	SOIL NUTRIENTS	SOIL ALGAE	WILD RICE STUDY
Site 1	-	+	-	-	-	-	-
Site 2	-	+	+	-	-	-	-
Site 3	+		-	-	+	-	-
Site 4	-	+	+	-	-	-	-
Site 4A	+	+	-	+	+	+	+
Site 4B	+	+	-	+	+	-	+
Site 4C	+	+	-	-	-	-	-
Site 5	+	+	-	+	+	+	+
Site 5A	+	+	-	+	+	+	+
Site 5B	+	-	-	-	+	+	+
Site 6	-	+	-	-	-	-	-
Site 7	+	+	+	-	+	+	+
Site 8	-	+	-	-	-	-	-

Samples were collected in the field by driving the sampler into the substrate and removing the core. Samples were collected in the major vegetation zones. The cores were returned to the laboratory and sliced into sections representing 10 centimeter depth intervals. The plugs were then air dried and ground to pass through a 2mm soil sieve. Organic matter was determined by ignition in a muffle furnace at 600°C. Nitrogen content was determined by using a microdiffusion technique (Stanford, et al, 1973). Initially samples were analyzed in duplicate but because there was very little variability between subsamples of the same soil plug, we decided to perform one analysis. In the future we will combine corresponding plugs from 3 soil cores at each sampling area. Triplicate determinations will be made on the combined plugs.

Results

Table 2 shows the results of the organic matter determinations. With one exception, there is no significant trend in organic matter from the top of the soil to the 50 cm level and there is only a slight decrease in organic matter from the top to the bottom of the profile. The exception is at Site 4A where there is a sharp decrease in organic matter between 20 and 30 cm. We attribute this to the fact that the nearby stream probably flowed over that site at one time and that it has since changed course and a soil has been built upon the old stream bed.

The amount of organic matter in the soils of the marsh is much

Table 2. Organic matter analysis of marsh soils. Refer to Figure 2 for locations of the sampling sites. All values are means (%) $\pm$ 1 standard error.

Table 2

ORGANIC MATTER CONTENT OF MARSH SOILS

<u>Site Number</u>		7	7	7
<u>Dominant Vegetation</u>		Yellow Water lily	Arrow arum	Sweet flag
<u>Number of samples</u>		1	1	1
<u>Soil Horizon</u>	0-10 cm	13.2	21.1	30.0
	10-20 cm	13.8	16.2	X
	20-30 cm	14.3	16.1	34.2
	30-40 cm	14.7	15.4	23.8
	40-50 cm	14.6	12.4	21.2
MEAN ± 1 S.E.$_{\bar{X}}$:		14.1 ± .6	18.7 ± 6.6	27.3 ± 5.9

<u>Site Number</u>		5	5	5
<u>Dominant Vegetation</u>		Yellow Water lily	Arrow arum	Reed Canary grass
<u>Number of samples</u>		4	2	3
<u>Soil Horizon</u>	0-10 cm	13.4 ± 2.0	15.2 ± .9	18.1 ± 4.1
	10-20 cm	13.3 ± 2.3	15.8 ± .5	17.9 ± 1.0
	20-30 cm	16.1 ± 3.7	16.8 ± 0.	15.8 ± 2.5
	30-40 cm	12.4 ± 1.2	16.3 ± .5	14.1 ± 2.1
	40-50 cm	12.0 ± 2.0	12.5 ± .8	12.8 ± 1.6
MEAN ± 1 S.E.$_{\bar{X}}$:		13.4 ± 2.6	15.3 ± 1.6	15.8 ± 3.0

Site Number		5A	5A	5A
Dominant Vegetation		Yellow Water lily	Arrow arum	Sweet flag
Number of samples		3	2	3
Soil Horizon	0-10 cm	20.4 ± 1.6	21.4 ± 1.0	28.6
	10-20 cm	20.7 ± 1.1	22.3 ± 2.5	24.5 ± 2.0
	20-30 cm	20.3 ± 2.4	20.1 ± .7	36.6 ± .2
	30-40 cm	19.7 ± 6.6	18.7 ± 5.5	23.4 ± .4
	40-50 cm	15.3 ± 7.7	21.2 ± 1.9	22.3 ± .2
MEAN ± 1 S.E.$_{\bar{X}}$:		19.3 ± 4.5	20.7 ± 2.5	26.8 ± 5.8

Site Number		5B	5B
Dominant Vegetation		Arrow arum	Cattail and Sweet flag
Number of samples		3	4
Soil Horizon	0-10 cm	21.7 ± 5.9	46.5 ± 5.1
	10-20 cm	26.5 ± 2.5	44.5 ±10.1
	20-30 cm	29.2 ± 9.1	45.7 ± 7.2
	30-40 cm	37.8 ± 3.3	41.8 ±13.0
	40-50 cm	39.1 ± 5.6	19.3 ± 4.7
MEAN ± 1 S.E.$_{\bar{X}}$:		30.6 ± 7.8	39.6 ±12.6

Site Number		4A	4A	4A
Dominant Vegetation		Loosestrife	Arrow arum	Cattail
Number of samples		2	3	3
Soil Horizon	0-10 cm	25.3 ± 4.5	20.3 ± 2.9	23.3 ± 3.3
	10-20 cm	22.3 ± 5.8	15.5 ± 3.5	27.9 ± 2.5
	20-30 cm	15.7 ± 5.4	7.8 ± 1.3	22.5 ± 1.5
	30-40 cm	8.4 ± 1.4	4.5 ± .6	12.4 ± 3.6
	40-50 cm	5.0 ± .2	4.2 ± .5	6.1 ± 1.1
MEAN ± 1 S.E.$_{\bar{X}}$:		15.3 ± 9.0	10.5 ± 6.8	18.4 ± 8.6

higher than most upland forest or agriculture soils but not as high as one finds in peat dominated soils. The fact that there is little differentiation from the top of the substrate to a depth of 50 cm implies that the conditions of deposition have not changed drastically for a long period of time, probably since sections of the marsh were diked. Our experience has been that most of the movement of inorganic sediment takes place in or near the channels. During the summer there is a net increase in the amount of material in the channels, probably due to the presence of vegetation which acts as a trap, and that during the winter months much of the accumulated sediment is washed away.

There are significant differences between the amounts of organic matter at different habitats. Areas dominated by yellow water lily, mostly in and along stream channels, have lower amounts of organic matter (Table 2). This is probably due to the scouring effects of tidal waters. High marsh areas have higher amounts of organic matter. Except for Site 4A, most of the arrow arum areas have between 10-15% organic matter. There are locations in the marsh where the substrate is extremely soft and walking is very precarious. Under those circumstances we have measured the greatest amounts of organic matter. Site 5B is an example of this situation. Sweet flag and cattail dominate the area and the organic matter is as high as 30-40%. One section of Site 5A is dominated by sweet flag and the amount of organic matter is greater at that location also (Table 2).

Total inorganic nitrogen (nitrate and ammonium) of soils in the Hamilton Marshes is not appreciably different from surface organic layers of many soils. There is, however, a significant difference in the relative amounts of nitrate nitrogen (NO_3^-) and ammonium (NH_4^+) nitrogen. The inorganic forms of nitrogen in most soils are ammonium, nitrate, and nitrite (American Society of Agronomy, 1965). Under most conditions, nitrite is present in very small amounts compared to the other forms and the quantity is usually assumed to be negligible. Ammonium is primarily formed as a result of the breakdown of organic matter. Under aerobic conditions (with oxygen present in the soil) NH_4^+ is usually short-lived and is oxidized to nitrate nitrogen, with nitrite as an intermediate in the process. As a result, most soils contain more nitrate than ammonium. Under anaerobic (lack of oxygen) conditions, the ratio is changed. Because there is little oxygen and because of low pH there is usually little nitrification in anaerobic soils. As a result, ammonium accumulates and it is more abundant than nitrate. Such is the case in the Hamilton Marshes. Table 3 shows our summary statistics for inorganic nitrogen in the marsh soils. There are no significant differences between sites. Values ranged from 19.7 ± 2.2 ppm to 29.5 ± 6.6 ppm. Within sites, differences do occur. In areas where the substrate is very

Table 3

Summary statistics for ammonium and nitrate nitrogen. All values are ppm ± 1 standard error.

	Arrow-arum	Yellow water lily	Sweet flag	Cattail	Loosestrife	Other	Site Average
			Dominant Vegetation				
Site 7	40.2 ± 20	15.7 ± 3.9	29.8 ± 6.0	X	X	X	28.6 ± 7.1
Site 5	20.9 ± 1.7	14.6 ± 2.5	X	X	X	17.9 ± 2.5	20.6 ± 1.5
	17.7 ± 3.5	25.0 ± 12.5				24.1 ± 5.2	
						24.3 ± 12.5	
Site 5A	32.0 ± 3.9	11.1 ± 1.6	43.2 ± 25.8	X	X	X	27.8 ± 4.4
	24.8 ± 11.6	14.7 ± 2.2	40.0 ± 8.4				
		17.8 ± 1.3	38.7 ± 10.2				
Site 5B	12.2 ± 3.8	X	46.3 ± 8.7	34.6 ± 2.2	X	X	29.5 ± 6.6
	16.8 ± 3.8			49.6 ± 2.8			
	17.2 ± 1.8						
Site 4A	11.3 ± 9.9	X	X	28.3 ± 5.7	21.6 ± 7.2	X	19.7 ± 2.2
	14.9 ± 6.7			23.2 ± 6.8	15.9 ± 7.8		
				28.0 ± 13.3			
Average for Vegetation Type	20.8 ± 2.9	16.5 ± 1.9	39.6 ± 2.8	31.7 ± 4.9	18.8 ± 2.8	22.1 ± 3.6	

soft and highly organic, the soil is waterlogged (sweet flag and cattail areas at Sites 5A and 5B) and there is significantly more nitrogen, especially ammonium. Habitats dominated by yellow water lily are somewhat lower in nitrogen (16.5 ± 1.9 ppm) and as stated, they are also lower in organic matter. Table 4 shows detailed ammonium and nitrate data for the study sites.

Table 4. Ammonium and nitrate data for marsh soils. Refer to Figure 2 for locations of the sample sites. All values are means (ppm) ± 1 standard error.

Table 4

AMMONIUM AND NITRATE CONTENT (p.p.m.) OF MARSH SOILS ± 1 STANDARD ERROR

Site Number		7	7	7
Dominant Vegetation		Arrow arum	Yellow water lily	Sweet flag
Number of samples		1	1	1
Soil Horizon	0-10 cm	X	9.5 ± .8	36.3 ± 4.9
	10-20 cm	37.2 ± 5.5	12.4 ± .9	18.8 ± 2.3
	20-30 cm	33.8 ± 4.8	17.0 ± 1.6	24.2 ± 2.1
	30-40 cm	14.2 ± 1.1	15.5 ± 1.3	28.8 ± 6.2
	40-50 cm	52.3 ± 11.8	18.3 ± 1.3	28.7 ± 2.8
		40.2 ± 20.0	15.7 ± 3.9	29.8 ± 6.0

Site Number		5	5	5	5
Dominant Vegetation		Arrow arum	Arrow arum	Yellow water lily	Yellow water lily
Number of samples		1	2	1	2
Soil Horizon	0-10 cm	18.5 ± 2.4	11.1 ± 2.3	11.6 ± 1.6	36.2 ± 5.0
	10-20 cm	18.2 ± 2.5	12.1 ± 2.7	10.2 ± 1.2	25.4 ± 2.8
	20-30 cm	17.1 ± 2.3	17.2 ± 2.3	10.7 ± 1.3	15.7 ± 2.8
	30-40 cm	18.0 ± 2.0	17.4 ± 1.9	14.3 ± 1.5	11.4 ± .9
	40-50 cm	20.1 ± 3.6	18.5 ± 3.3	15.8 ± 1.7	X
		20.9 ± 1.7	17.7 ± 3.5	14.6 ± 2.5	25.0 ± 12.5

Site Number		5	5	5	5A
Dominant Vegetation		Reed canary grass	Reed canary	Reed canary	Arrow arum
Number of samples		1	2	3	1
Soil Horizon	0-10 cm	15.1 ± 1.8	10.2 ± 1.9	18.1 ± 1.8	29.7 ± 4.6
	10-20 cm	16.3 ± 2.7	24.9 ± 2.9	27.5 ± 3.5	31.9 ± 5.7
	20-30 cm	16.7 ± 1.8	26.2 ± 4.5	21.7 X	26.6 ± 3.9
	30-40 cm	13.2 ± 1.0	15.4 ± 1.6	17.0 ± 1.5	25.2 ± 3.9
	40-50 cm	19.3 ± 1.5	X	24.8 ± 2.8	24.9 ± 3.4
		17.9 ± 2.5	24.3 ± 12.7	24.1 ± 5.2	32.0 ± 3.9

Site Number		5A	5A	5A	5A
Dominant Vegetation		Arrow arum	Sweet flag	Sweet flag	Sweet flag
Number of samples		2	1	2	3
Soil Horizon	0-10 cm	21.9 ± 2.3	21.5 ± 2.0	28.6 ± 3.7	35.1 ± 5.6
	10-20 cm	21.5 ± 1.9	30.5 ± 10.3	32.6 ± 4.3	34.4 ± 5.1
	20-30 cm	11.0 ± .7	53.2 ± 13.2	41.8 ± 7.5	24.3 ± 3.6
	30-40 cm	34.6 ± 5.4	37.7 ± 5.2	23.8 ± 2.3	34.7 ± 5.6
	40-50 cm	X	53.5 ± 10.5	41.5 ± 7.3	42.8 ± 8.8
		24.8 ± 11.6	43.2 ± 25.8	38.7 ± 10.2	40 ± 8.4

Site Number		5A	5A	5A
Dominant Vegetation		Yellow water lily	Yellow water lily	Yellow water lily
Number of samples		1	2	3
Soil Horizon	0-10 cm	9.8 ± 1.6	10.5 ± 3.0	14.7 ± 2.2
	10-20 cm	13.6 ± 2.1	7.8 ± 2.0	14.5 ± 2.2
	20-30 cm	14.0 ± 2.7	8.7 ± 1.7	15.0 ± 2.2
	30-40 cm	11.4 ± 1.7	8.3 ± 1.6	16.1 ± 2.2
	40-50 cm	13.1 ± 3.1	9.6 ± 2.3	17.2 ± 2.6
		14.7 ± 2.2	11.1 ± 1.6	17.8 ± 1.3

Site Number		5B	5B	5B
Dominant Vegetation		Arrow arum	Arrow arum	Arrow arum
Number of samples		1	2	3
Soil Horizon	0-10 cm	14.8 ± 2.7	16.5 ± 3.0	13.8 ± 2.0
	10-20 cm	11.3 ± 2.3	12.6 ± 2.5	16.2 ± 2.7
	20-30 cm	11.0 ± 2.2	17.2 ± 3.1	12.2 ± 2.7
	30-40 cm	6.3 ± 1.4	15.2 ± 3.0	16.7 ± 2.3
	40-50 cm	7.7 ± 1.6	8.8 ± 2.1	15.3 ± 2.6
		12.2 ± 3.8	16.8 ± 3.8	17.2 ± 1.8

Site Number		5B	5B	5B	4A
Dominant Vegetation		Cattail	Cattail	Sweet flag	Arrow arum
Number of samples		1	2	1	1
Soil Horizon	0-10 cm	30.7 ± 5.6		37.5 ± 8.7	20.7 ± 3.0
	10-20 cm	30.7 ± 5.6	43.0 ± 9.0	36.8 ± 6.7	13.3 ± 2.0
	20-30 cm	29.7 ± 4.6	42.0 ± 9.9	32.2 ± 4.8	9.1 ± 2.0
	30-40 cm	27.4 ± 4.3	38.1 ± 8.2	38.3 ± 5.9	X
	40-50 cm	X ± 4.9	40.4 ± 7.8	52.8 ± 7.8	5.8 ± 1.1
		34.6 ± 2.2	49.6 ± 2.8	46.3 ± 8.7	11.3 ± 9.9

Site Number		4A	4A	4A	4A
Dominant Vegetation		Arrow arum	Cattail	Cattail	Cattail
Number of samples		2	1	2	3
Soil Horizon	0-10 cm	X	X	41.8 ± 3.5	23.9 ± 3.6
	10-20 cm	12.7 ± 1.3	25.0 ± 3.7	24.3 ± 4.0	24.8 ± 4.0
	20-30 cm	19.1 ± 1.7	25.0 ± 4.2	22.3 ± 2.8	X
	30-40 cm	17.6 ± 1.4	16.2 ± 2.9	11.5 ± 1.8	17.2 ± 2.4
	40-50 cm	5.4 ± 9.0	14.3 ± 1.6	X	11.5 ± 5.9
		14.9 ± 6.7	23.2 ± 6.8	28.0 ± 13.3	28.3 ± 5.7

Site Number		4A	4A
Dominant Vegetation		Loosestrife	Loosestrife
Number of samples		1	2
Soil Horizon	0-10 cm	X	24.5 ± 6.2
	10-20 cm	21.2 ± 4.2	20.2 ± 2.9
	20-30 cm	17.0 ± 1.0	16.1 ± 2.7
	30-40 cm	10.5 ± 2.5	11.5 ± 2.2
	40-50 cm	6.5 ± .5	X
		15.9 ± 7.8	21.6 ± 7.2

VEGETATION

Research in 1974 focused on the open marsh areas because we did not have sufficient personnel to continue our investigations of the forests and shrub forests that were described in our previous work (Whigham, 1974). We are hopeful that we will be able to examine the ecological significance of the shrub forests at a later date.

A. VEGETATION ANALYSIS

1. Introduction

A considerable volume of vegetation data was collected in 1974. We have found a considerable number of discrepencies between our interpretation of vegetation patterns and the manner in which vegetation patterns are portrayed on the New Jersey Wetland Maps (N.J.D.E.P., 1972). We have described these dissimilarities to officials of the New Jersey Department of Environmental Protection and they have expressed concern about the discrepancies. They are presently working with the contract company that produced the maps in order to determine why the discrepancies exist and to correct them if necessary. We believe that this is another valuable contribution of our work.

2. Results

Vegetation of the forests, shrub forests, and open marsh areas was analyzed in 1973 (Whigham, 1974). Our interpretation of the vegetation patterns has been modified since our first report.

We interpret the marshes as being divided into four habitats: (1) streams and stream banks - included in this category are drainage channels that connect streams to high marsh areas, (2) high marsh areas, (3) sections of the marsh that are pond-like at high tide and drained at low tide, and (4) areas that are continuously covered by water. Several vegetation types exist in each habitat (Table 5). There is much overlap between the vegetation types and it is difficult to delineate between them.

High marsh areas (vegetation types 6,7,9,10) cover approximately 137 hectares (Table 6). Compared to those vegetation types, others occupy a much smaller area. Vegetation types dominated by yellow water lily occupy approximately 58 hectares. Cattail and wild rice vegetation types occupy 19 and 24 hectares respectively. The remaining vegetation types are minor components in terms of their aerial coverage.

Table 5. Our interpretation of major habitates and associated vegetation typé in the Hamilton Marshes. Refer to Figure 2 for site locations. Dominant species are underlined.

HABITAT TYPE (see Figure 2 for site location)	VEGETATION TYPE
I. Stream channels (Site 5A)	1. Yellow water lily, wild rice, wild celery, arrowhead, water millfoil
Stream banks (exposed at low tide) (Site 5, 5A, 7)	2. Yellow water lily, water hemp, arrowhead, pickerelweed, water smartweed, wild rice
Drainage channels that connect streams to high marsh areas (Sites 4A, 5, 5A, 7)	3. Yellow water lily, wild rice, pickerelweed, water smartweed, water hemp
II. High marsh areas (Sites 3, 4A, 5, 5A, 7)	4. Cattail (3 species), arrow arum, sweet flag, touch-me-not, tearthumbs, marsh mallow
	5. Swamp loosestrife, arrow arum, tearthumbs, touch-me-not, marsh mallow
	6. Sweet flag, arrow arum, tearthumbs, touch-me-not
	7. Bur marigold, arrow arum, tearthumbs, arrowhead, water hemp, touch-me-not
	8. Giant ragweed, arrow arum, touch-me-not, tearthumbs
	9. Reed canary grass
	10. Wild rice, bur marigold, sweet flag, arrow arum
III. Pond-like environments that are water covered at high tide and exposed at low tide (Site 4B)	11. Yellow water lily, pickerelweed, water smartweed, arrowhead, wild rice, swamp loosestrife
	12. Arrow arum, wild rice, arrowhead, water smartweed
	13. Swamp loosestrife, arrow arum, yellow water lily, marsh mallow
	14. Cattail, arrow arum, water smartweed

IV.	Ponds that are continuously water covered (Site 4C)	15. Marsh mallow, swamp loosestrife, arrow arum, yellow water lily
		16. Yellow water lily, pickerelweed, Elodea, pondweeds, water smartweed
		17. Swamp loosestrife, yellow water lily, arrow arum, water smartweed, marsh mallow
		18. Marsh mallow, yellow water lily, arrow arum, water smartweed, swamp loosestrife

Table 6: Aerial extent and total aboveground production estimates for dominant vegetation associations of the Hamilton Marshes.

VEGETATION TYPE	COVERAGE (HA)	ANNUAL ABOVEGROUND PRODUCTION (T/HA)	TOTAL PRODUCTION (T)
Mixed	137	9.1	1246.7
Cattail	19	13.2	250.8
Giant Ragweed	3	11.6	34.8
Arrow arum	11	6.5	71.5
Spiked Loosestrife	10	21.0	210.0
Wild Rice	24	9.4	225.6
Yellow Water Lily	58	7.8	452.4
TOTAL	262	$\bar{X} = 9.5$	2491.8

B. PRIMARY PRODUCTIVITY

1. Introduction

Using the vegetation scheme given in Table 5 , we designed a stratified random sampling procedure to study primary production of marsh vegetation throughout the 1974 growing season. Figure 2 and Table 1 show and list the locations of our sample areas. Within each vegetation type, all vascular plants in three $\frac{1}{4}m^2$ quadrats were harvested. The sampling breakdown was a follows:

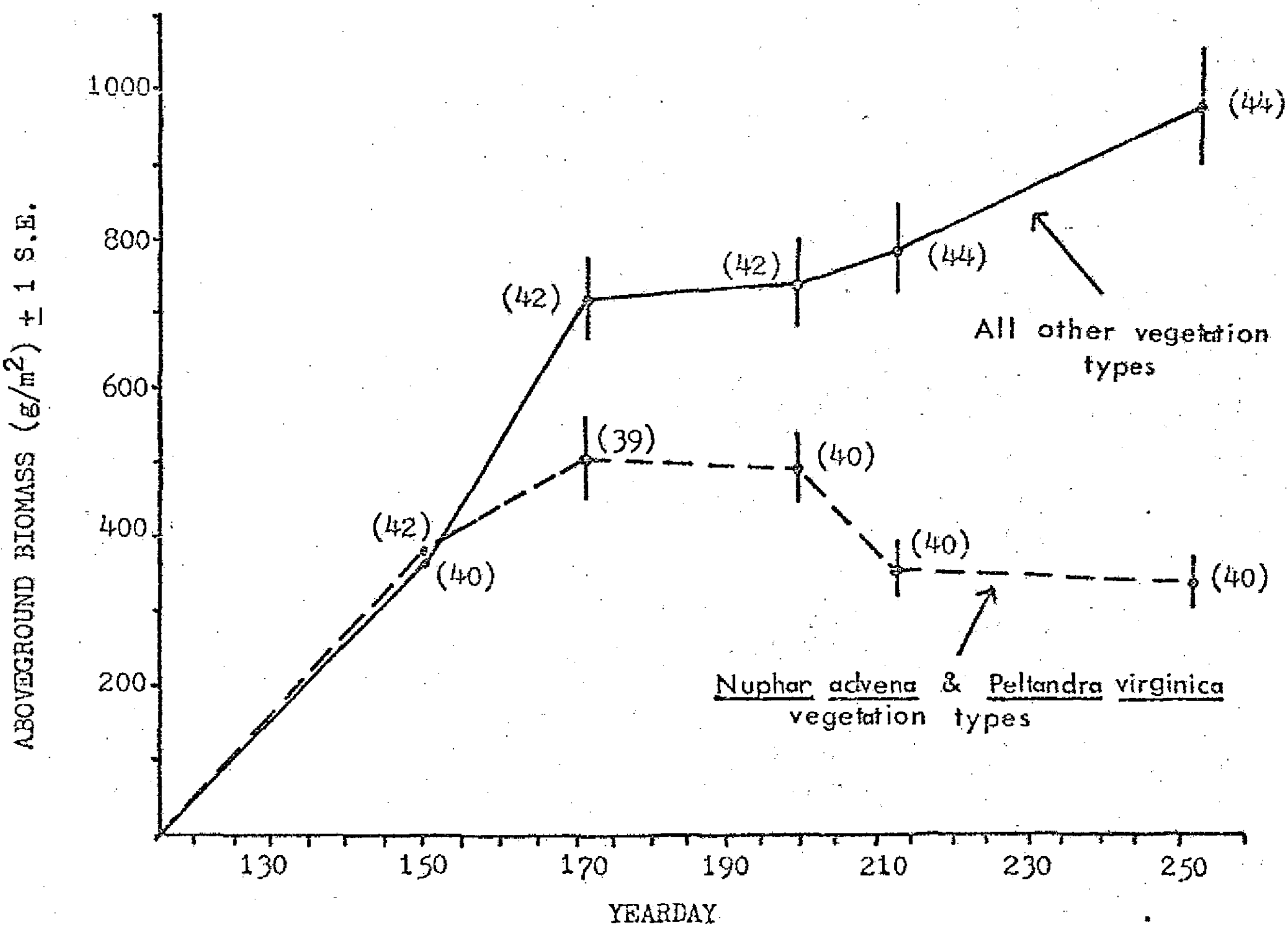
	Vegetation types sampled (from Table 5)	Total number of quadrats samples per sampling date	Total number of samples collected during growing season
Site 7	2,10,6	9	54
Site 5	2, 7,9	9	54
Site 5A	3,10,6,7	12	72
Site 5B	4, 6,7	12	72
Site 4C	16	3	18
Site 4B	12,11	9	54
Site 4A	4, 5,10	12	72
Site 3	2, 6, 7, 4	12	72
			468

All samples were returned to the laboratory where they were washed, separated by species, and dried at 105°C.

2. Results

Seasonal primary production patterns of the entire marsh are shown in Figure 3 . The data have been separated into two categories: (1) sites dominated by arrow arum and/or yellow water lily, and (2) all other sites. This separation was necessary because of a bimodal production patterns for both arrow arum and yellow water lily. Having no internal dormancy mechanisms, both species grow during the winter whenever temperatures are above

Figure 3. Aboveground primary production for all study sites. As described in the text, data were divided into two categories: (1) vegetation types dominated by Nuphar advena and Peltandra virginica, (2) all other vegetation types. Numbers in parenthesis represent sample size ($g/m^2 \times 10^{-2}$ = t/Ha)

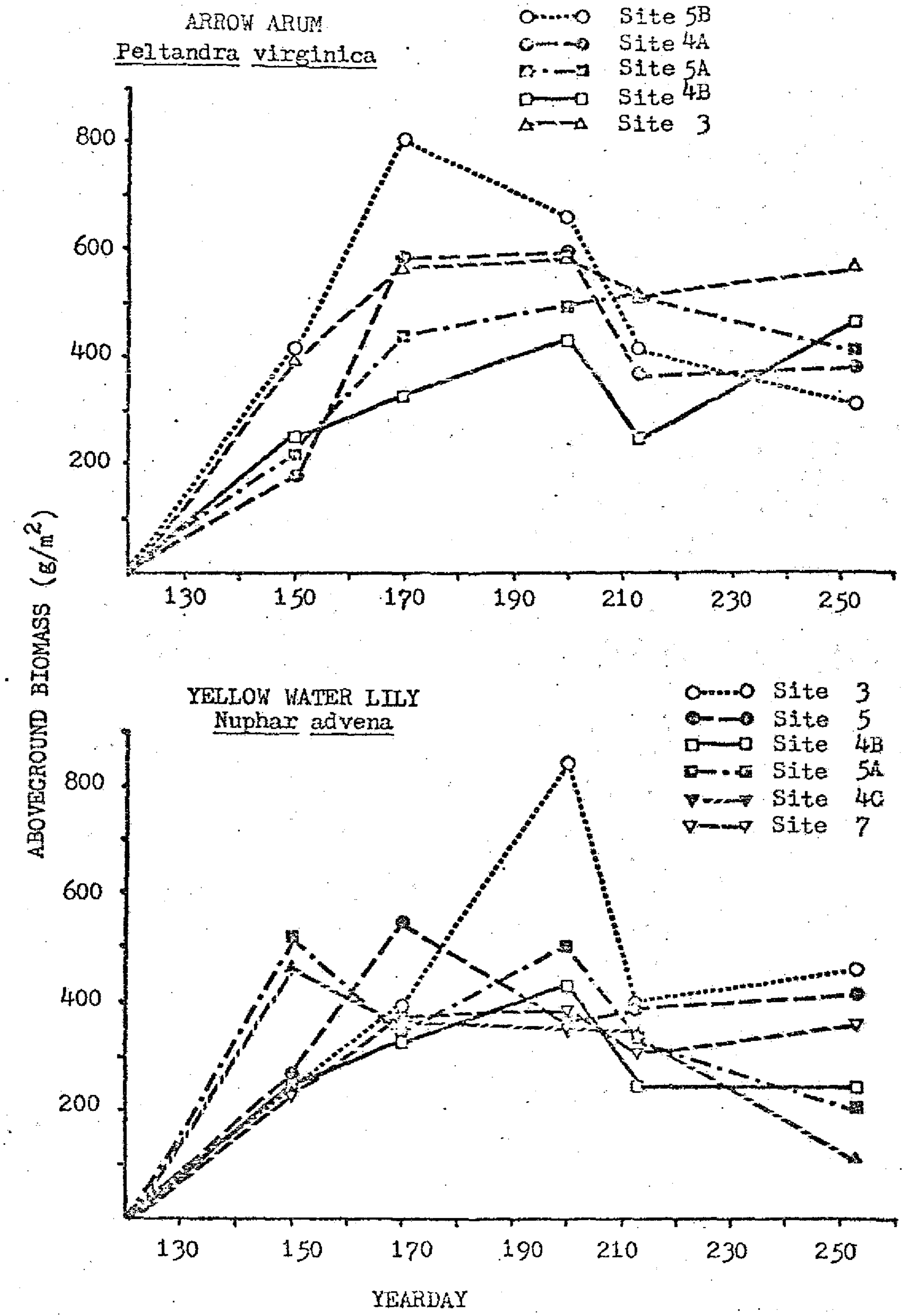


ABOVEGROUND BIOMASS (g/m2) ± 1 S.E.
1000
800
600
400
200
130
150
170
190
210
230
250
YEARDAY
(44)
(42)
(42)
(44)
All other vegetation types
(39)
(40)
(42)
(40)
(40)
(40)
Nuphar advena & Peltandra virginica vegetation types

freezing for several consecutive days. Initial growth is very rapid and both species assume aspect dominance throughout the marshes by May 30 (Figure 4).

Average daily aboveground production rates were 4.6-11.4 g/m^2 for arrow arum and 6.4-14.7 g/m^2 for yellow water lily during the period April 25 - May 30. For the period May 30 - June 20 daily aboveground production values were 7.9 - 16 g/m^2 for arrow arum. During the remainder of June and into July, the standing crop of both species remained fairly constant. Peak biomass was measured on either the June 20th or July 19th sampling periods. By mid-July, leaves of both species began to die and as a result the aboveground standing crop began to decrease on subsequent sampling dates. The decrease would have been more pronounced except that other species (mostly pickerelweed and arrowhead) were still growing and accounted for much of the biomass. Site 4C (Figure 4) is the best example of this die-off phenomenon. The area sampled is in a pond where the water level fluctuates very little during each tide cycle. Yellow water lily was the dominant species and it accounted for almost 100% of the cover. Other species in the area were submerged aquatics (water millifoil, waterweed, and pondweeds). Peak aboveground biomass at Site 4C was 460 g/m^2 (Figure 4). The standing crop remained fairly constant until late July when the yellow water lily dieback began. Many leaves died naturally while others were consumed by sucking insects. McCormick

Figure 4. Aboveground primary production of yellow water lily (*Nuphar advena*) and arrow arum (*Peltandra Virginica*) dominated marsh sites. ($g/m^2 \times 10^{-2} = T/Ha$) Refer to Figure 2 for site locations.


ARROW ARUM
Peltandra virginica
Site 5B
Site 4A
Site 5A
Site 4B
Site 3
800
600
400
200
130
150
170
190
210
230
250
ABOVEGROUND BIOMASS (g/m2)
YELLOW WATER LILY
Nuphar advena
Site 3
Site 5
Site 4B
Site 5A
Site 4C
Site 7
800
600
400
200
130
150
170
190
210
230
250
YEARDAY

cited a similar die-off phenomenon in Oldmans Creek, a freshwater tidal marsh in Salem County, New Jersey (McCormick, 1972). In most populations there was renewed growth during September that lasted until the first heavy frosts. In one area where yellow water lily was completely gone after the dieback in late July, we measured new aboveground growth of 101.6, 278.4, and 366.0 g/m^2. Arrow arum also went through a die-off period in July. The die back began shortly after other plants began to overtop the arrow arum. Because arrow arum grows best during the high light regime of the early part of the growing season, it is most probable that the species was unable to maintain a positive photosynthesis to respiration ratio under the low light conditions that were present when the arrow arum was overlapped. Once the taller plants began to senesce, thus permitting higher amounts of solar radiation to reach the surface of the marsh, arrow arum produced a new crop of leaves. In some areas arrow arum assumed aspect dominance again. In the case of yellow water lily, the die-off didn't appear to be caused by low light conditions. If late season growth is considered, the total aboveground yearly production would be estimated at 700-800 g/m^2 for yellow water lily and arrow arum. This is an underestimate of total primary production for both species since a portion of the yearly net production is translocated to the underground stem where it is stored, used for maintenance, or used in vegetative propogation. A detailed presentation of the data used in Figure 4 is given in Table 7 .

Table 7

Aboveground biomass for Yellow Water lily and Arrow arum. All values are means (g/m^2) of 3 quadrats ± 1, S.E. X = no sample. Refer to Figure 2 for site locations.

Yellow Water lily

Site	7	5	5A	4C	4B	3
May 30	222 ± 128	266 ± 117	521 ± 74	460 ± 57	248 ± 14	X
June 29	362 ± 25	548 ± 147	346 ± 37	346 ± 47	323 ± 29	391 ± 70
July 19	380 ± 29	358 ± 32	501 ± 83	337 ± 32	427 ± 13	840 ± 283
August 1	305 ± 11	390 ± 67	332 ± 59	251 ± 55	242 ± 34	387 ± 44
September 10	361 ± 146	419 ± 134	201 ± 36	107 ± 39	244 ± 119	458 ± 145

Arrow Arum

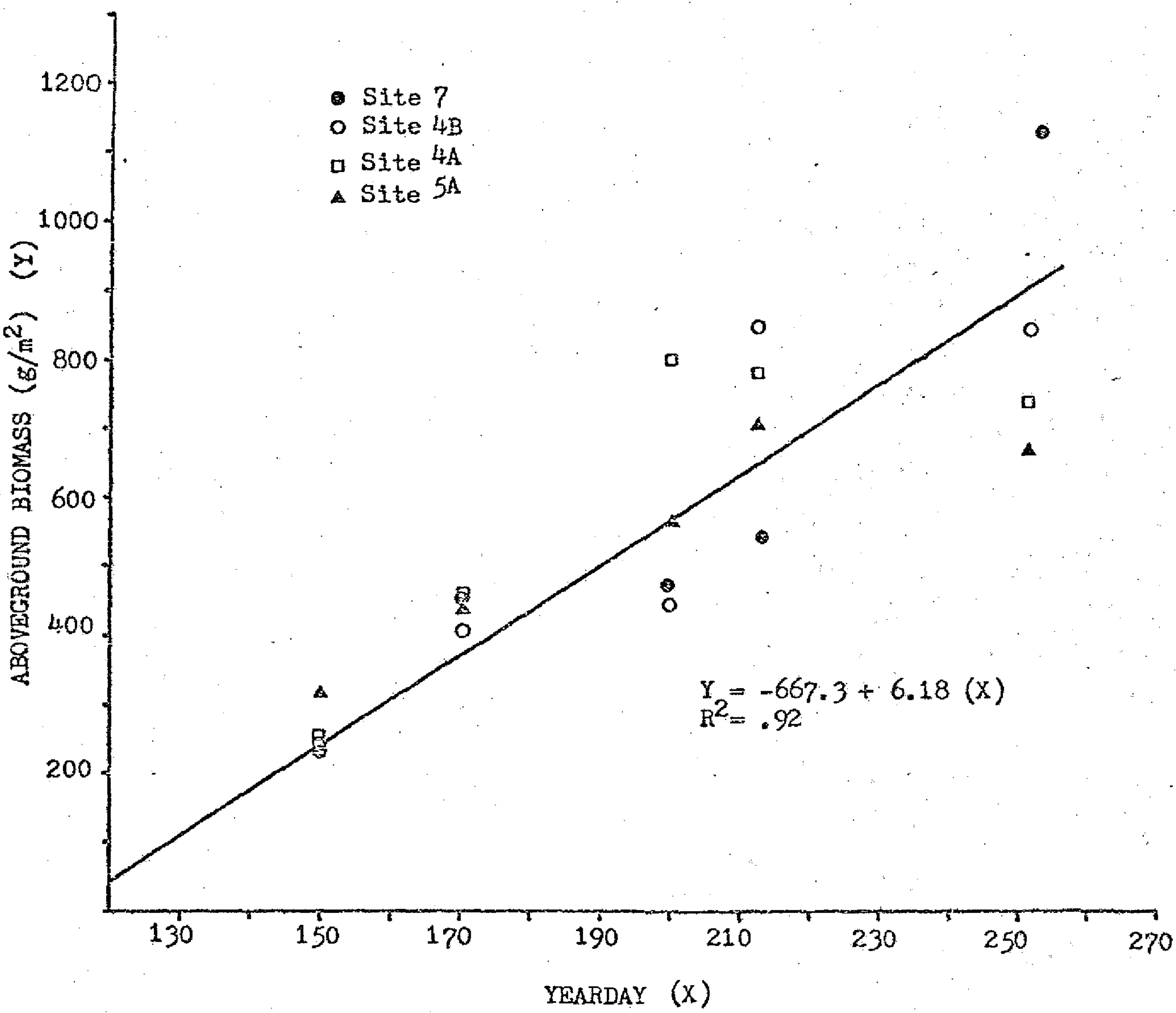
Site	5A	5B	4B	4A	3
May 30	270 ± 71	401 ± 44	248 ± 14	180 ± 53	389 ± 78
June 29	434 ± 79	802 ± 22	323 ± 29	588 ± 87	562 ± 112
July 19	490 ± 20	676 ± 234	427 ± 13	593 ± 32	576 ± 36
August 1	504 ± 235	410 ± 104	242 ± 34	365 ± 64	508 ± 23
September 10	403 ± 57	304 ± 130	468 ± 74	X	562 ± 112

In areas not dominated by yellow water lily or arrow arum, there was a continual increase in aboveground biomass throughout the growing season. Peak biomass averaged 980 g/m^2 in early September (Figure 3). The patterns of aboveground biomass accumulation were different for each community type due to differences in plant size and patterns of seasonal primary production.

Areas dominated by wild rice showed a linear increase in biomass throughout the growing season (Figure 5 and Table 8). Peak biomass varied between 659 and 1125 g/m^2 and daily production rates in those communities were between 4.8 - 8.6 g/m^2 per day. These values only account for aboveground biomass. Wild rice has a root:shoot ratio that averages .25. Adding 25% to the aboveground total production biomass, we estimated that the total production was between 800-1400 g/m^2. These values are comparable to the data obtained during the study of wild rice that is discussed in pgs. 124-144 of this report.

In areas dominated by annual species (primarily bur marigold, touch-me-not, and tearthumbs) primary productivity patterns were similar to those found in wild rice dominated areas. Peak aboveground biomass was 756-1162 g/m^2 (Figure 6 and Table 8). This corresponds to an average daily production rate of between 5.8 and 8.9 g/m^2.

Figure 5. Aboveground primary production of wild rice (*Zizania aquatica*) dominated marsh sites. Refer to Figure 2 for site locations. ($g/m^2 \times 10^{-2}$ = T/Ha)



ABOVEGROUND BIOMASS (g/m²) (Y)
1200
1000
800
600
400
200
Site 7
Site 4B
Site 4A
Site 5A
Y = -667.3 + 6.18 (X)
R²= .92
130
150
170
190
210
230
250
270
YEARDAY (X)

Table 8. Aboveground production data for dominant vegetation types in the Hamilton Marshes. See Table 5 for a listing of species found in each vegetation type. ($g/m^2 \times 10^{-2} = T/HA$)

Table 4

I. Aboveground production in wild rice (Zizania aquatica) areas. Values are means (g/m^2) of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	Site 7	Site 5A	Site 4B	Site 4A
May 30	222 ± 77	310 ± 24	290 ± 123	223 ± 72
June	450 ± 72	442 ± 101	401 ± 45	451 ± 53
July	463 ± 75	561 ± 172	441 ± 31	796 ± 161
August	540 ± 39	700 ± 44	841 ± 67	774 ± 79
September	1125 ± 218	659 ± 74	835 ± 224	729 ± 94

II. Aboveground production in mixed vegetation mostly bur marigold (Bidens laevis) areas. Values are means of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	Site 1	Site 2A	Site 2B
May	240 ± 41	203 ± 108	324 ± 12
June	579 ± 117	432 ± 65	547 ± 132
July	629 ± 168	492 ± 53	581 ± 43
August	635 ± 91	X	X
September	1160 ± 289	756 ± 86	1162 ± 332

III. Aboveground production in Sweet flag (*Acorus calamus*) areas. Values are means of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	Site			
	5A	5	5	3
May	450 ± 110	334 ± 68	328 ± 44	501
June	452 ± 36	624 ± 120	764 ± 272	712 ± 258
July	439 ± 96	739 ± 81	633 ± 234	580 ± 156
August	722 ± 41	711 ± 175	830 ± 81	478 ± 67
September	596 ± 72	946 ± 300	896 ± 89	418 ± 38

IV. Aboveground production in Cattail (*T. latifolia*, *T. angustifolia*, and *T. glauca*) areas. Values are means of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	Site		
	5B	4A	3
May	505 ± 42	379 ± 47	X
June	939 ± 257	1119 ± 32	1528 ± 103
July	1189 ± 357	936 ± 176	1502 ± 250
August	932 ± 234	900 ± 88	1212 ± 25
September	975 ± 161	963 ± 78	1489 ± 239

V. Aboveground production in Swamp loosestrife (*Lythrum salicaria*) areas. Values are means of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	Site
	4A
May	419 ± 147
June	1059 ± 300
July	1014 ± 82
August	1505*
September	2104 ± 104

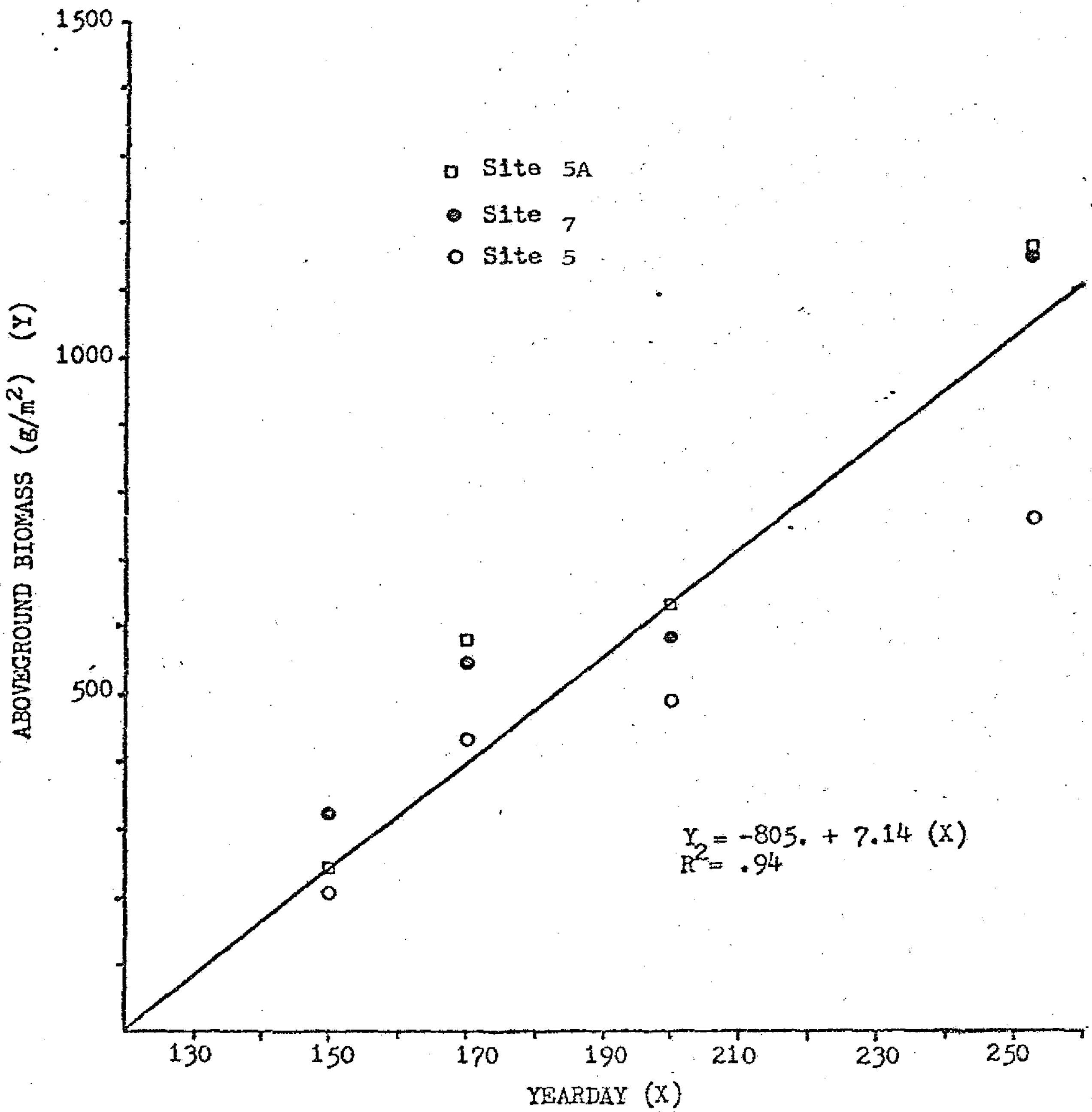
* No sample was collected due to fantastic bee population working on Lythrum flowers. The value was estimated by regression analysis of biomass against yearday (r^2 = .99).

V. Aboveground production in Swamp loosestrife (<u>Lythrum salicaria</u>) areas. Values are means of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	Site
	4A
May	419 ± 147
June	1059 ± 300
July	1014 ± 82
August	1505*
September	2104 ± 104

* No sample was collected due to fantastic bee population working on Lythrum flowers. The value was estimated by regression analysis of biomass against yearday (r^2 = .99).

Figure 6. Aboveground primary production of mixed vegetation dominated by bur marigold (*Bidens laevis.*) All values are means (g/m^2) $\pm$ 1 standard error of the mean. Refer to Figure 2 for site locations ($g/m^2 \times 10^{-2}$ = T/Ha)


1500
1000
500
ABOVEGROUND BIOMASS (g/m2) (Y)
Site 5A
Site 7
Site 5
Y = -805. + 7.14 (X)
R2 = .94
130
150
170
190
210
230
250
YEARDAY (X)

A linear increase in biomass was also measured in communities dominated by swamp loosestrife (Figure 7 and Table 8). The daily production rate was 16 g/m^2 and a peak aboveground biomass of 2104 g/m^2 was measured in September.

Cattail and sweetflag dominated areas showed a different pattern of aboveground production. In both community types, there was an initial spurt of growth followed by a slow net accumulation throughout the remainder of the growing season (Figures 8,9 and Table 8). In both cases, the initial aboveground biomass was due primarily to those two species. Daily aboveground production rates in cattail communities varied between 16.9 and 27.2 g/m^2 (Figure 8). By mid-June, the aboveground standing crop was 939-1528 g/m^2 and it did not change significantly throughout the remainder of the growing season. This pattern of growth corresponds to phenological characteristics of cattail. The initial burst of growth is followed by the reproductive period which lasts for the remainder of the growing season. Three different cattail stands were studied and there were different species of cattail in each. Site 5B was dominated by the broad leafed species (Typha latifolia); while the narrow leafed species (Typha angustifolia) grew at Site 3. The hybrid between those two species (Typha glauca) grew at Site 4A. The T. angustifolia site had consistantly greater biomass than the other sites but there were no statistically significant differences between the three areas.

Figure 7. Aboveground primary production of a spiked loosestrife (*Lythrum salicaria*) dominated area at Site 4A. All values are means (g/m^2) $\pm$ 1 standard error of the mean. Refer to Figure 2 for site location.
($g/m^2 \times 10^{-2} = T/Ha$)

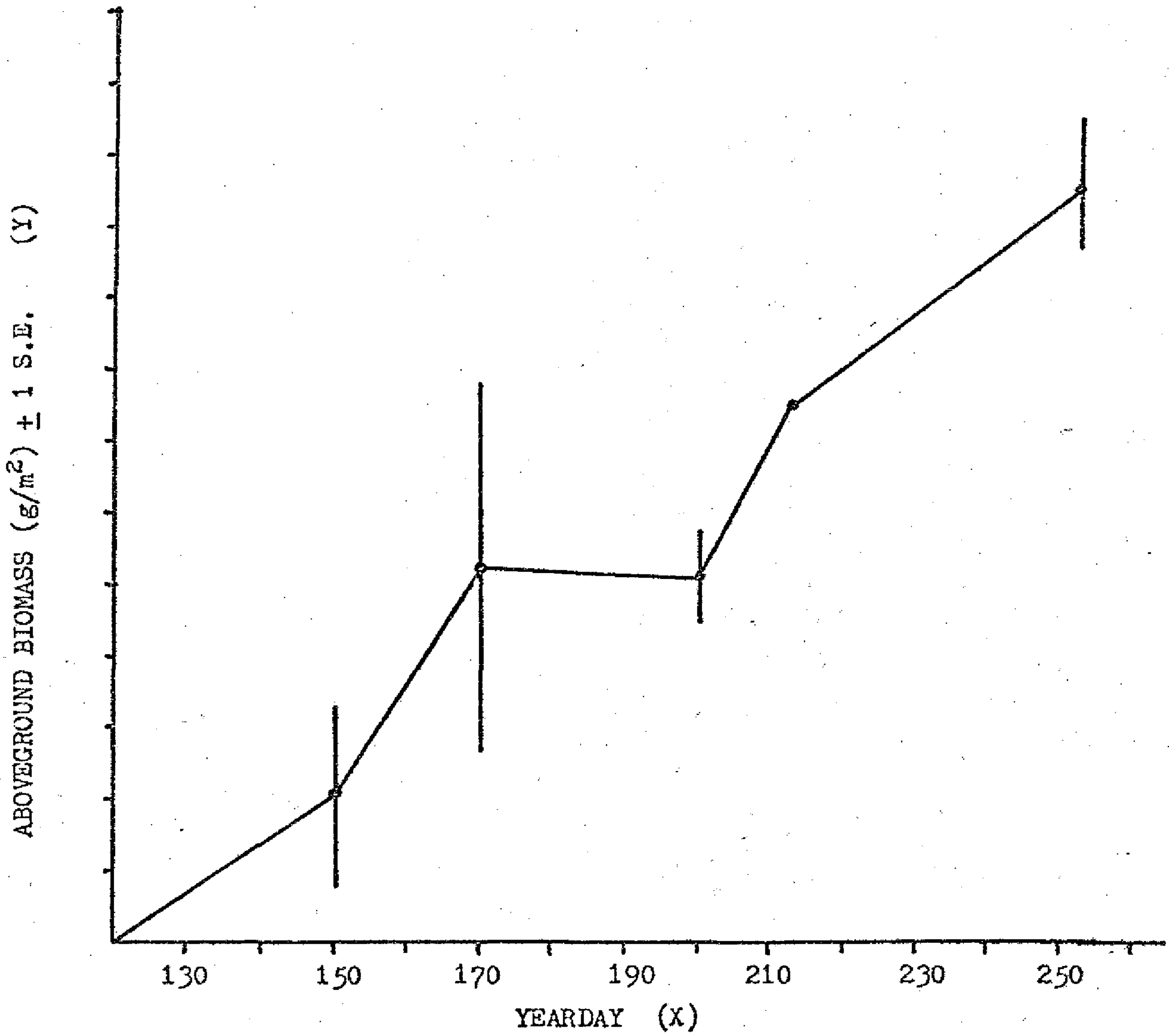

ABOVEGROUND BIOMASS (g/m²) ± 1 S.E. (Y)
130
150
170
190
210
230
250
YEARDAY (X)

Figure 8. Aboveground primary production of cattail (Typha sp.) dominated areas. All values are means (g/m^2) ± 1 standard error of the mean. Refer to Figure 2 for site locations. ($g/m^2 \times 10^{-2}$ = T/Ha)

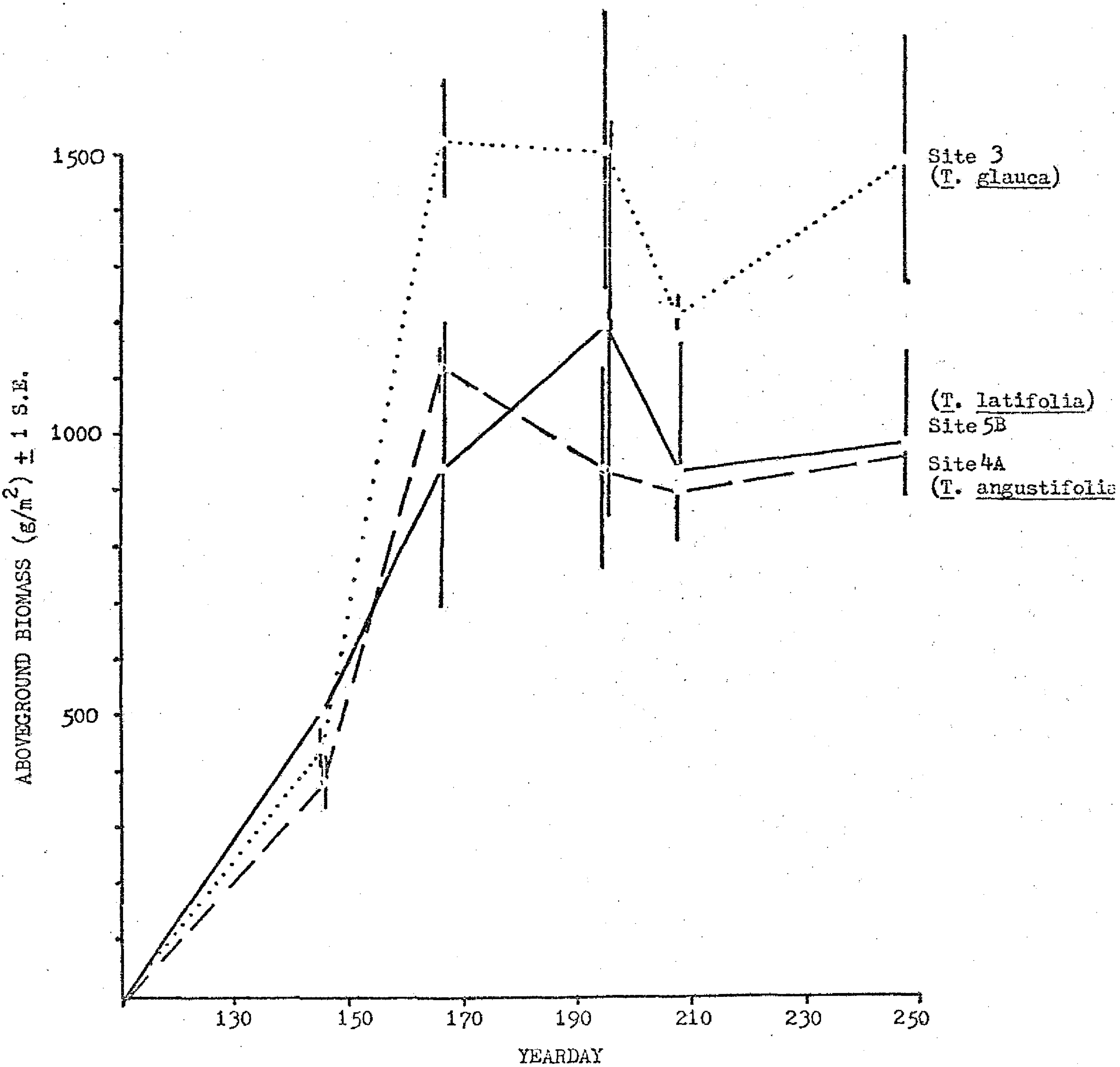
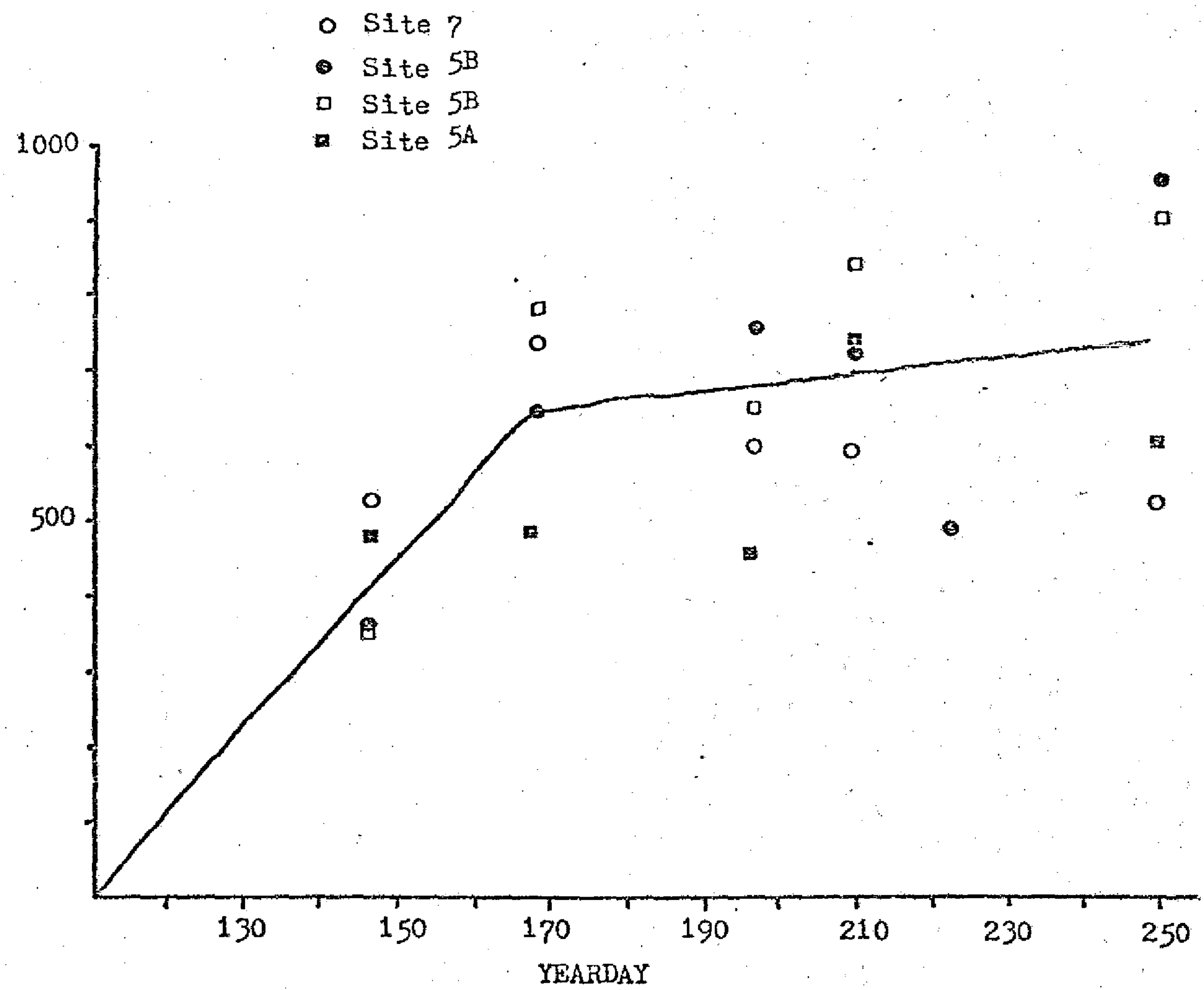

ABOVEGROUND BIOMASS (g/m²) ± 1 S.E.
1500
1000
500
130
150
170
190
210
230
250
YEARDAY
Site 3
(T. glauca)
(T. latifolia)
Site 5B
Site 4A
(T. angustifolia

Figure 9. Aboveground primary production of sweet flag (*Acorus calamus*) dominated marsh sites. All values are means (g/m^2) of triplicate samples. Table 4 lists the same data and also the standard errors. Refer to Figure 2 for site locations.

($g/m^2 \times 10^{-2} = T/Ha$)



o Site 7
Site 5B
Site 5B
Site 5A
1000
500
130
150
170
190
210
230
250
YEARDAY

High marsh areas dominated by sweet flag showed a pattern of biomass accumulation similar to cattail. Like arrow arum, however, sweet flag leaves went through dieback in mid-summer. Sweet flag is one of the first species to break dormancy in the spring. Reproductive phenophases are initiated early and by July it is an insignificant species in the overall physiognomy of the high marsh areas. Due to its short stature (less than 1m), most other species overtop sweet flag by late June. We believe that the die-off of sweet flag leaves is due to shading by taller plants. Evidence for this conclusion was seen near the end of the growing season when the other taller species began to die or fall to the marsh surface. At that time, sweet flag had a second period of leaf growth. Peak aboveground biomass in sweet flag dominated areas varied between 596-946 g/m^2 (Figure 9 and Table 8). During the period of maximum net biomass accumulation, daily production rates were 9.2-15.2 g/m^2.

The ranking of community types based on the amount of annual aboveground production is: swamp loosestrife, cattail, mixed vegetation, wild rice, sweet flag, arrow arum, and yellow water lily. We have data for two other minor vegetation types. A population of giant ragweed was sampled on September 10. Aboveground net production averaged 1160 $\pm$ 500 g/m^2 with most of the biomass being contributed by giant ragweed. Reed canary grass formed dense, but small in total area, mats in some high marsh areas. We measured biomass of 566 g/m^2 in one population.

Figure 3 summarizes the production data. The average annual net production for sites not dominated by arrow arum and yellow water lily was 980 g/m^2. Maximum aboveground biomass for the latter two community types is approximately 500 g/m^2 per year. If one considers the second period of leaf production that occurs in those communities, the estimated yearly production would be approximately 700-800 g/m^2.

Table 6 shows an estimate of the total yearly production within the Hamilton Marshes. The data do not account for production in the forests and shrub forests. The coverage data for vegetation types was compiled from the New Jersey Wetland Maps. Comparison of this data with the breakdown as reported in our 1974 study (Whigham, 1974) shows the degree of dissimilarity between our interpretation of vegetation pattern and those shown on the New Jersey Wetland Maps. High marsh sites dominated by mixed vegetation cover most of the Hamilton Marshes. Yellow water lily dominated communities are the most expansive in low marsh areas (streams and ponds). We estimate the total annual aboveground production in the marshes to be 491.8 tons of material and the average production rate to be 950 g/m^2.

C. NUTRIENT CONTENT OF PLANTS

In addition to measuring primary productivity, we are interested in determining the amounts of nitrogen, phosphorous, calcium, magnesium, sodium, and potassium that are utilized by the plants during primary production.

Plants from the productivity study are ground and analyzed for their nutrient content. To date, we have ground all of the plants from two sampling dates. We are presently determining nitrogen concentrations in those plants. Levels for the other macronutrients will be determined later.

Table 9 shows the contents of plants analyzed thus far. Arrow arum and touch-me-not contain more nitrogen than the other plant species. As expected, the grasses (reed canary and wild rice) contain the least. Our values compare well with other reported data. Reported nitrogen values for cattail range from .9% to 3.6% (Harpe and Daniel, 1934) with nitrogen levels in most other plants near 2.3%.

When this study is completed, we will be able to estimate total macronutrient uptake by the marsh vegetation.

Table 9

Nitrogen content (%) of Hamilton Marsh vegetation. Values are means ± 1 S.E.

Bur marigold (*Bidens laevis*)	2.43 ± .43
Sweet flag (*Acorus calamus*)	2.53 ± .30
Arrow arum (*Peltandra virginica*)	3.59 ± .35
Cattail (*Typha angustifolia*, *T. latifolia*, *T. glauca*)	2.44 ± .78
Halberd tearthumb (*Polygonum arifolium*)	2.30 ± .27
Touch-me-not (*Impatiens capensis*)	3.45 ± .41
Reed canary grass (*Phlaris arundinacea*)	1.73 ± .32
Wild rice (*Zizania aquatica*)	.9 ± .57

D. MUD ALGAE

Studies are currently assessing the role mud algae play in the Hamilton Marshes. Working with the top two centimeters of marsh soil, we have estimated mud algal standing crop using chlorophyll extraction techniques outlined by Golterman (1969) and modified for our system. Samples are collected at two to four week intervals depending on the season using a number 15 cork borer. Between 19 and 33 samples are taken on each sampling date from selected areas of the marsh including the stream banks and regions dominated by Nuphar, Zizania, Typha, Lythrum, Peltandra-Nuphar, and mixed vegetation. At each sample site, four replicate samples are collected and the mean chlorophyll and phaeophytin values for each site are calculated from these samples. Using these mean site values, the amount of chlorophyll and phaeophytin for each vegetation subdivision in the marsh is calculated.

Figures 10-16 give the levels of chlorophyll a and its degradation product phaeophytin for the first and second centimeter of the marsh surface and Figure 17 presents a summary of this data.

Mean chlorophyll a levels in the top two centimeters of mud show definite seasonal patterns and range from a high of 6.29 ug/top 2 cm^3 in early summer to a low of 1.96 ug/top 2 cm^3 in mid fall. These values are considerably lower than those reported by Leach (1969) and Riznyk and Phinney (1972) for estuarine mudflats. Mean phaeophytin values always exceeded chlorophyll

Figure 10. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in Nuphar dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

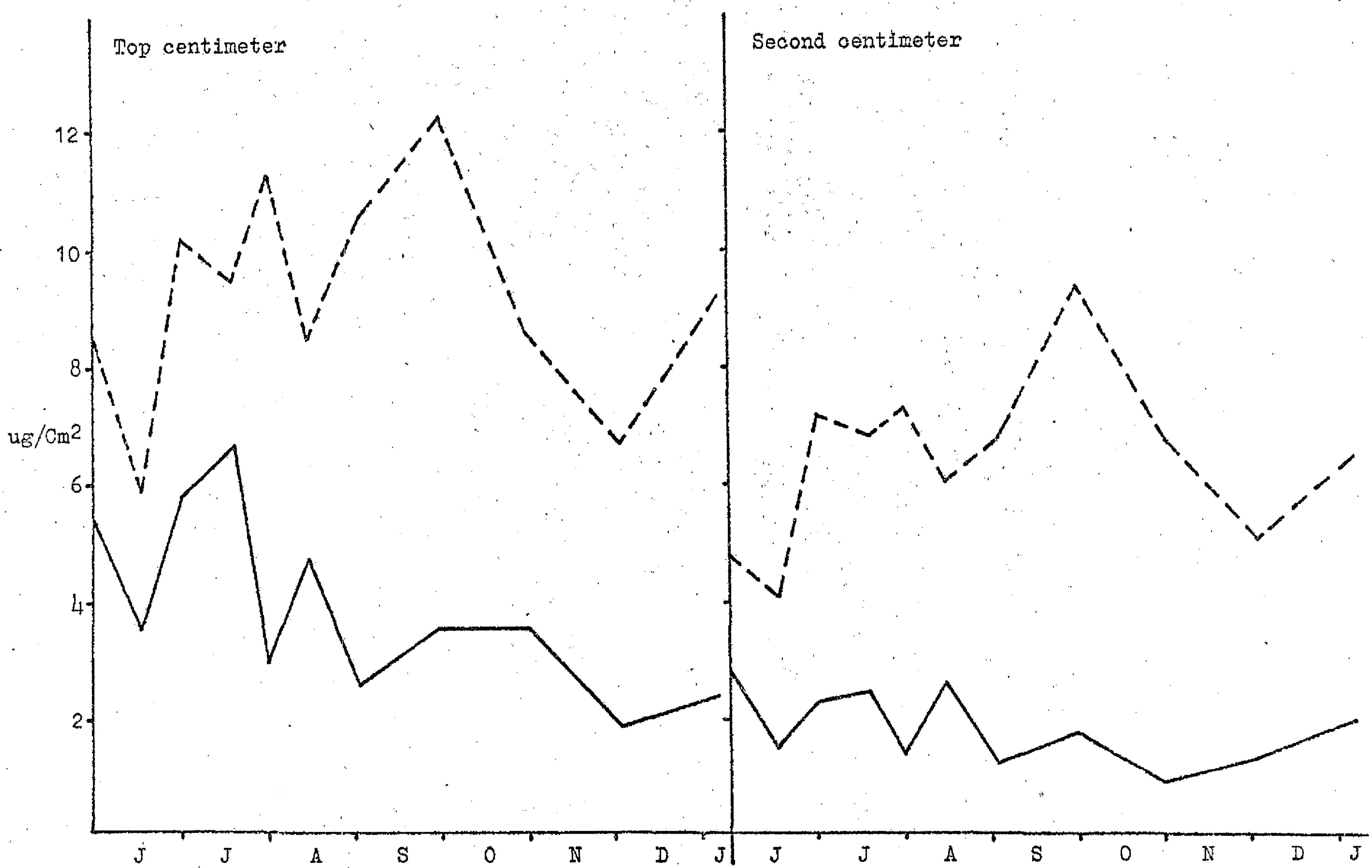


Figure 11. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in Peltandra-Nuphar dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

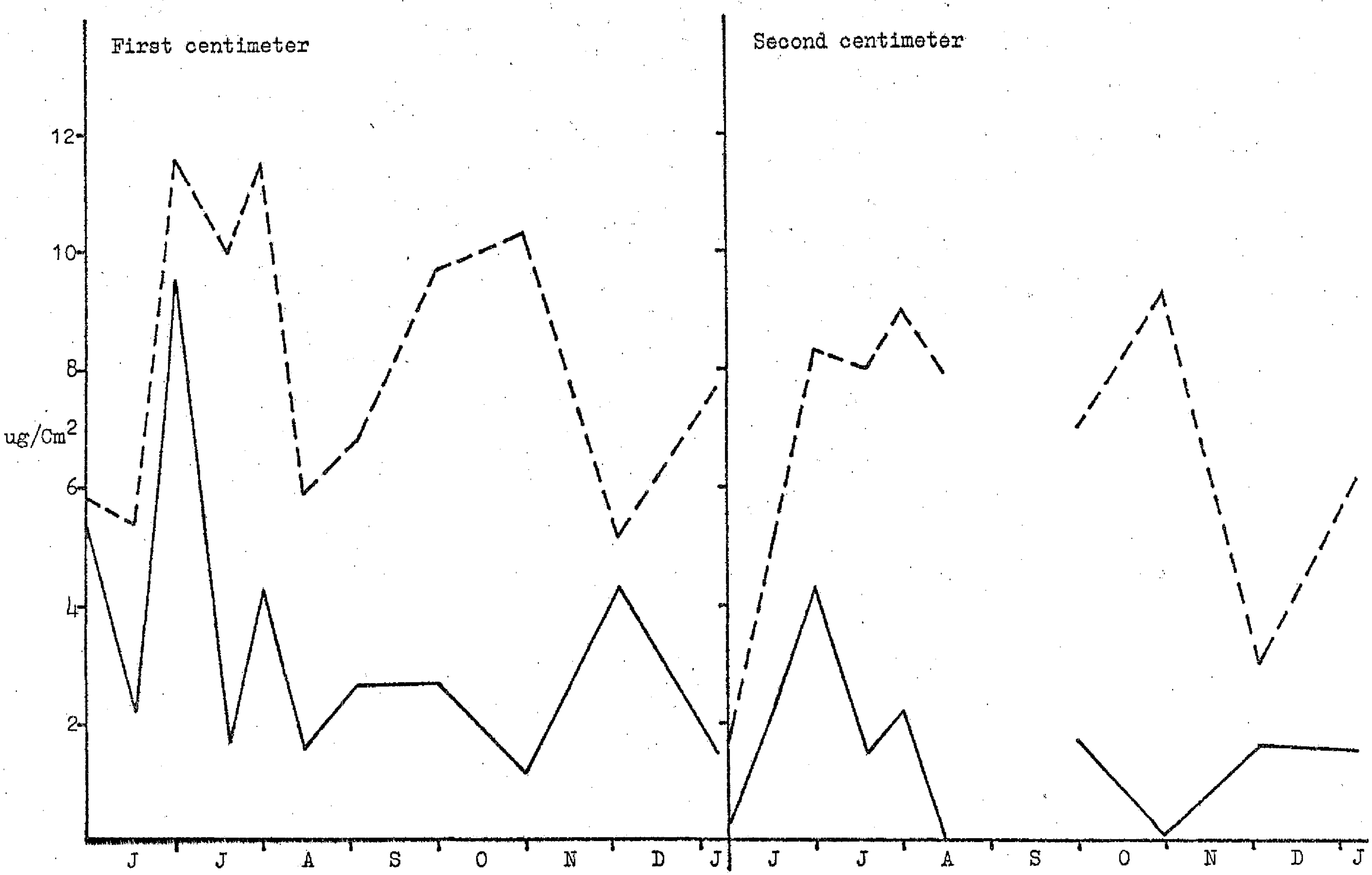


Figure 11. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in Peltandra-Nuphar dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

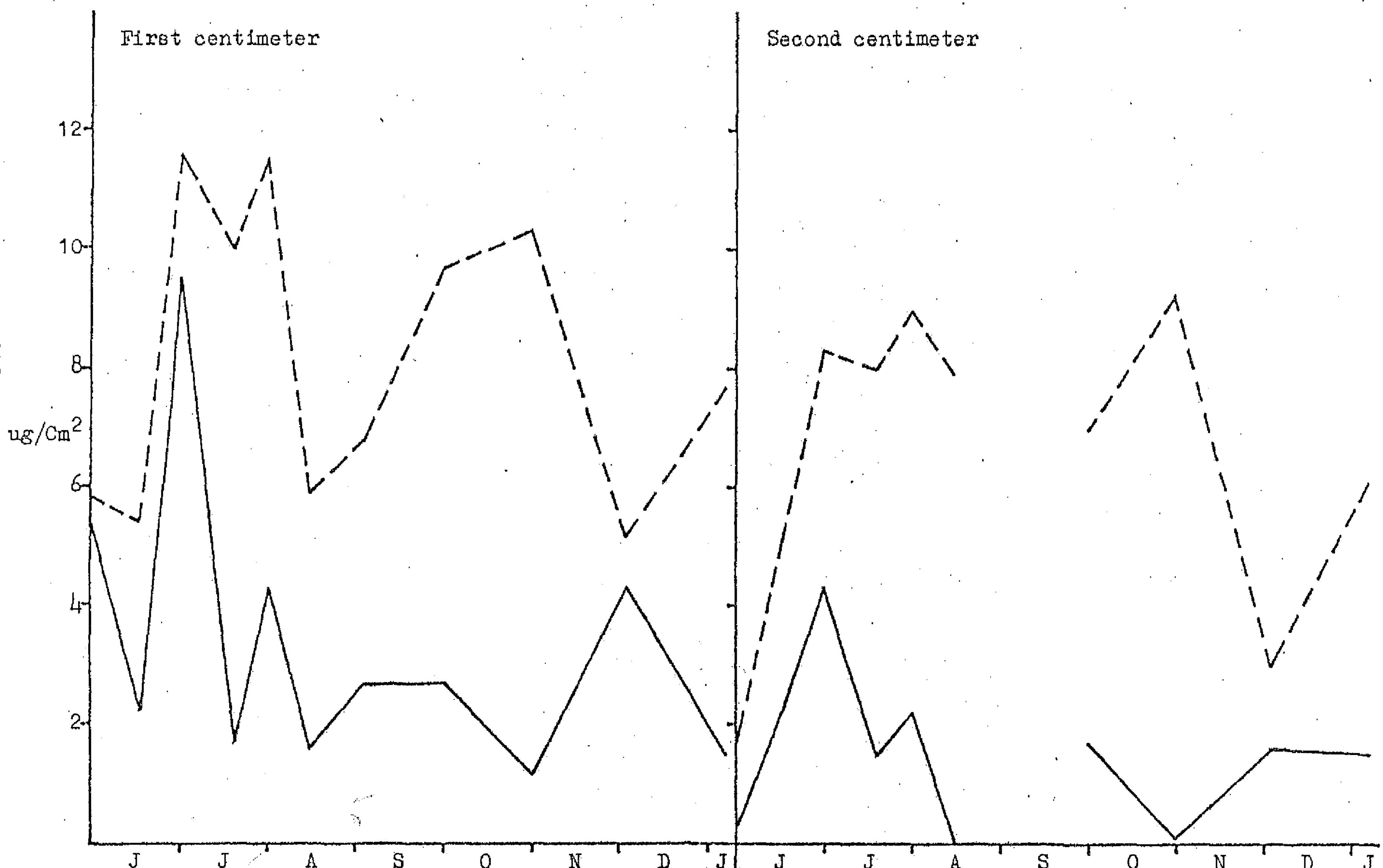


Figure 12. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in stream bank areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

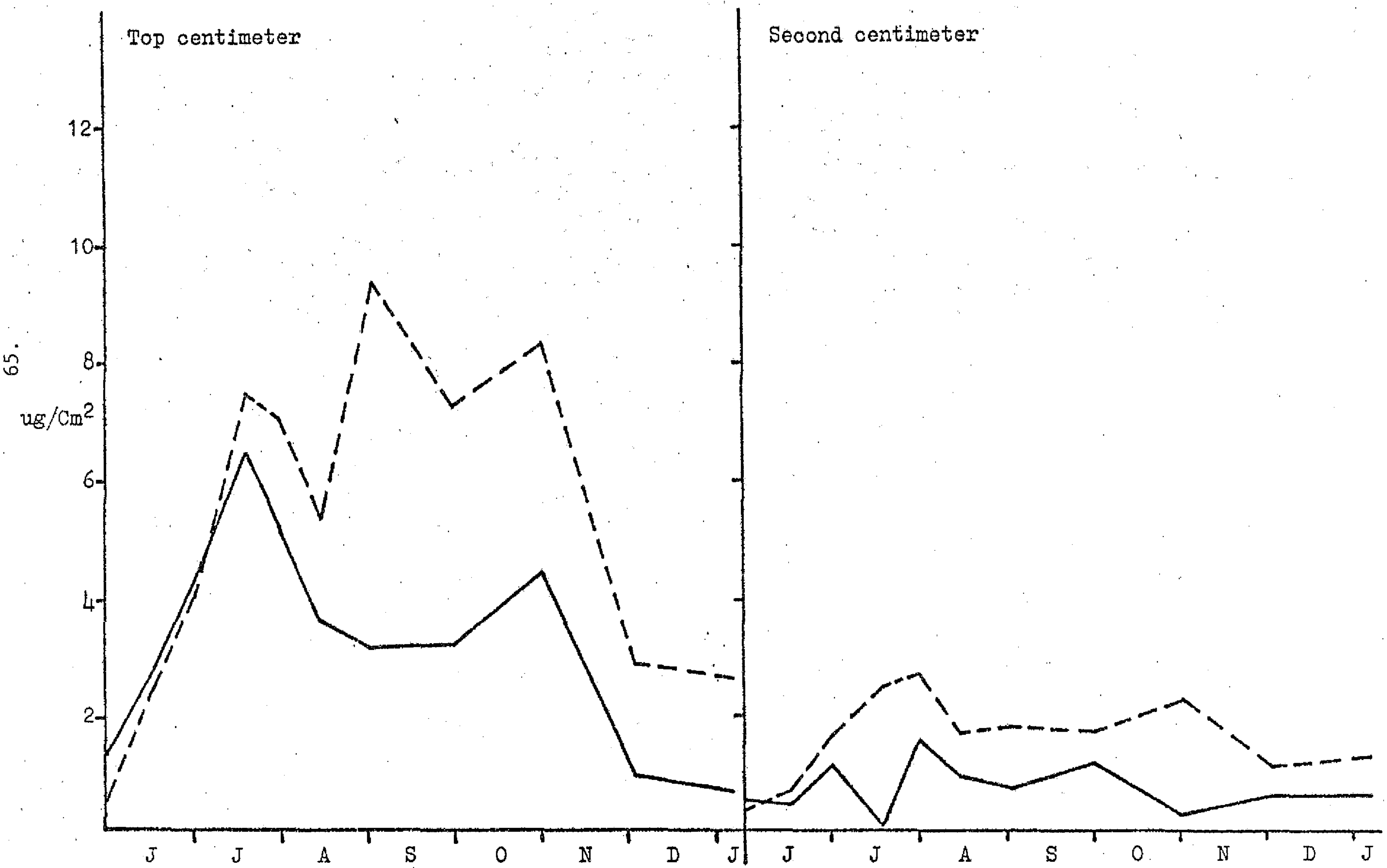


Figure 13. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in *Typha* dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

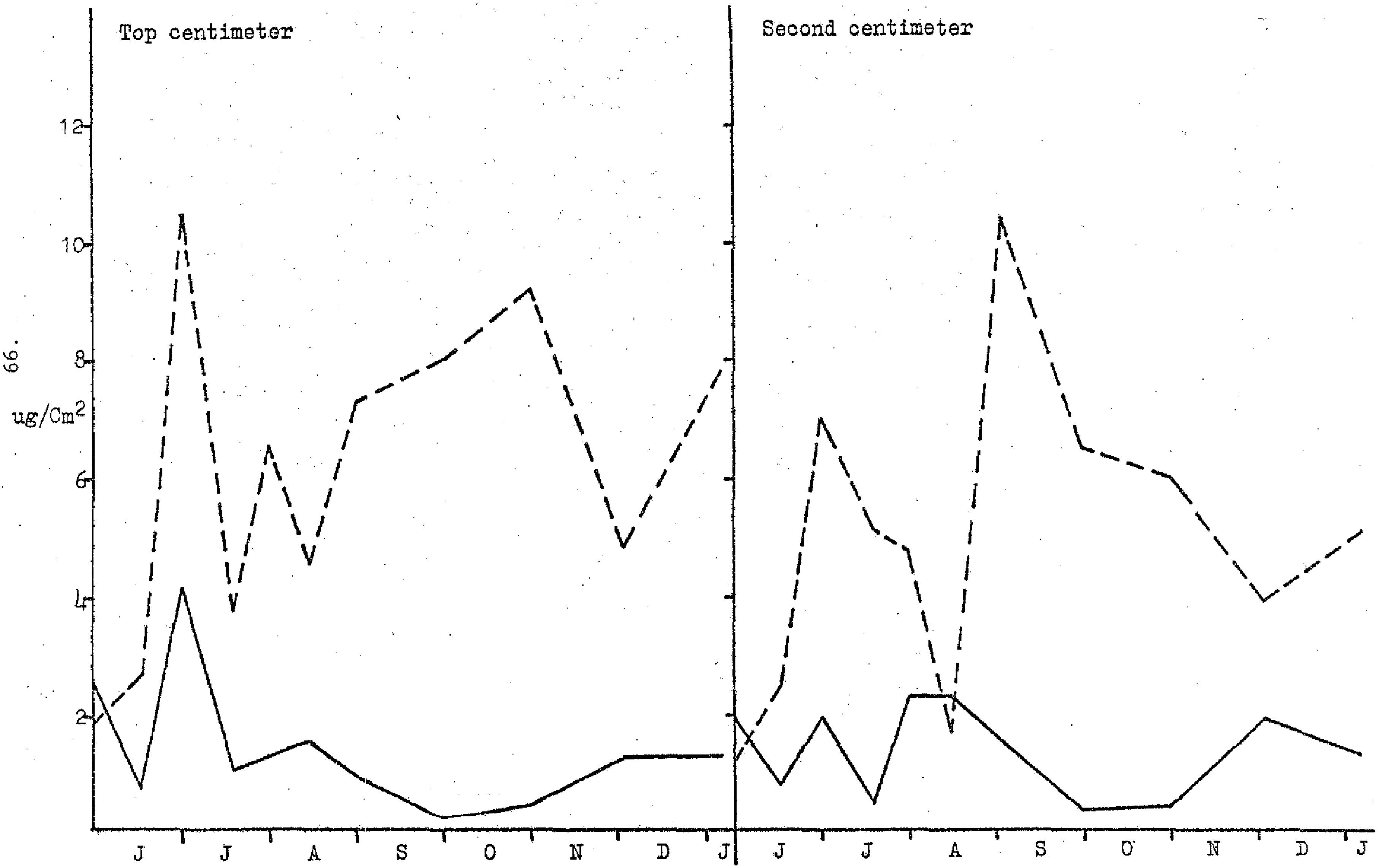


Figure 14. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in <u>Zizania</u> dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

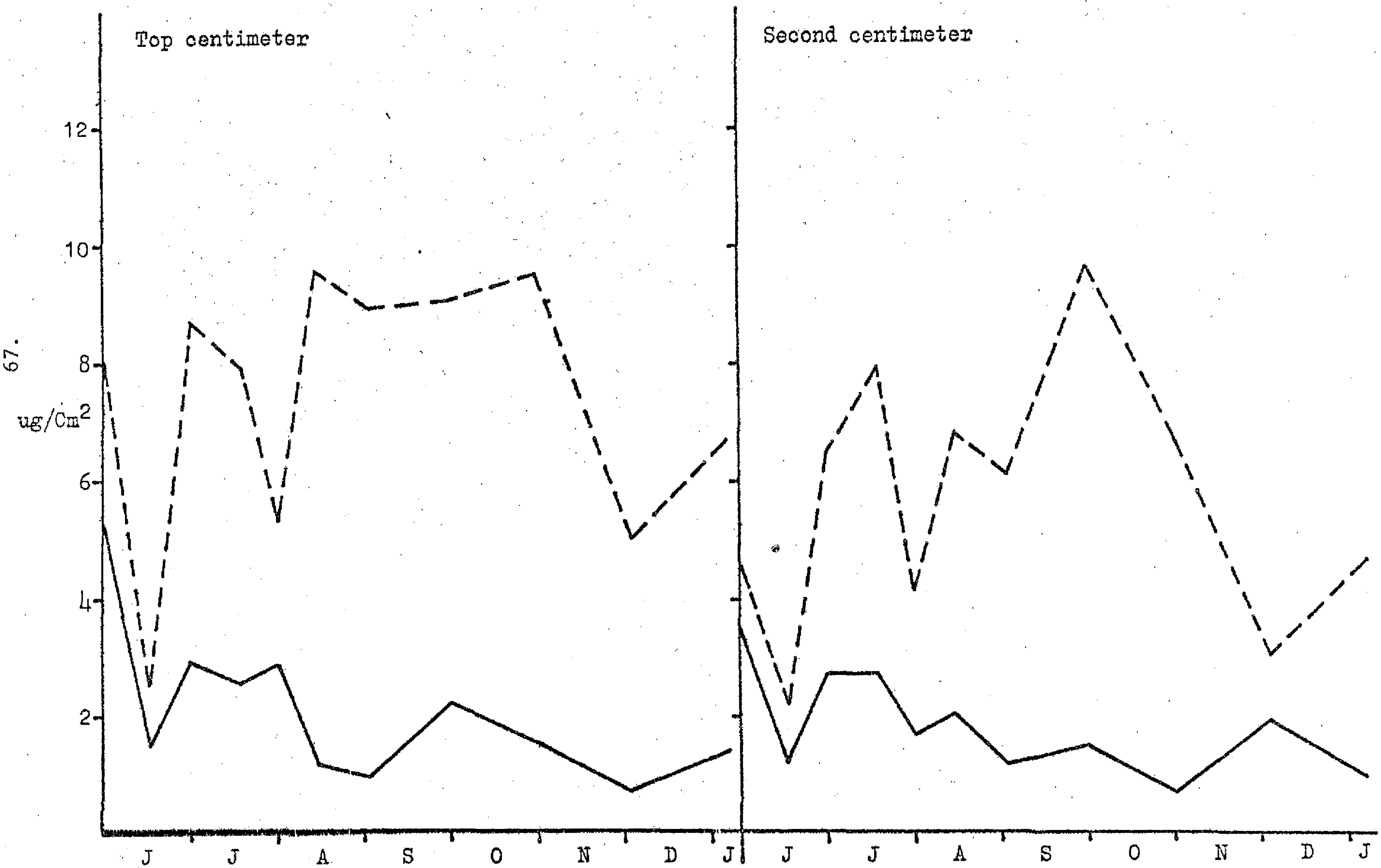


Figure 15. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in mixed vegetation dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

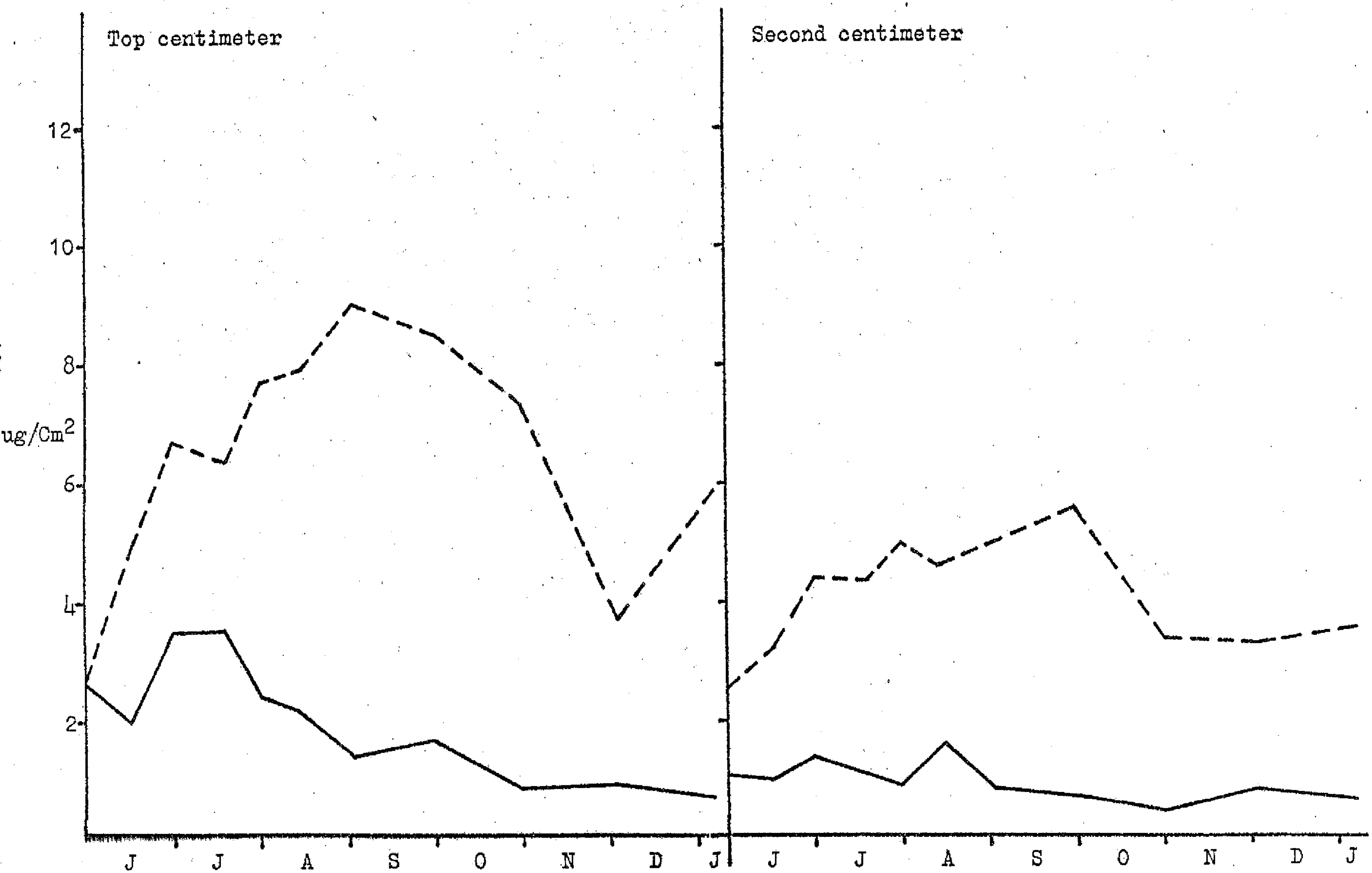


Figure 16. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in *Lythrum* dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

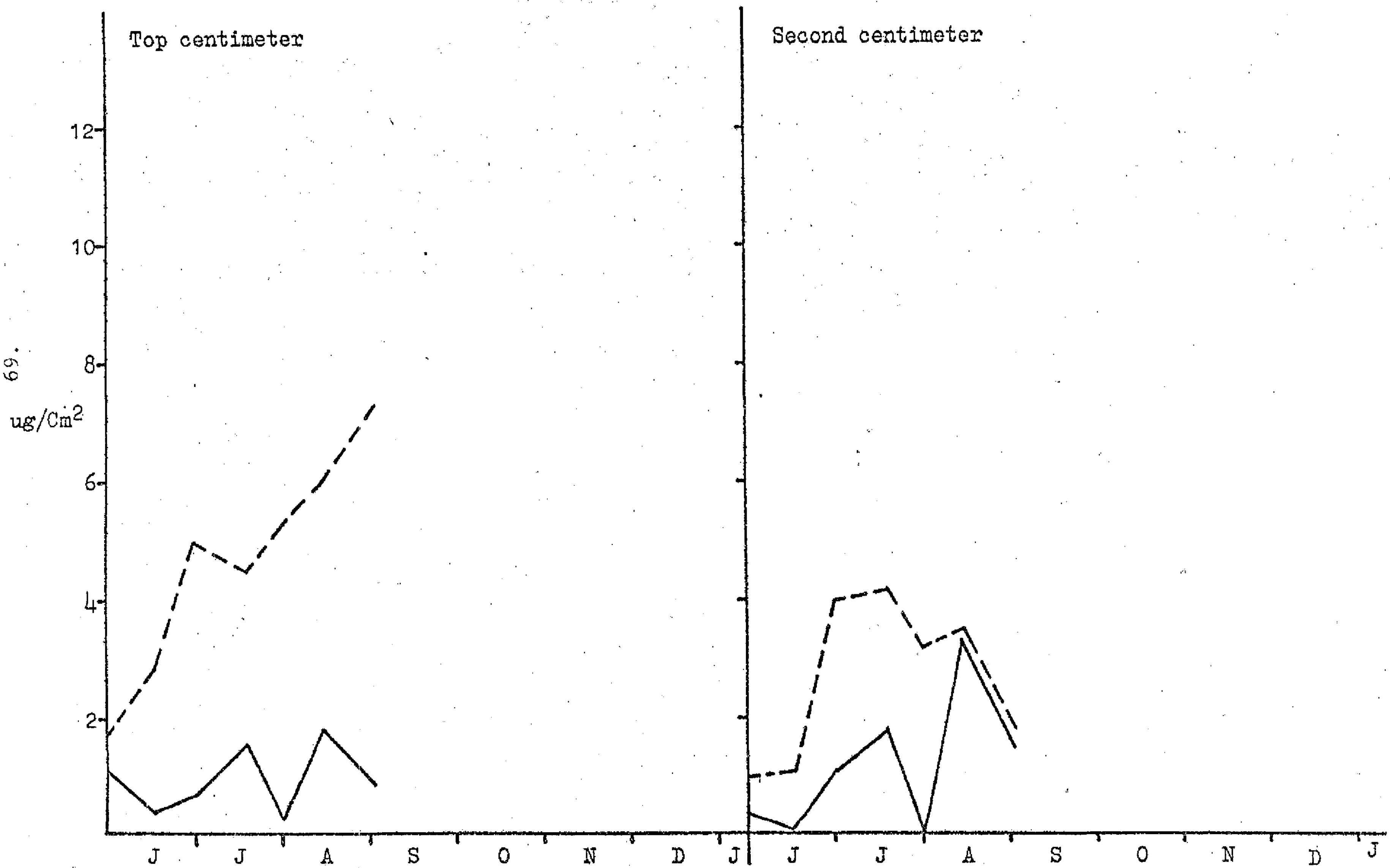
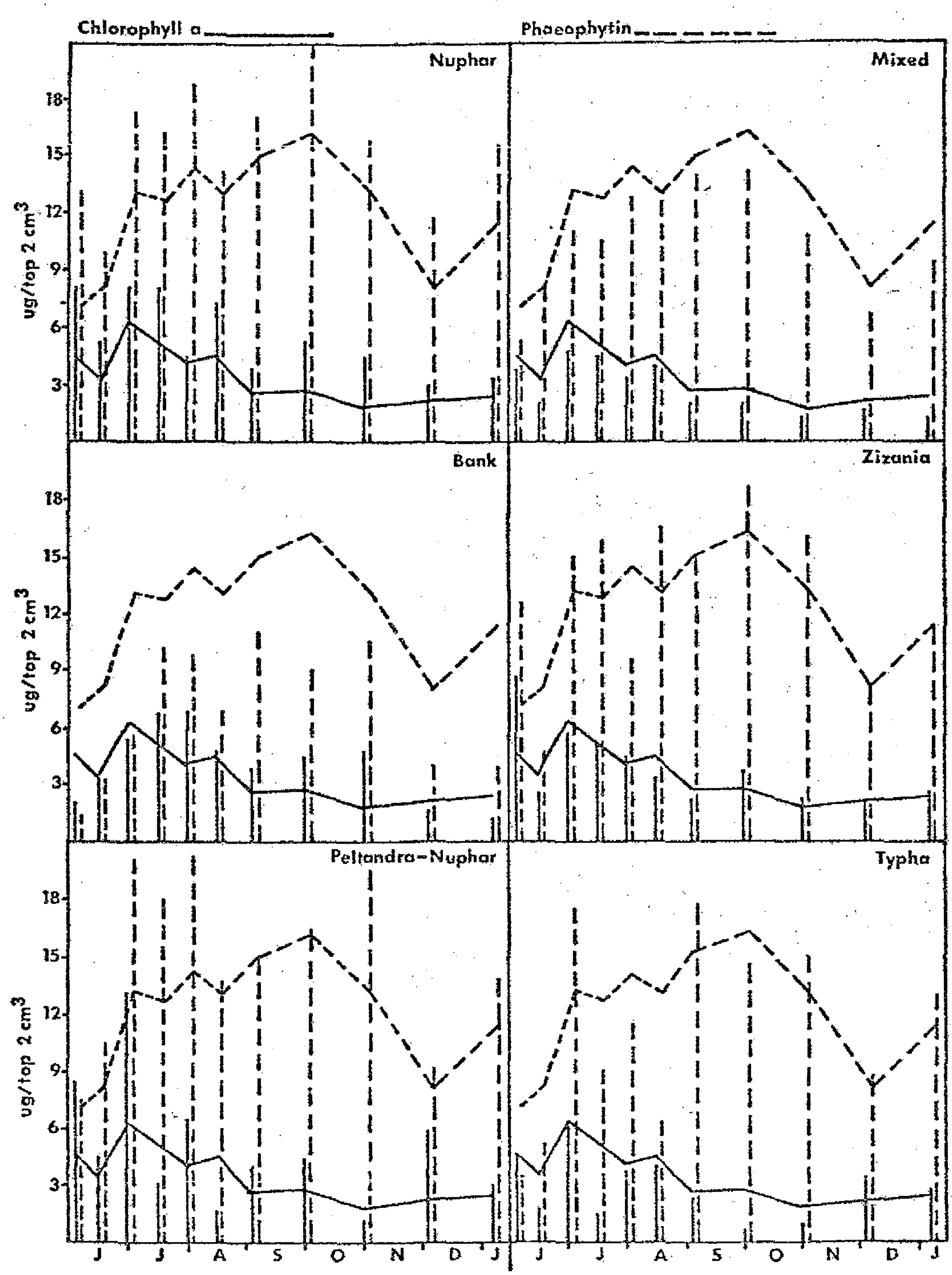


Figure 17. Changes in chlorophyll a and phaeophytin concentrations in the top two centimeters of the marsh soil from June, 1974 through January 1975. Vertical lines represent values for each dominant vegetation type sampled. Horizontal lines give mean chlorophyll a and phaeophytin values for the entire marsh. In each case, solid lines represent chlorophyll a and dashed lines represent phaeophytin.



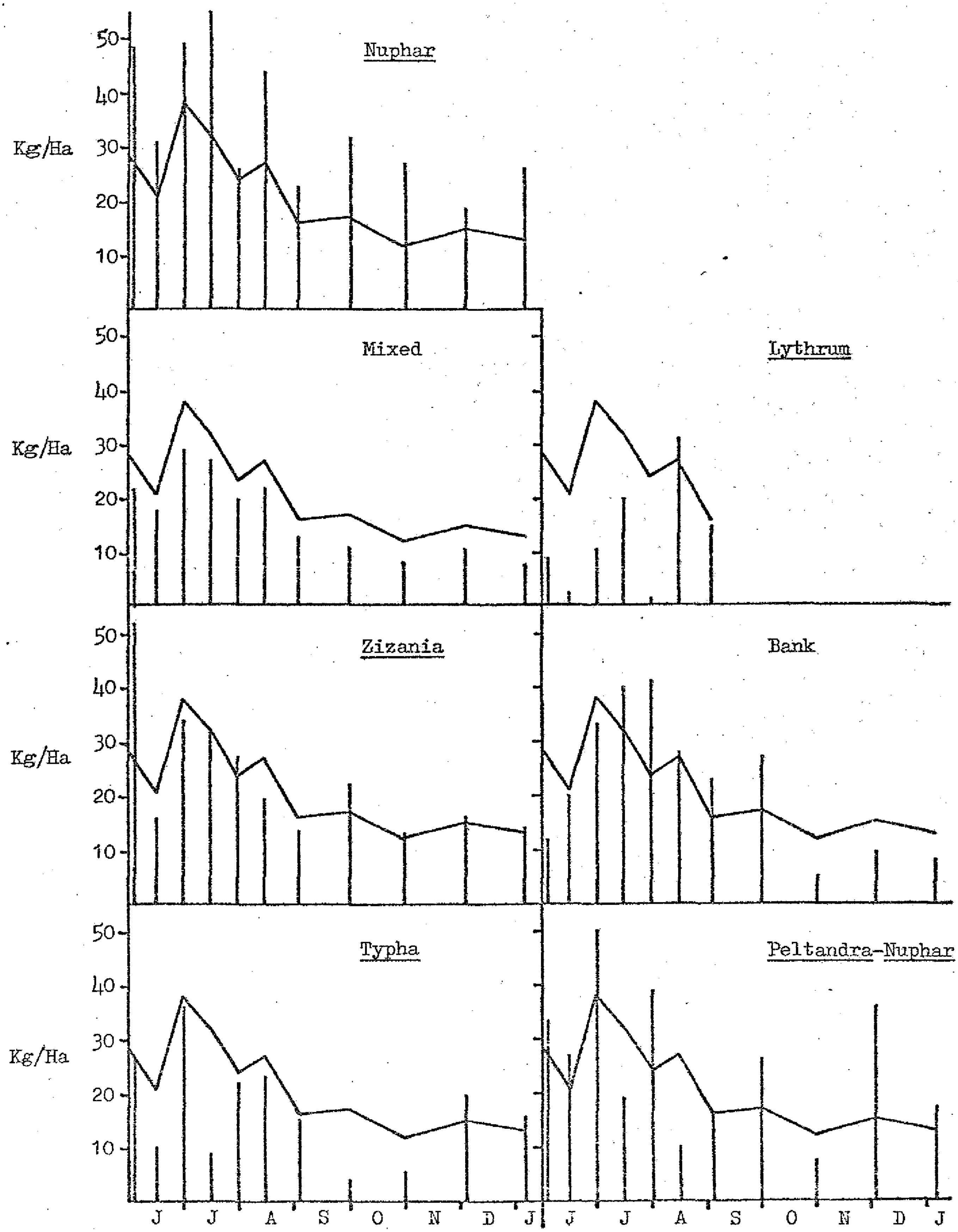
Chlorophyll a
Phaeophytin
Nuphar
Mixed
Bank
Zizania
Peltandra-Nuphar
Typha
ug/top 2 cm3
18
15
12
9
6
3
J
J
A
S
O
N
D
J

a reaching a maximum of 16.29 ug/top 2 cm^3 in early fall.

Mud algal standing crop appears to be influenced by the dominant vascular plant communities in the marsh. Areas dominated by yellow water lily consistently have chlorophyll a levels greater than mean values while high marsh areas dominated by mixed vegetation (bur marigold and others) have chlorophyll a values below the mean. This relationship appears to be a function of differences in soils in the marsh. Silty sand soils of low organic content (about 15%) found in the yellow water lily areas provide the best substrate for algal growth and silty clay soils of high organic content (25-50%) found in the mixed vegetation and cattail communities providing the poorest substrate. Shading by the higher plants also influences algal standing crops with the highest values occurring in the spring and early summer while the vascular plants are still relatively small. As the higher plants grow, chlorophyll a values decline and phaeophytin levels rise correspondingly.

Peak algal biomass for the marsh, (Figure 18) estimated from chlorophyll a values using Wetzel's (1969) factor of 60 for conversion of chlorophyll a to organic matter in non-nutrient limiting environments, was 37.7 kg/Ha, which was two to three orders of magnitude less than the peak biomass of the vascular plants. Nevertheless the mud algae cannot be overlooked. They are the only functioning producers in the marsh for almost eight months of the year and Gallagher and Daiber (1974) have found that mud algae may contribute up to 25 per cent of the total

Figure 18. Seasonal patterns of mud algae biomass, (Kg/Ha) in several marsh vegetation types. The horizontal curve is similar in each graph and represents the average standing crop for the entire marsh. Vertical lines represent monthly values .


Nuphar
Mixed
Lythrum
Zizania
Bank
Typha
Peltandra-Nuphar
Kg/Ha
50
40
30
20
10
J J A S O N D J
J J A S O N D J

annual production in Delaware River salt marshes with a substantial part of this production coming during the winter and spring when the vascular plants are dormant.

LITTER DECOMPOSITION

The vast majority of plants in the Hamilton Marshes are annuals or perennials whose aerial parts die with the onset of winter. When the annuals die and when the aboveground portions of the perennials are killed, a tremendous quantity of biomass (Table 6) is deposited on the marsh surface. Only a small amount of biomass is grazed by herbivores during the growing season and that amount is minimal compared to the total biomass that is deposited as litter.

The decomposition of litter is a necessary process in the cycling of nutrients and the rate of decomposition determines the rate at which the important minerals are made available for use by living organisms. Part of the litter that reaches the marsh surface is used as food by a community of microorganisms. These organisms collectively belong to the detritus food chain of the marsh ecosystem. In the process of utilizing the energy in the litter, minerals are released. These are either utilized directly, stored in the soil, or removed by tidal waters. Water accelerates the decomposition process by producing conditions favorable to the organisms in the detritus food chain. Much of the litter is converted to detritus during the decomposition process. Detritus is finely divided organic matter in a partial state of decomposition. What happens to the litter on a yearly basis? If it is not all mineralized or exported as detritus there will be a net increase in the amount of organic matter. If all of the litter is mineralized or otherwise transported from the marshes, there will be no build up of organic matter. The purpose of the litter decomposition study is to determine the dynamics of litter remineralization for several marsh plants and to predict the fate of the approximately 2500 metric tons of organic matter that is annually deposited on the marsh surface.

METHODS

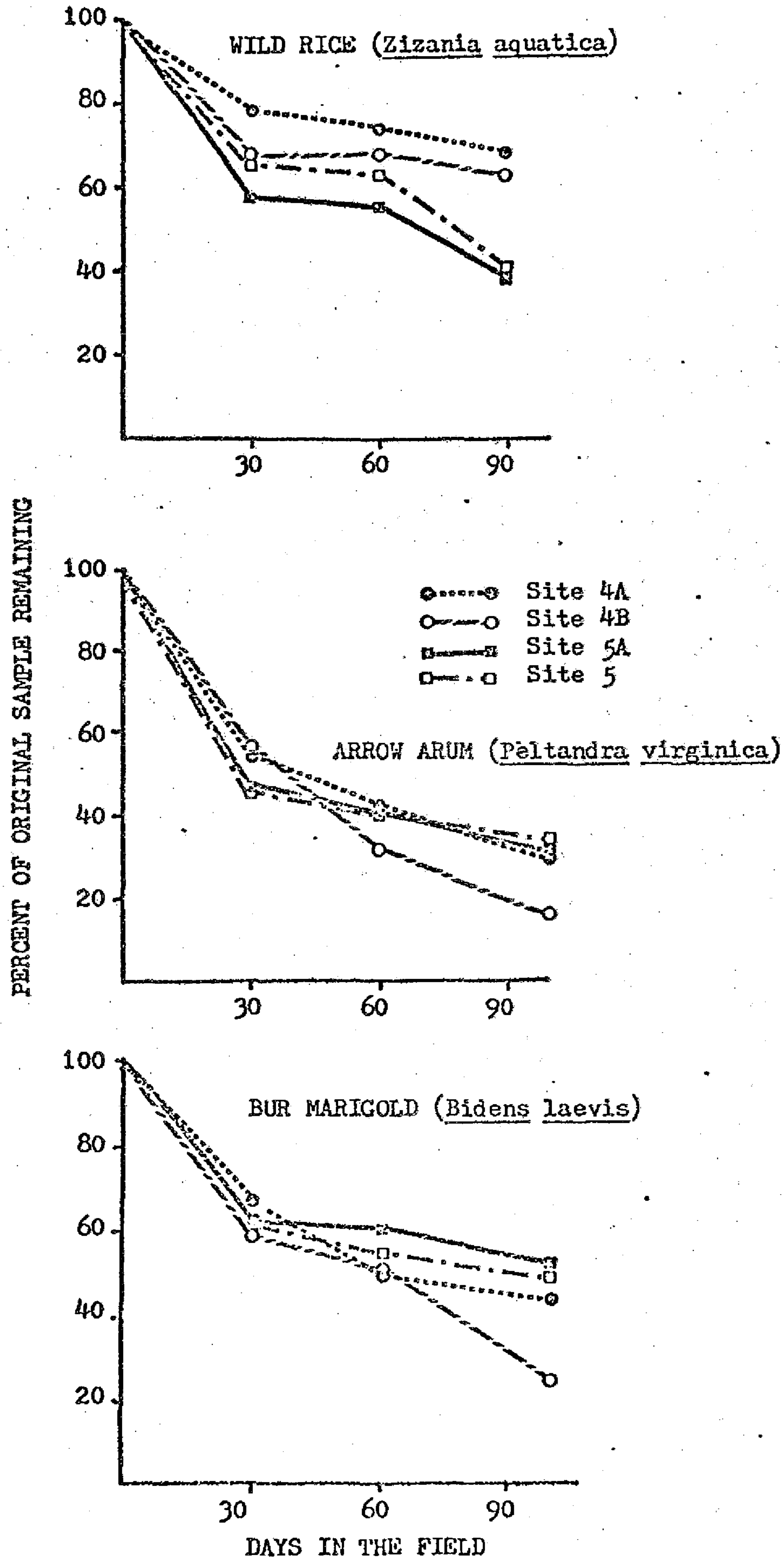
Decomposition is being measured by setting out nylon bags that contain measured amounts of dried plant material. The bags are collected monthly and the amount of material remaining is determined. We are studying decomposition rates of three species. Wild rice is an example of a dominant annual species and, being a grass, it contains a large amount of inorganic matter, mostly silica. Bur marigold is another dominant that is being studied. It is an example of a species that is not a grass, yet it has a large amount of schlerenchymatous tissue, mostly in the stems. Arrow arum is the third species. It is representative of the group of plants that have typical hydrophytic leaves that are large, leathery, and mostly water. Yellow water lily, pickerelweed, and arrowhead are other species that possess this type of leaf. They all have very little hard mechanical tissue in the leaves.

For each species, approximately 10 grams of material was placed into each litter bag. For each species, 24 litter bags were placed at each of four locations (Figure 2 and Table 1). The total number of litter bags used in the experiment was 288. Duplicate samples of each species are being collected from each site monthly. Because of siltation, the bags are gently washed upon return to the laboratory. They are then oven dried at 105°C and the dry weights of the remaining litter determined.

RESULTS

The decompositon study began in October and five monthly collections have been made. Results of the study are shown in Figure 19.. For all species the rate of decomposition was highest during the first month, about 30% weight loss for wild rice, 50% for arrow arum, and 35% for bur marigold. Except for wild rice at sites 4A and 4B, weight loss was more than 50% occurred during the first three months. Boyd (1970) and de la Cruz (1974) have ascribed the initial rapid rate loss to solubilization and leaching of substances. The succulent leaves of arrow arum decompose faster than either wild rice or bur marigold. To date, there appears to be no significant differences in decomposition rates between the four sites, although wild rice has decomposed faster at Sites 5 and 5A and bur marigold and arrow arum lost more weight at Site 4B between the second and third months. From our observations and the results of the experiments, we predict that almost all of a given years product is decomposed by the beginning of the next growing season.

Figure 19. Decomposition of wild rice (*Zizania aquatica*), arrow arum (*Peltandra virginica*), and bur marigold (*Bidens laevis*) litter. Site locations are shown on Figure 2.


WILD RICE (Zizania aquatica)
ARROW ARUM (Peltandra virginica)
BUR MARIGOLD (Bidens laevis)
Site 4A
Site 4B
Site 5A
Site 5
PERCENT OF ORIGINAL SAMPLE REMAINING
DAYS IN THE FIELD
100
80
60
40
20
30
60
90

DETRITUS TRANSPORT

Introduction

A very important aspect of the ecology of the Hamilton Marshes is its link to the Delaware River through tidal activity. During flood tides water flows from the river into the marshes, while the reverse occurs during ebb tides. The ecology of the marshes is also linked to water movement within Crosswicks Creek. During each ebb tide, water flowing in Crosswicks Creek moves directly toward the Delaware and does not, at that time, affect the marshes. The influence occurs when the tide reverses and Crosswicks Creek water is distributed, in addition to Delaware River water, throughout the marshes.

Much of the material that moves between the marshes and the Delaware River is detritus. Detritus is finely divided organic matter that is in a partial state of decomposition. It is also the chief energy link between the marshes and the Delaware River and, eventually, Delaware Bay.

The purpose of this study is(1) to determine the physical make-up of detrital materials that move into and out of the Hamilton Marshes, (2) to determine the levels of yearly variations in detritus concentrations of water imported and exported from the marshes, (3) to determine if there are any seasonal variations in the movement of detrital materials, and (4) to calculate a yearly balance of detritus movement in the marshes.

We are also seeking to determine what happens to the estimated 2500 tons of organic matter produced annually. Does it decompose in place (see section on litter decomposition)? Is a portion of it lost from the marsh as detritus?

Methods

We have adapted the techniques used during a study by scientists of the U.S. Environmental Protection Agency (Carter et. al., 1973). Three sampling locations were established (Figure 2 and Table 1). Site 7 permits us to sample detrital movement into and out of the marsh area north of the Route 206 bridge. Site 4 enables us to determine the movement of detritus into and out of the northern section (all areas between Site 4 and Spring Lake) of the marsh. At Site 2 we can monitor movement into and out of the entire marsh with the exception of a small portion of the marsh that is connected to a small stream that lies between Site 2 and the Delaware River.

When we first began the study we sampled all sites at high tide, low tide, mid-ebb tide, and mid-flood tide. Analysis of the data after three months of sampling showed that it is only necessary to sample at mid-ebb and mid-flood tides.

Our sampling procedure was as follows: while anchored at a station, calibrated buckets were used to pour 300 liters of water through two stacked sieves. The water samples were collected just below the water surface. The material remaining in the sieves (U.S. Standard #50 (297 microns) and #230 (63 microns) was transferred to labeled bottles and returned to the laboratory for analysis. Two bottles (one liter each) of filtered water were also collected and returned to the laboratory for processing.

The detrital fractions collected on the two sieves were analyzed for dry weight. A third detrital fraction was collected by passing replicate samples of the filtered water through a .8 micron millipore filter. Dry weight determination is also carried out on this nannofraction. Concentrations (mg/l) of the three site fractions of detritus are then calculated.

In order to determine the total amount of detritus moving through each station, additional data is collected. Stream velocity is determined at 20 cm and 80 cm depths with a Pygmy Current Meter. Water depth at the time of sampling is measured. Using the depth readings and cross-sectional diagrams of each station, we are able to determine the cross-sectional area of each station at the time of sampling.

Combining data on stream velocity, cross-section area, and detritus concentration, the total amount of detrital material moving through each site was calculated. This study, initiated in October, 1974, will continue for one year.

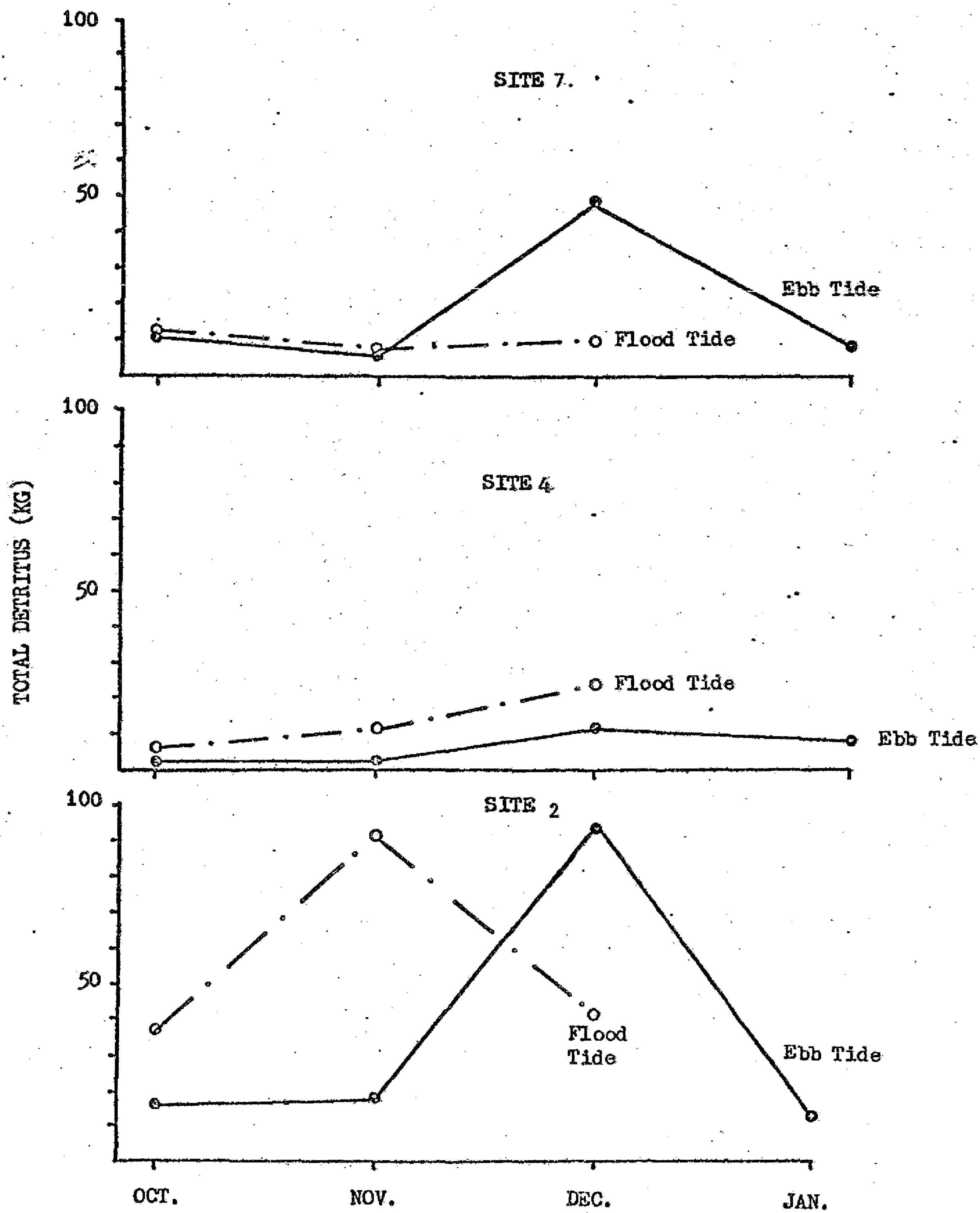
RESULTS

Results of the first four sampling periods are shown in Figure 20 . More detritus moved through Site 3 than either Sites 7 or 4. This would be expected since detritus moving through Site 3 during flood tide would be partitioned into various sections of the marsh. Comparing Sites 7 and 2, slightly more detritus was measured moving past Site 7 during flood tide.

During ebb tide, water passing through Site 7 and 4 carry materials from separate large sections of the marsh. One would expect that the total amount of detritus moving past those two sites would be approximately equal to the amount measured at Site 2. Figure 20 shows that was the case during the first four months of the study.

Except for December, there was a greater amount of suspended material moving into the marsh from the Delaware River than moving out of the marsh during ebb tide. December samples were collected shortly after a heavy rainfall. As one might expect, there would be a considerable amount of sediment moving in Crosswicks Creek from upstream areas. Figure 20 shows that more material moved through Sites 7 and 2 during ebb tide than was returned during flood. It is also apparent that the increased detrital load was not generated within the marshes. More material moved through Site 4 during flood tide than returned during ebb tide. Again, this would be expected because most of the water that moves into and out of the Rowan Lake and Spring Lake section

Figure 20. Patterns of detritus movement during ebb and flood tides at 3 sampling stations in the Hamilton Marshes. See Figure 2 for site locations.



100
SITE 7.
50
Ebb Tide
Flood Tide
100
SITE 4
50
Flood Tide
Ebb Tide
100
SITE 2
50
Flood Tide
Ebb Tide
TOTAL DETRITUS (KG)
OCT.
NOV.
DEC.
JAN.

of the marsh is tidal water. As a result, we would expect less material to move out of those areas during ebb tide than moves in during flood tide. This relationship should hold even during periods of peak flow in the Delaware River and in Crosswicks Creek.

Most of the detritus that moves through the marshes is in the nannofraction. Figures 21-23 show that approximately 90-98% of all suspended materials are within the nannofraction during both ebb and flood tides.

Others (Odum and de la Cruz ,1967 and Carter et. al. ,1973) have obtained similar results.

Obviously, the preponderance of material carried into and out of the marshes is in a highly fractionalized state. The lower values for the nannofraction during ebb tide in November was due to an increase in the number of seeds floating in the water.

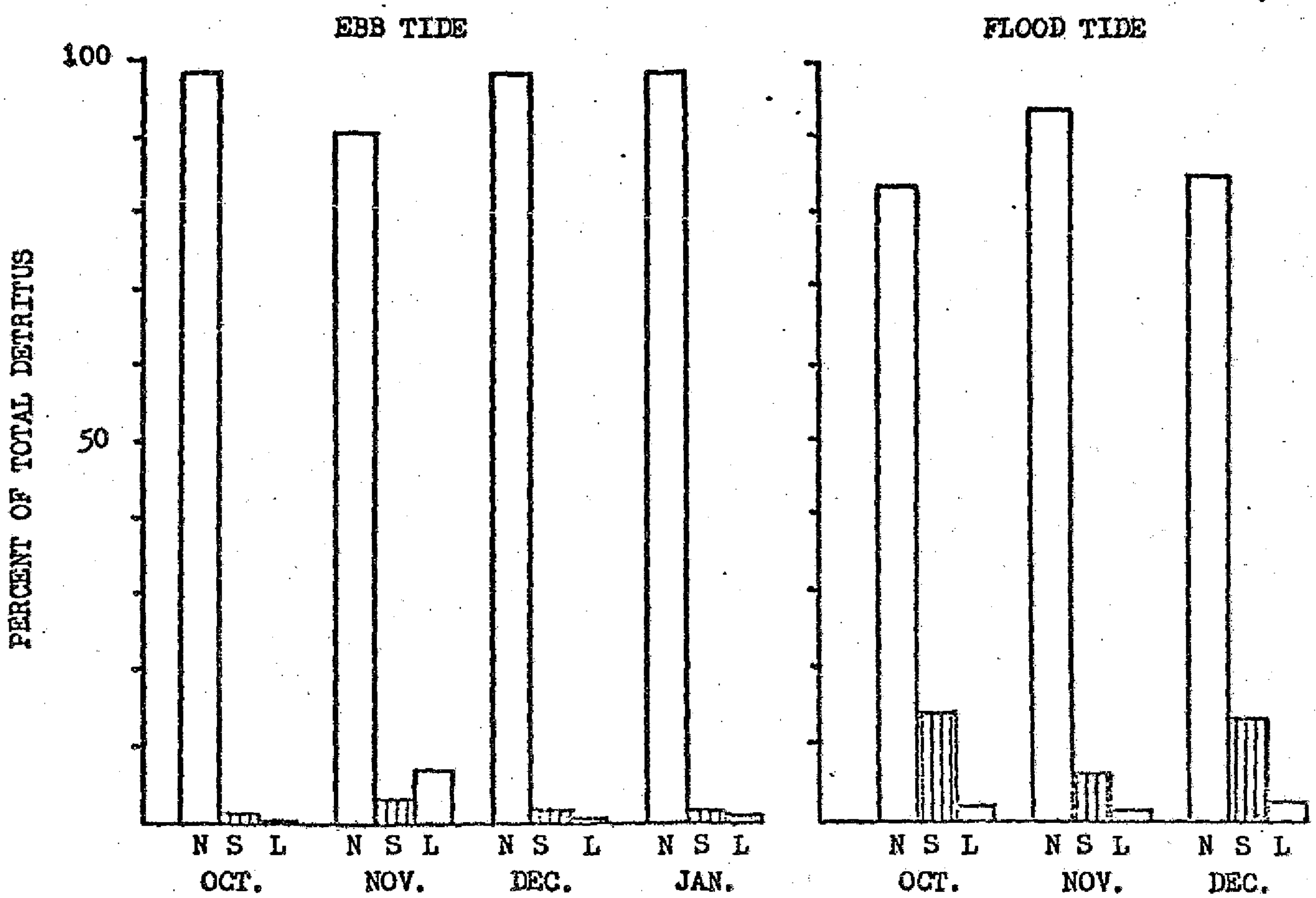
No conclusion can be made concerning the yearly balance of material moving into and out of the marsh, but if the present trend continues, it appears that much of the decomposing litter is mineralized in the marshes.

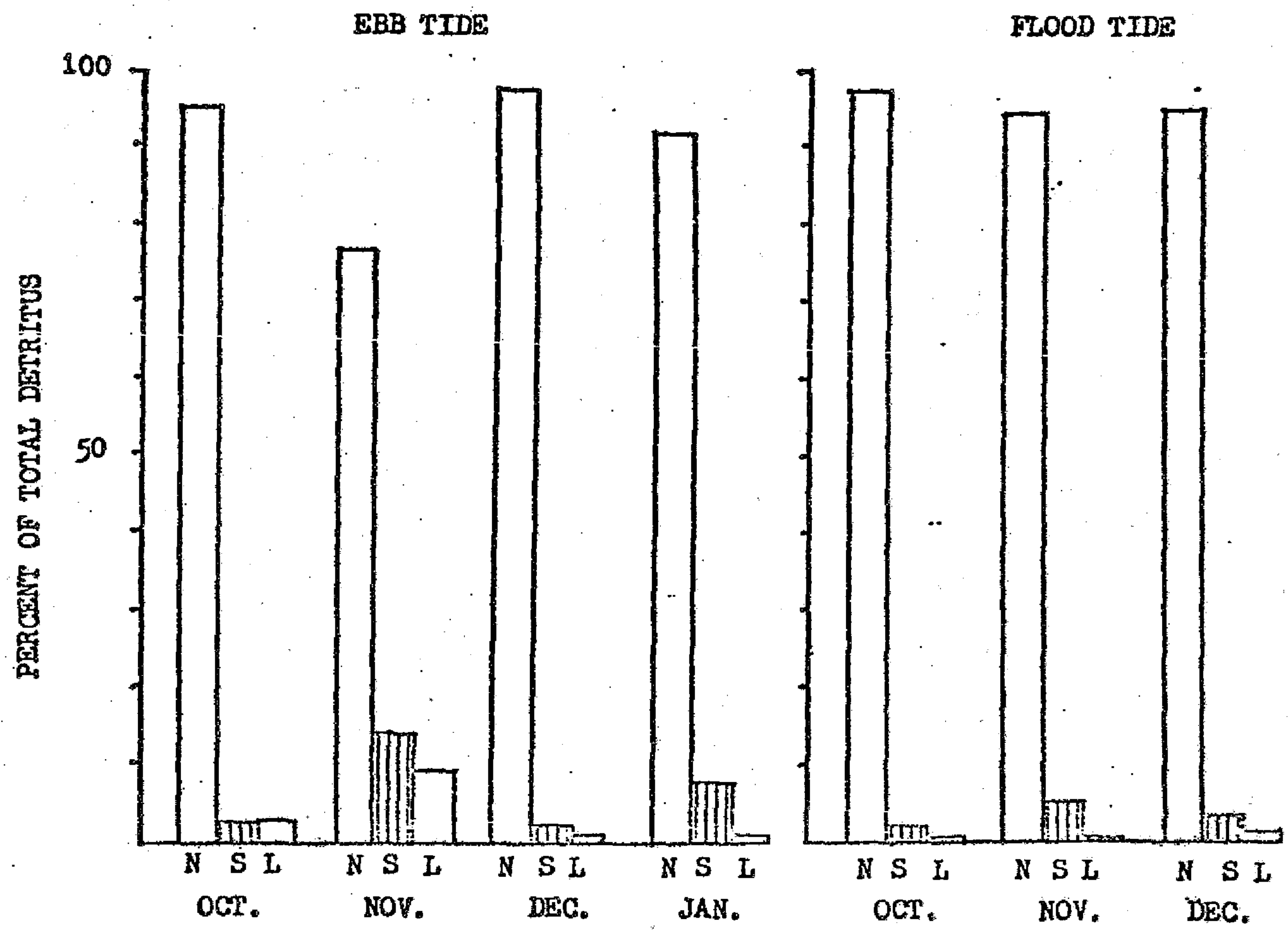
We also hesitate to draw conclusions until we compare the data on an ash-free basis. A portion of the suspended materials that we measure contains phytoplankton and zooplankton and inorganic sediment. We especially need to know how much of the detritus is in the inorganic fraction. We are presently working on that

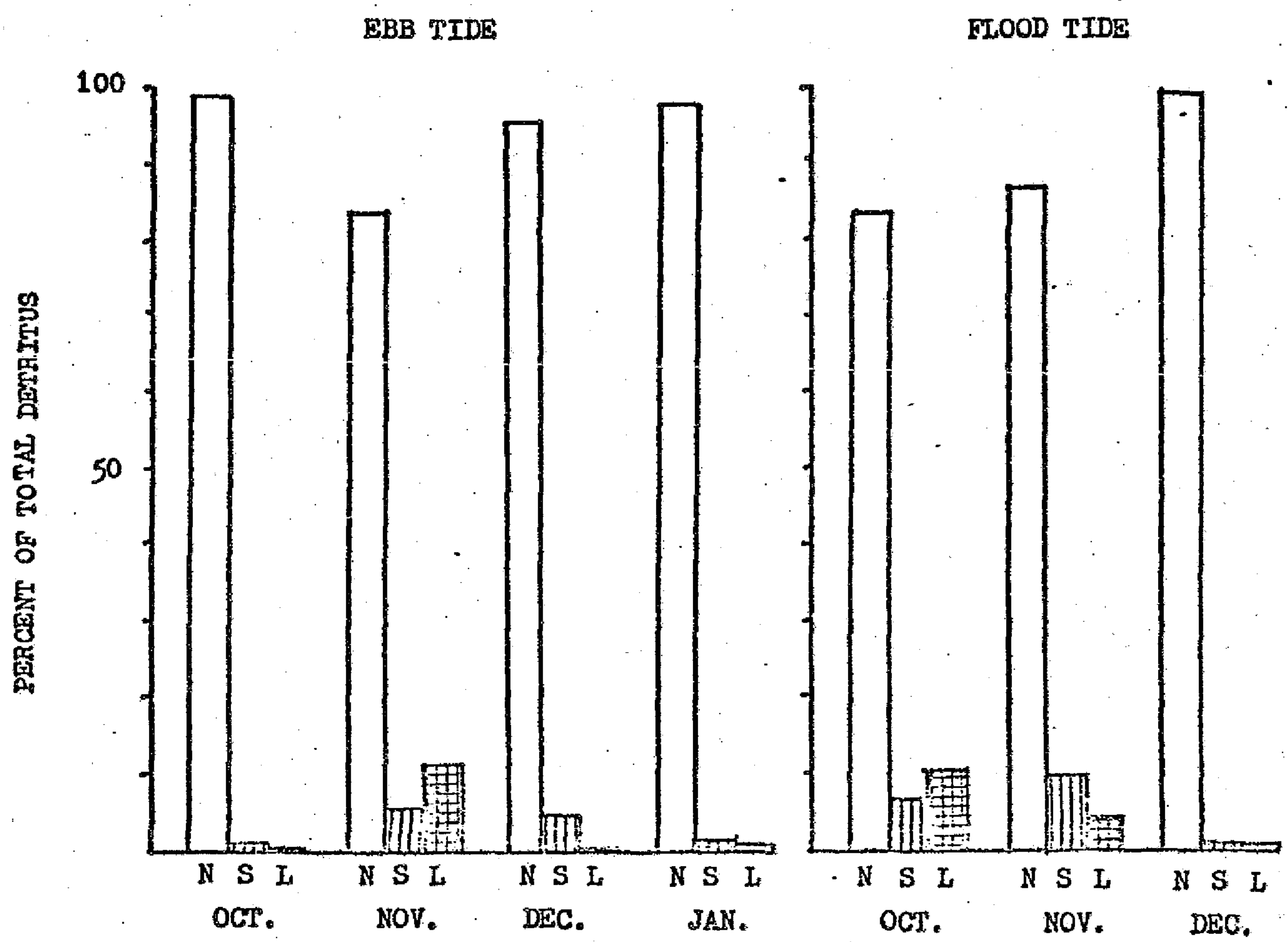
Figures 21-23. Particle size distribution of detritus samples at sites 2,4, and 7 respectively.

The size fractions are:

N = Nannofraction (.8-62 microns)
S = Small fraction (63 - 296 microns)
L = Large fraction (+ 296 microns)


EBB TIDE
FLOOD TIDE
100
50
PERCENT OF TOTAL DETRITUS
N S L
OCT.
NOV.
DEC.
JAN.


EBB TIDE
FLOOD TIDE
100
50
PERCENT OF TOTAL DETRITUS
N S L
OCT.
N S L
NOV.
N S L
DEC.
N S L
JAN.
N S L
OCT.
N S L
NOV.
N S L
DEC.


EBB TIDE
FLOOD TIDE
100
50
PERCENT OF TOTAL DETRITUS
N S L
OCT.
NOV.
DEC.
JAN.
OCT.
NOV.
DEC.

aspect of our study and preliminary data show that the amount of organic matter in the suspended material is usually between 50 and 85%.

WATER QUALITY

Introduction

Except for Grant and Patrick's (1970) study of Tinicum Marsh, little information is available on seasonal changes in water quality in freshwater tidal marshes. Such data are important if we are to understand the functional processes that occur in freshwater marshes. So that the role selected water quality parameters play in the Hamilton Marshes can be determined, studies were initiated in June 1974 to monitor several chemical species, including (dissolved oxygen, carbon dioxide, total alkalinity, reactive nitrate, reactive nitrite, ammonia (plus amino acids), reactive and total phosphate) known to reflect metabolic processes in aquatic environments.

Materials and Methods

Water samples are being taken at two week intervals in the summer and monthly intervals through the remainder of the year at eleven sites encompassing the major marsh habitats. These areas include Sites 1, 2, 6, 7, and 8 in the main channel of Crosswicks Creek, Sites 4A, 4B, 4C, and 4D in Watson Creek and the Rowan Lake area, and Sites 5 and 5A in the side channel draining from Site 5B. On each date, samples are collected at the morning high slack water (hsw) and the afternoon low slack water (lsw). On two occassions, a third set of samples was collected at the evening high slack water. All samples are surface samples and collected by hand except at Sites 1 and 8 where a horizontal 2 liter Dorn water bottle is used. To insure that samples are collected as close to slack water as possible, Sites 2, 4, 5, 6, and 7 located on Crosswicks Creek and accessible only by boat were collected by one team while a second team collected Sites 1, 5A and 8 which are approachable from land. Because slack water occurs later at Sites 4A, 4B, and 4C, they are visited after sampling is completed at the other sites. About one and one half hours elapses between the iniation of sampling and delivery of the samples to the laboratory..

The following parameters are measured at each station: dissolved oxygen, carbon dioxide, total alkalinity, reactive nitrate, reactive nitrite, ammonia (plus amino acids), reactive phosphate and total phosphate. Dissolved oxygen samples are collected in duplicate and fixed in the field. Water for carbon dioxide, alkalinity, and nitrogen species are taken in well stoppered glass bottles, and phosphate samples are collected in polyethylene bottles.

Samples for carbon dioxide, alkalinity, ammonia, and nitrites are processed within two hours of delivery to the laboratory and nitrates within six hours. Phosphate samples are frozen for later analysis. American Public Health Association (1971) procedures are followed for analysis of carbon dioxide, total alkalinity (methyl orange), and dissolved oxygen (azide modification of the standard Winkler method). Reactive nitrate, reactive nitrite, and ammonia (plus amino acids), and reactive phosphate are analyzed following the methods of Strickland and Parsons (1968). Total phosphate is analyzed according to procedures given by Menzel and Corwin (1965). Temperature is measured with a telethermometer. Occassional measurements of pH using a Fisher pH meter and turbidity following Hach (1971) procedures are also made.

Results and Discussion

Dissolved oxygen and carbon dioxide

Figures 24-26 give the dissolved oxygen levels for each sample date. Several trends are apparent from the data. At those sites downstream from the Hamilton Township Sewage Treatment Plant effluent pipes (Sites 1, 2, 4, 4A, 5, 5A, 6) oxygen levels are almost always higher at hsw than they are a lsw. Site 7 located up stream from the effluent pipes shows somewhat the reverse of this pattern, but the trend is not consistent. Dissolved oxygen levels at Site 8 located on Crosswicks Creek well up stream from the effluent pipes and miminally influenced by the tide, fluctuates little between hsw and lsw.

All sites display expected seasonal trends in dissolved oxygen concentrations with levels being lower during the summer than the winter. Sites 4B and 4C which are pond-like had oxygen levels below 2 mg/l throughout the summer and at Site 4C less than 1 mg/l

Figure 24. Changes in dissolved oxygen from June 1974 through January 1975 at Sites 5, 5A, 7, and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

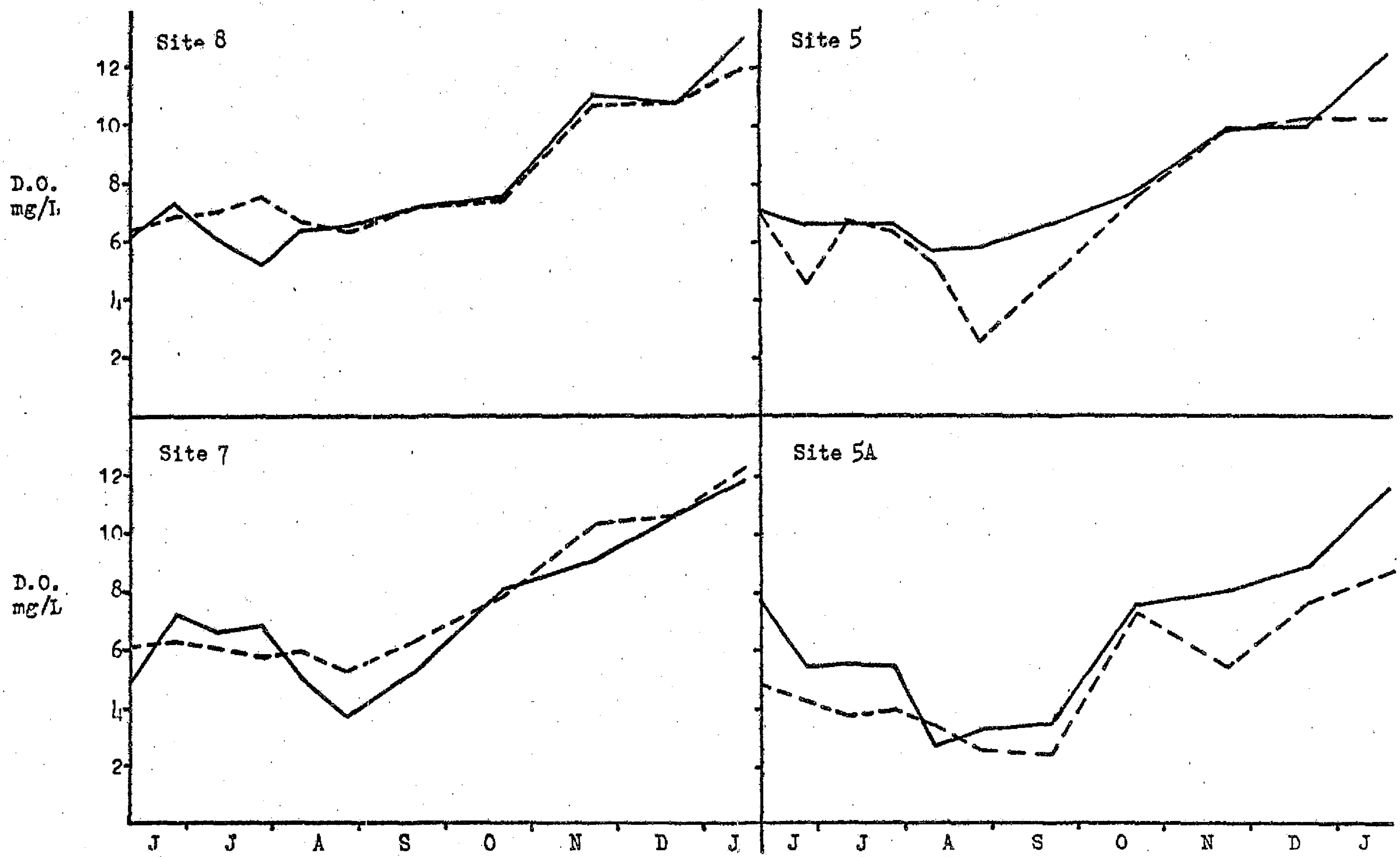


Figure 25. Changes in dissolved oxygen from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

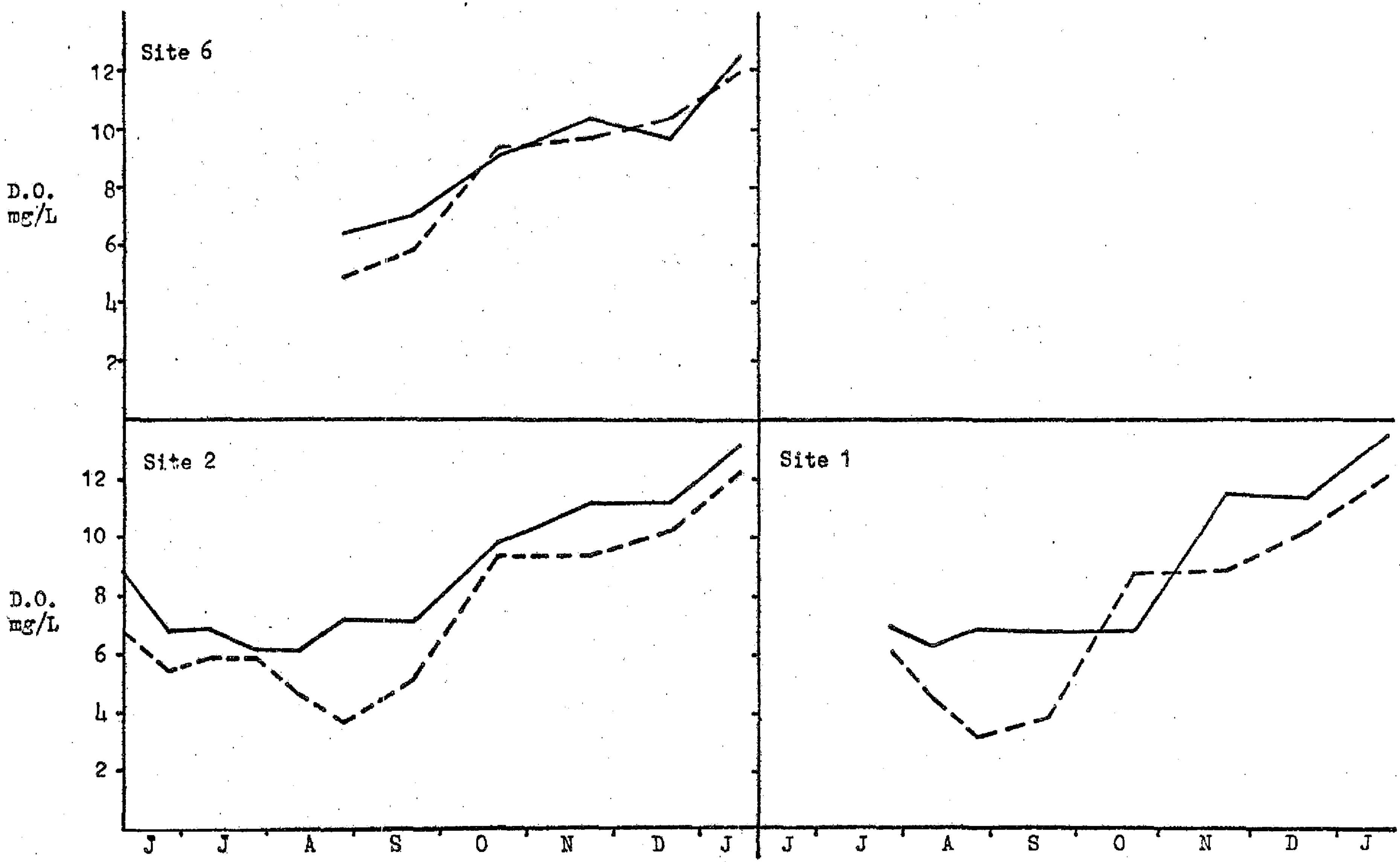
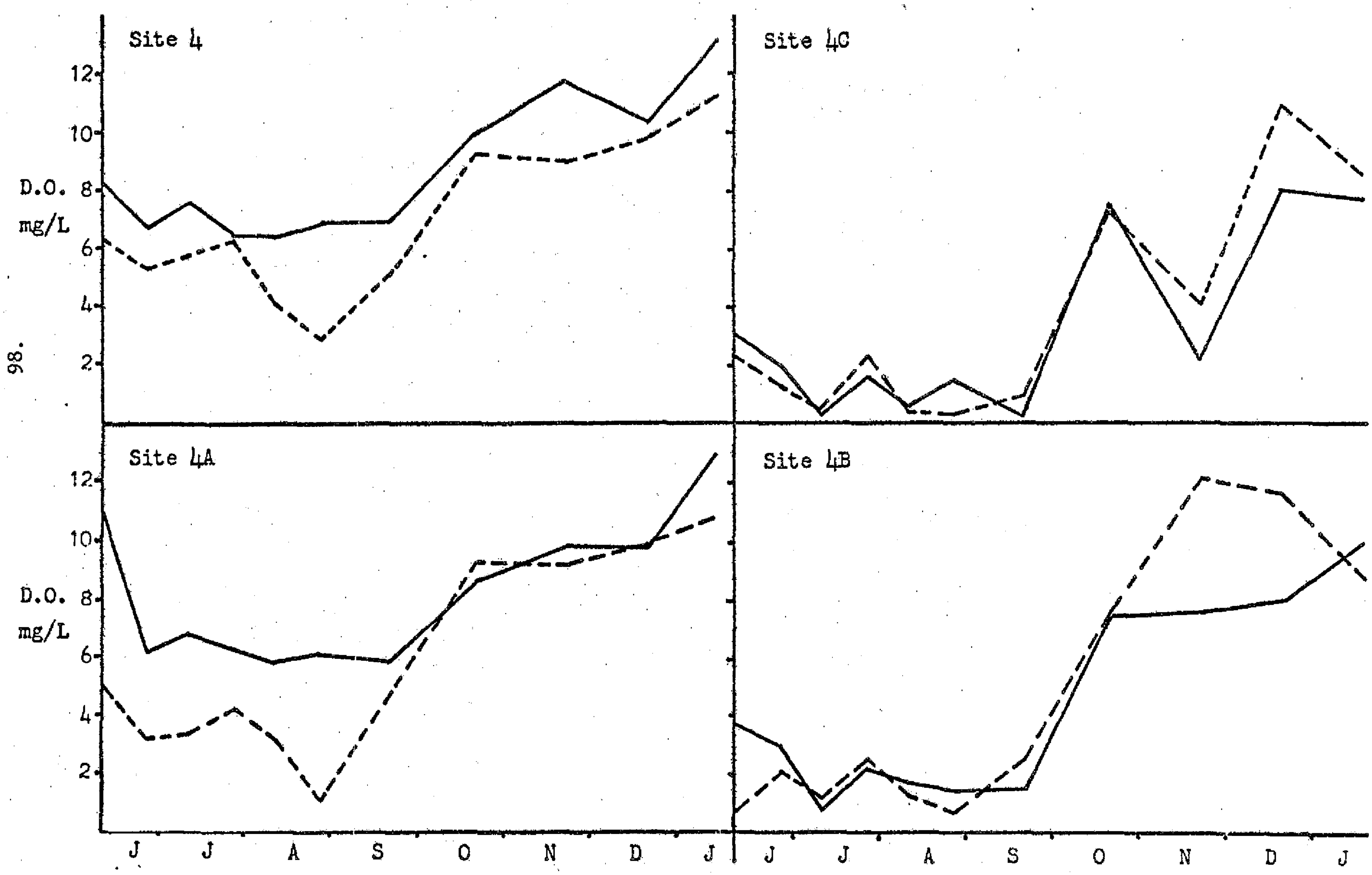


Figure 26. Changes in dissolved oxygen from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



oxygen was found on three occassions. Lsw summer oxygen levels at Site 4A averaged about 2 mg/l less than at Site 4 and Sites 1, 2, and 6 on Crosswicks Creek. Site 5A located at the confluence of a large section of high marsh had consistently lower oxygen concentrations during the summer than Site 5 locate downstream near Crosswicks Creek.

During the late fall, Sites 4B and 4C oxygen levels increased rapidly, but still remained somewhat lower than at other sites. Both November and December oxygen levels were 1 to 4 mg/l higher at the afternoon lsw than at the morning hsw. At site 5A, the reverse was seen with oxygen levels about 2 mg/l lower at the lsw than at hsw.

Figures 27-29 give the carbon dioxide levels for each sample date. Carbon dioxide levels are consistently higher at lsw than at the morning or evening hsw at Sites 1, 2, 4, 4A, 5, and 5A, and 6. Differences were particularly apparent at Sites 5 and 5A, where lsw levels are generally at least 10 mg/l higher than at hsw. During the summer Sites 4B, 4C, and 5A constantly had the highest carbon dioxide levels and during the fall Site 5A levels were highest. The elevated fall values at Site 5A corresponded with the period of most rapid die-back of the noted vascular plants.

Behavior of oxygen and carbon dioxide gives us some insight into the function of the marsh. As would be expected, a definite reciprocal relationship exists between dissolved oxygen and carbon

Figure 27. Changes in carbon dioxide from June 1974 through January 1975 at Sites 5, 5A, 7, and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

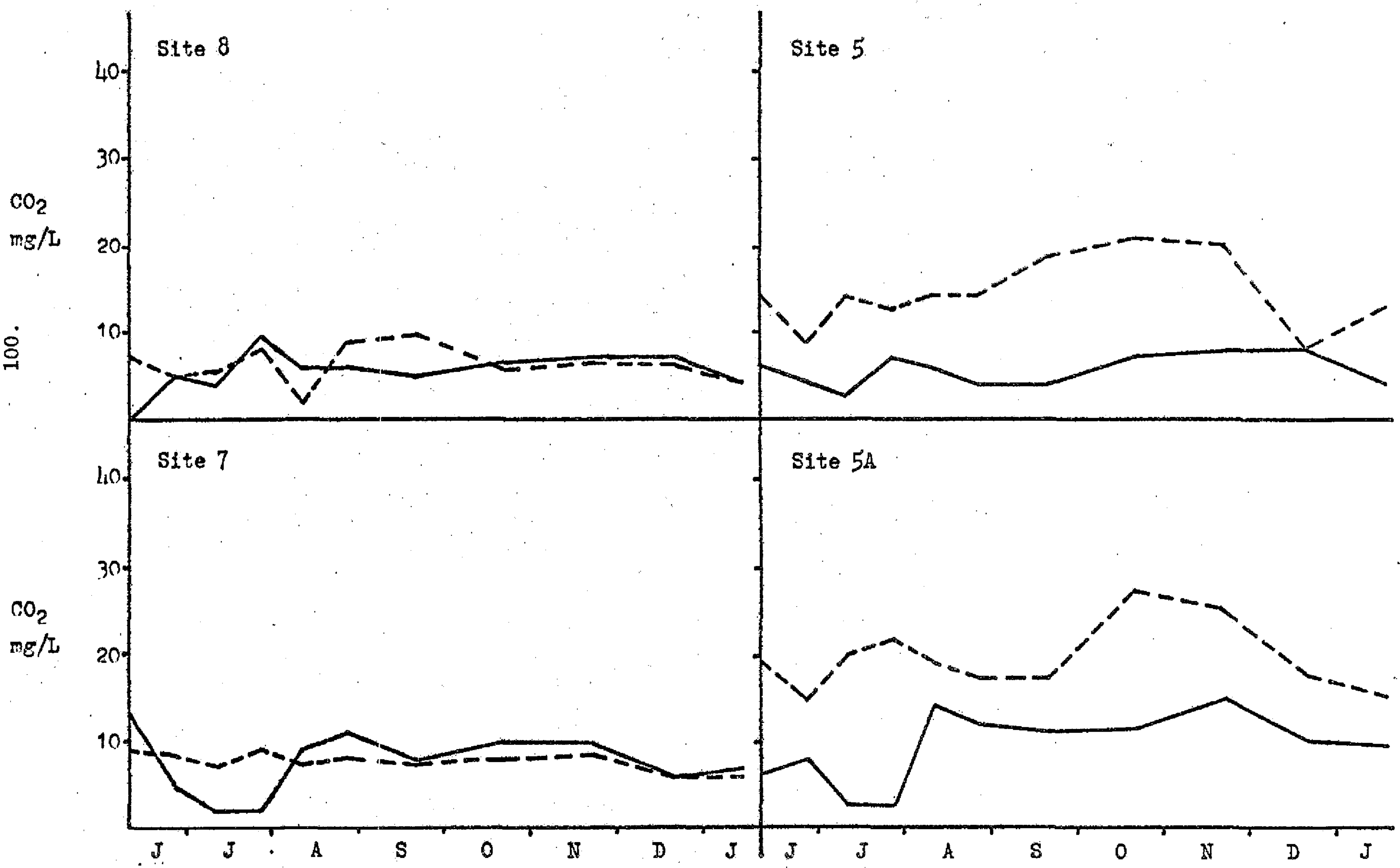


Figure 28. Changes in carbon dioxide from June 1974 through January 1975 at 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

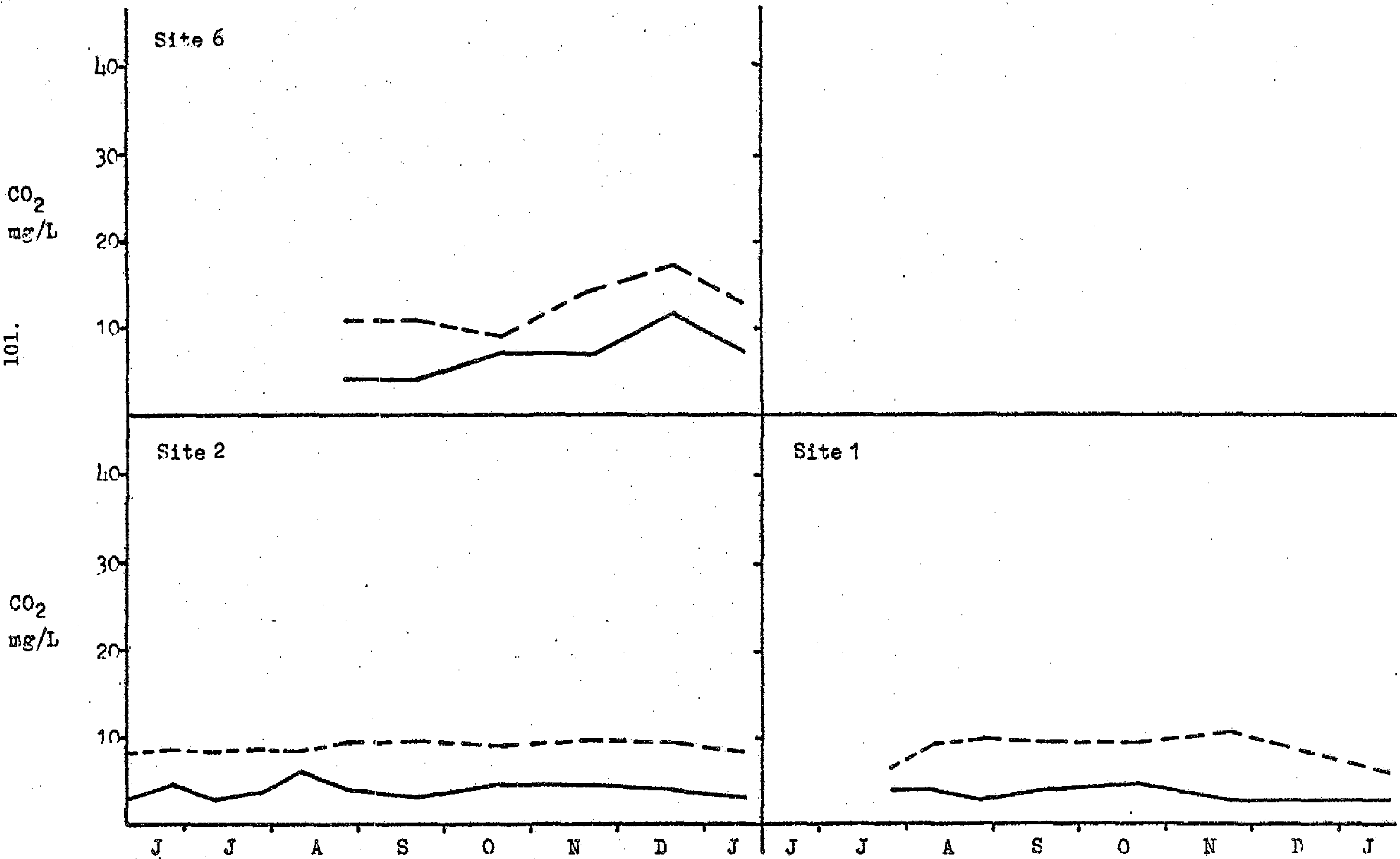
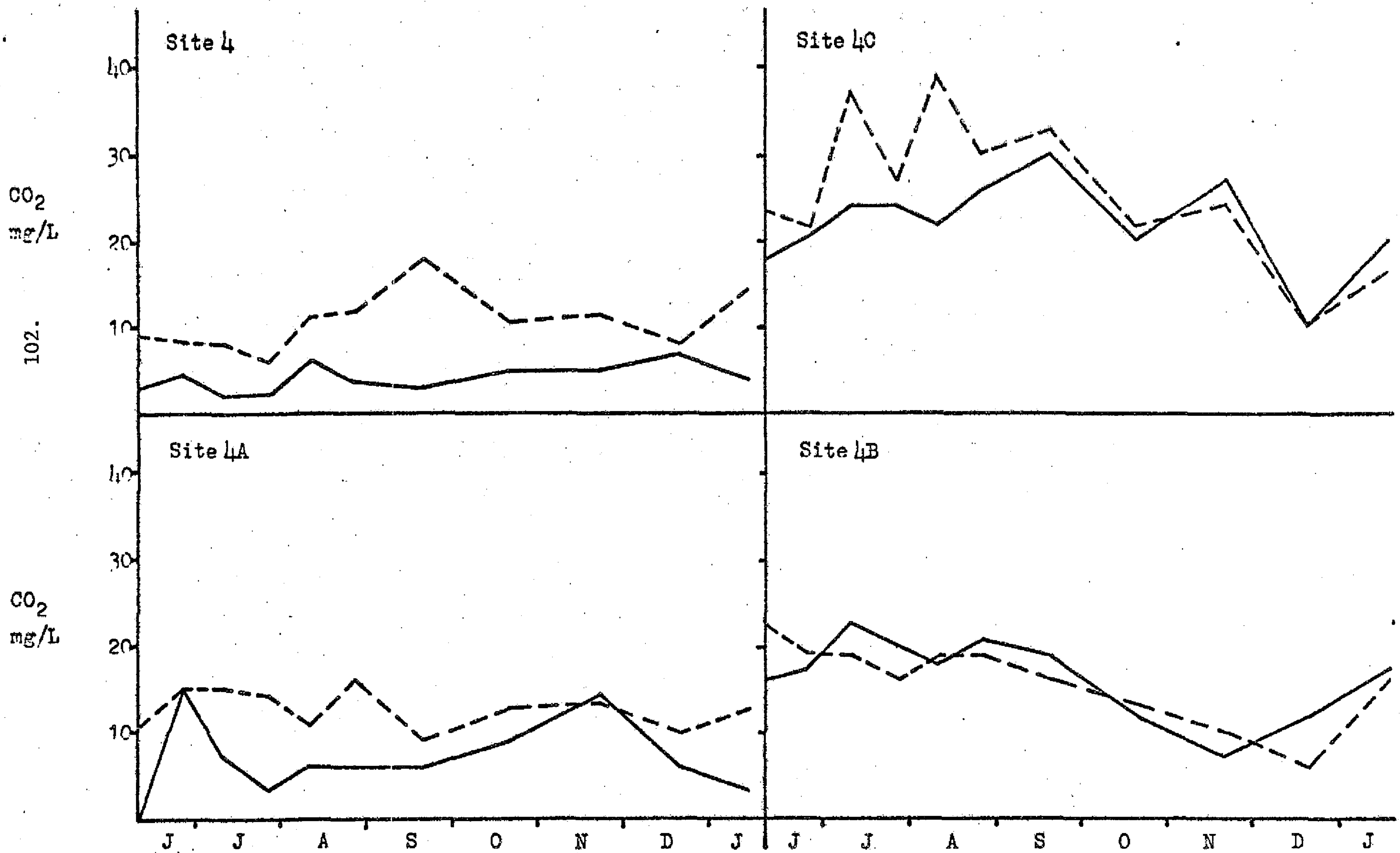


Figure 29. Changes in carbon dioxide from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



dioxide. All sites located downstream from the Hamilton Township Sewage Treatment Plant effluent pipes on either Crosswicks Creek (4, 4A, 5, 5A) had lower oxygen and higher carbon dioxide levels at lws than at hsw. In the case of Site 6, this undoubtly reflects the influence of the effluent from the sewage treatment plant. In the case of 4, 4A, 5, and 5A these differences reflect the metabolic process of the marsh itself because the effluent is not accessable to these sites as the tide ebbs. Sites 1 and 2 reflect the combined effects of the sewage effluent and the marsh, although the impact of the sewage plant is probably greater.

The different habitat types in the marsh have distinctly different effects on carbon dioxide and oxygen. Site 4B and 4C which are distinctly pond-like are almost depleted of oxygen and have very high carbon dioxide levels during the summer months, but as the marsh vegetation dies in the fall, oxygen levels rise dramatically while carbon dioxide levels decline. In November and December when the vascular plants have died back, dissolved oxygen are several mg/l higher in the afternoon than early in the morning. At Site 4B this is due to a dense growth of the algae <u>Rhizoclomium</u> that develops after the rooted plants dieback and at Site 4C it is due to blooms of diatoms and <u>Spirogyra</u>. Site 5A which is downstream from an extensive area of high marsh displays a different pattern of response. Here oxygen levels are somewhat depressed and carbon dioxide levels elevated over those found in the main channel of Crosswicks Creek, but the difference is not as dramatic as in the pond-like areas. In October and November, however, carbon dioxide levels rise noticably corresponding to the period of rapid dieback of vascular plants at the site. This dieback is followed by a rapid decomposition of vegetation as shown in Figure 19 .

It appears the dissolved oxygen and carbon dioxide levels at Site 8 are minimally affected by the movement of the tide, probably because little effluent from the sewage plant actually reaches this site. Oxygen and carbon dioxide levels at Site 7, except for some depression of dissolved oxygen in August and September, appear to closely parallel those of Site 8 suggesting that the effluent from the Hamilton Plant exerts little influence on these parameters at this site.

Nitrate, Nitrite, and Ammonia

Figures 30-32 give reactive nitrate concentrations for each sample date. Nitrate levels were very low at Sites 4B and 4C throughout the summer and early fall. At Site 4C, nitrate levels began increasing in October and climbed steadily. At Site 4B, nitrate began increasing in November, but the lsw levels remained substantially below hsw concentrations unlike at Site 4C where lsw values paralleled the increase in hsw values. Site 4A which in downstream from Site 4B some depression of lsw nitrate values was apparent during the summer months.

Figure 30. Changes in nitrate-nitrogen from June 1974 through January 1975 at Sites 5, 5A, 7, and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

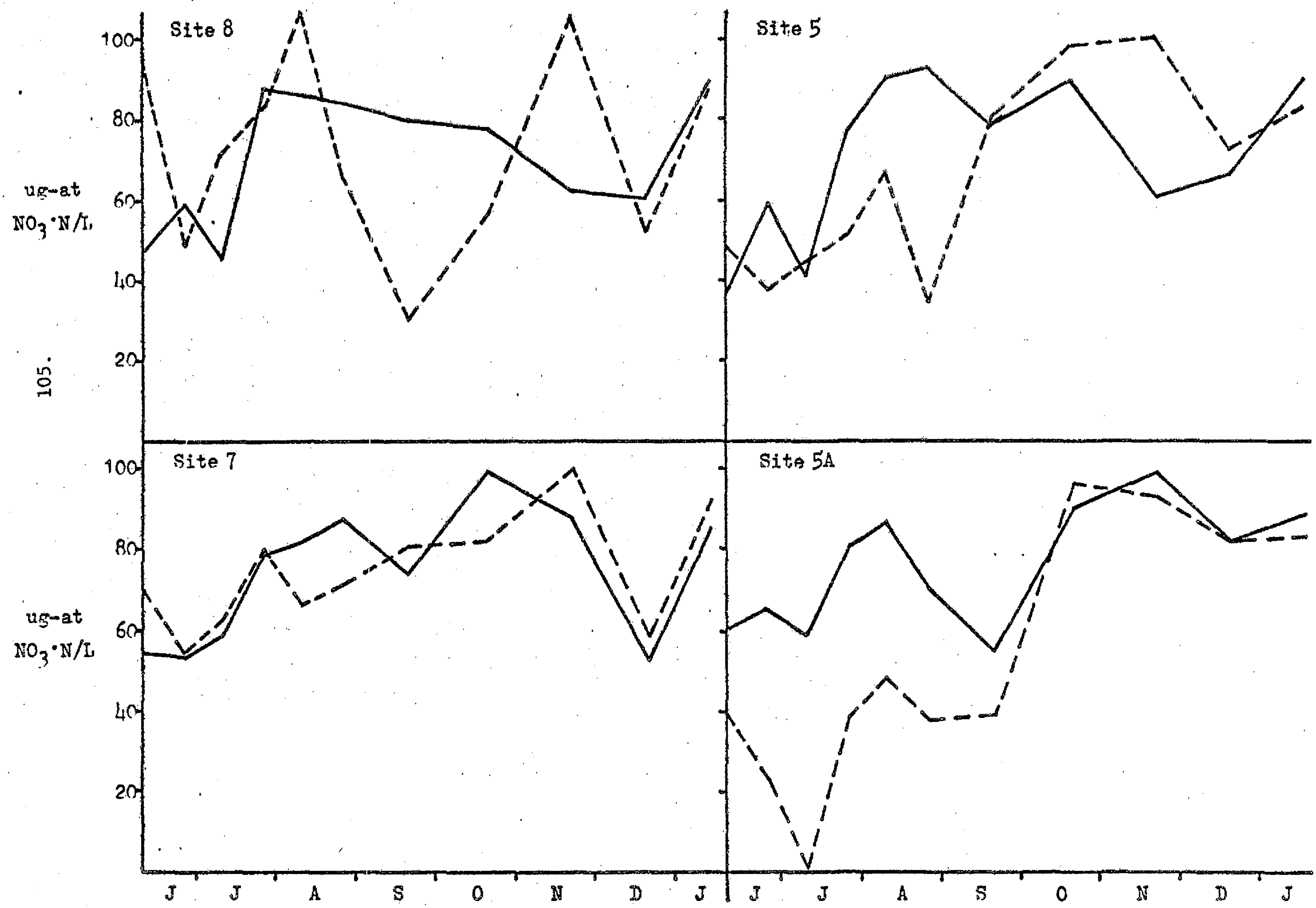
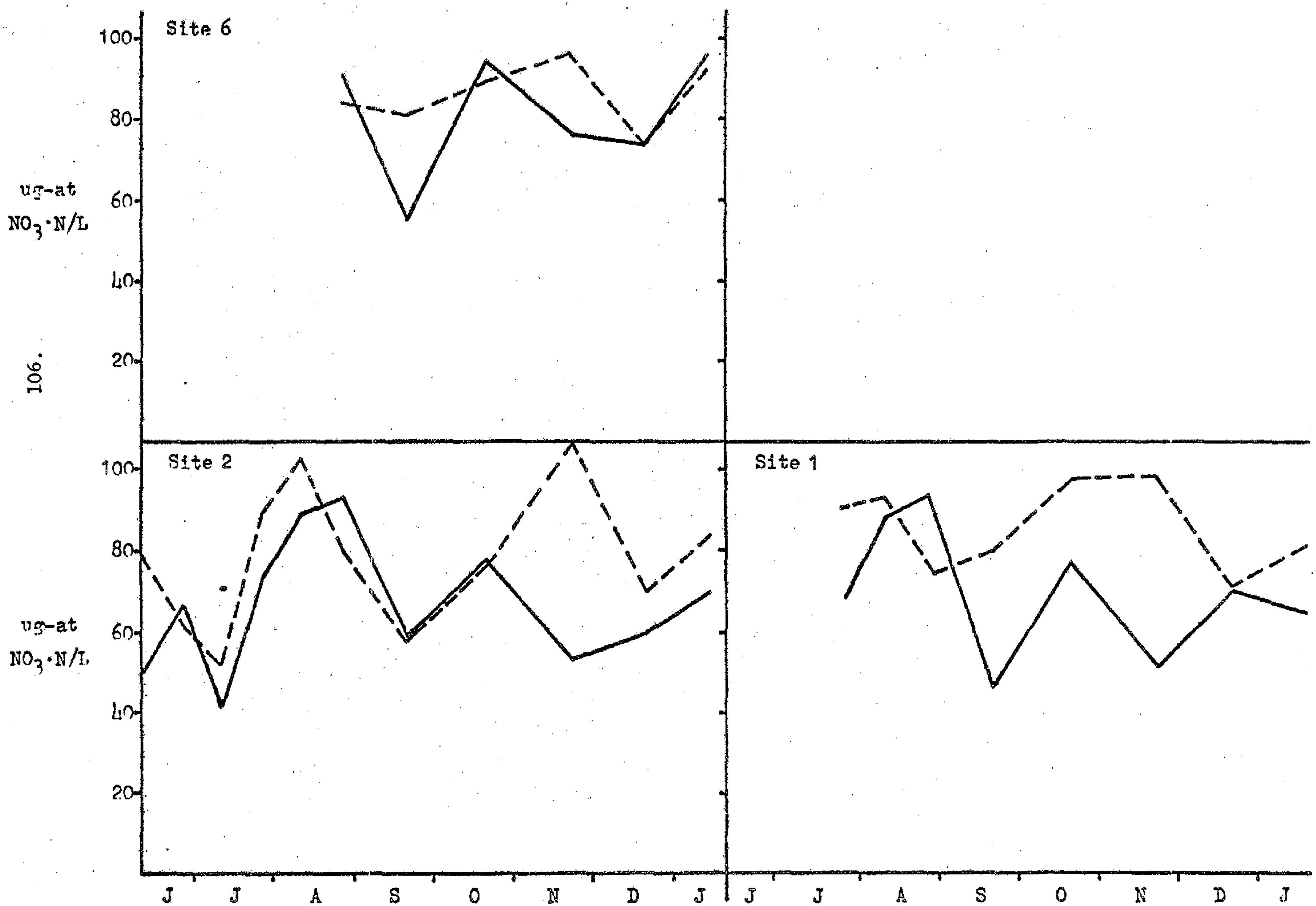


Figure 31. Changes in nitrate-nitrogen from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



Site 5A lsw nitrate values were at least 20 ug/l lower throughout the summer than were the high tide concentrations. A similar, but more variable pattern of nitrate values was also seen at Site 5. This pattern reverses itself during the fall with lsw nitrate levels being higher than hsw levels. Sites 1, 2, 6, and 8 on Crosswicks Creek show considerable fluctuation from one sample date to another and no consistent patterns appear at either hsw or lsw. Interestingly, Site 7 which is between Sites 6 and 8 has remarkably similar nitrate profiles for both hsw and lsw on each date.

Figures 33-35 give reactive nitrite levels for each sample date. Nitrite values generally ranged from 4 to 6 ug/l during the summer and by early fall they had declined to less than 2 ug/l at all sites. At Sites 4B and 4C, nitrite levels were virtually always less than 2 ug/l. Only Site 5A and to a lesser extent Sites 4B and 4C showed consistently lower nitrite values at lsw than at hsw in the summer months. Sites 1 and 2 located downstream from the sewage treatment plant usually had higher nitrite concentrations at lsw during the summer.

Ammonia (plus amino acids) concentrations for each sample date are given in Figure 36-38. Except for two hsw values in November and January, ammonia at Site 4B was consistently below 10 ug/l and was less than 1 ug/l on several occassions. During the summer months, Sites 4 and 4A which are downstream from Site 4B have ammonia concentrations generally below 10 ug/l at lsw. At hsw the ammonia concentrations generally are considerably higher being very similar

Figure 33. Changes in nitrite-nitrogen from June 1974 through January 1975 at Sites 5, 5A, 7, and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

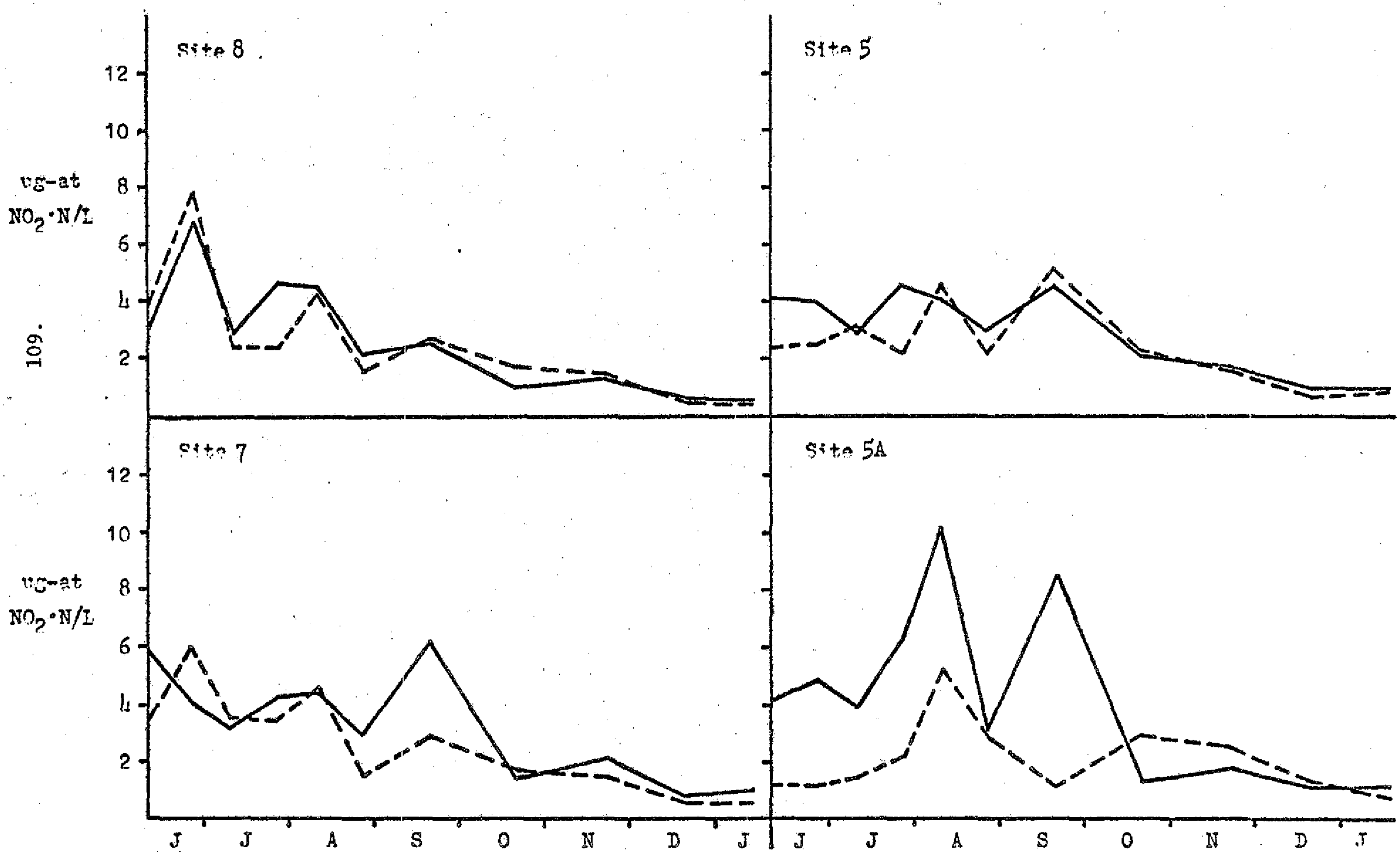


Figure 34. Changes in nitrite-nitrogen from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

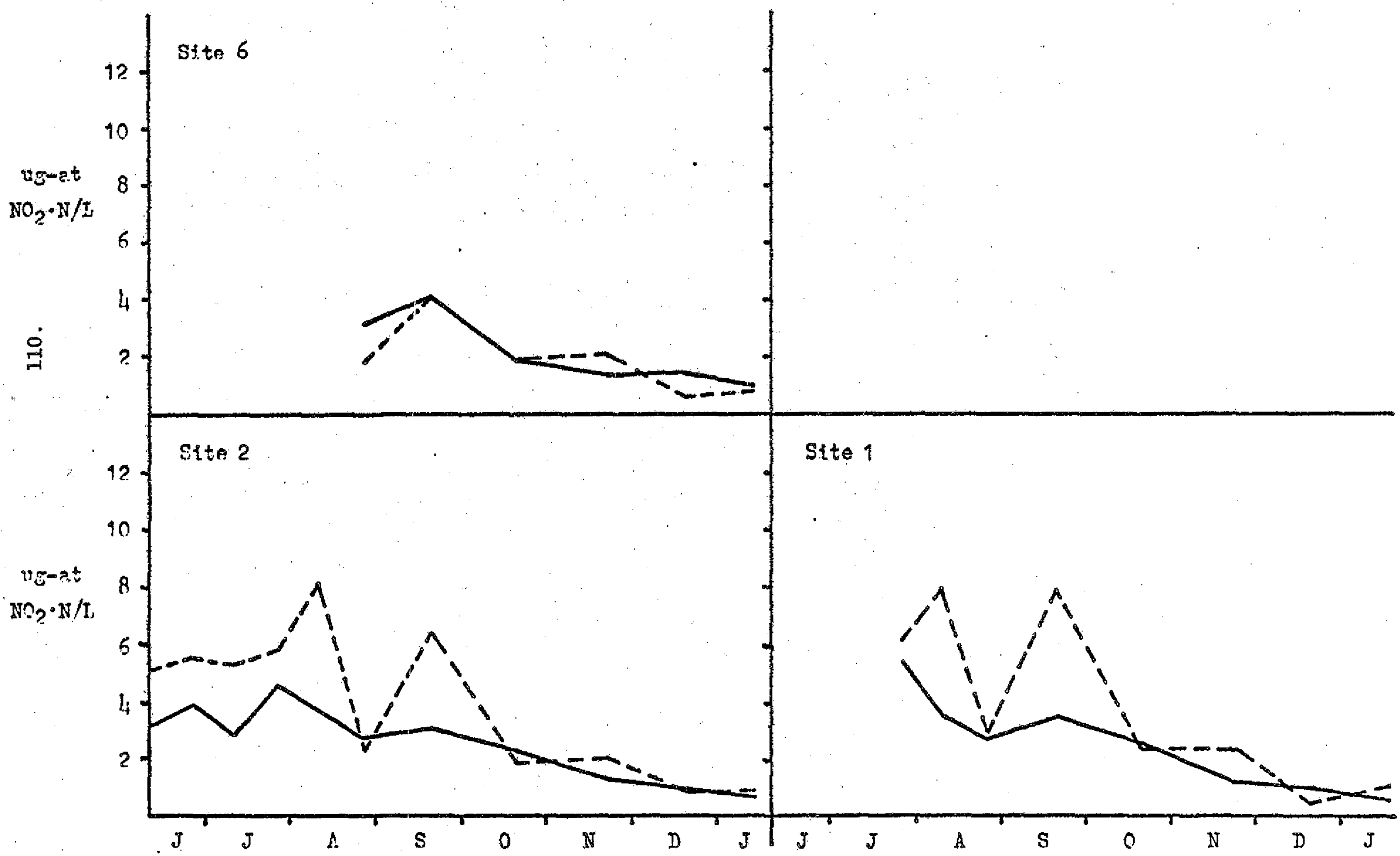


Figure 35. Changes in nitrite-nitrogen from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

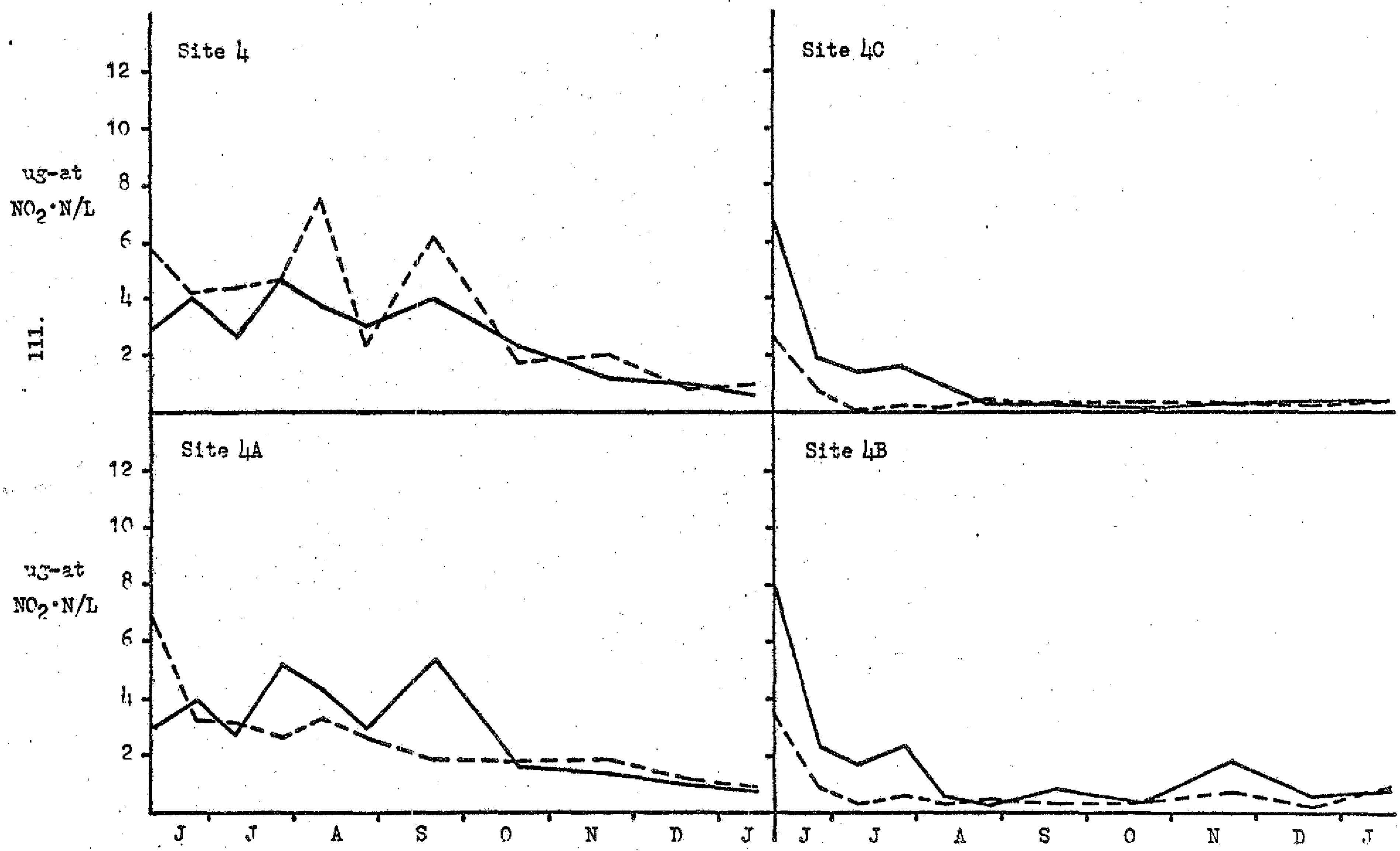


Figure 36. Changes in ammonia-nitrogen (plus some amino-acid nitrogen) from June 1974 through January 1975 at Sites 5, 5A, 7, and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

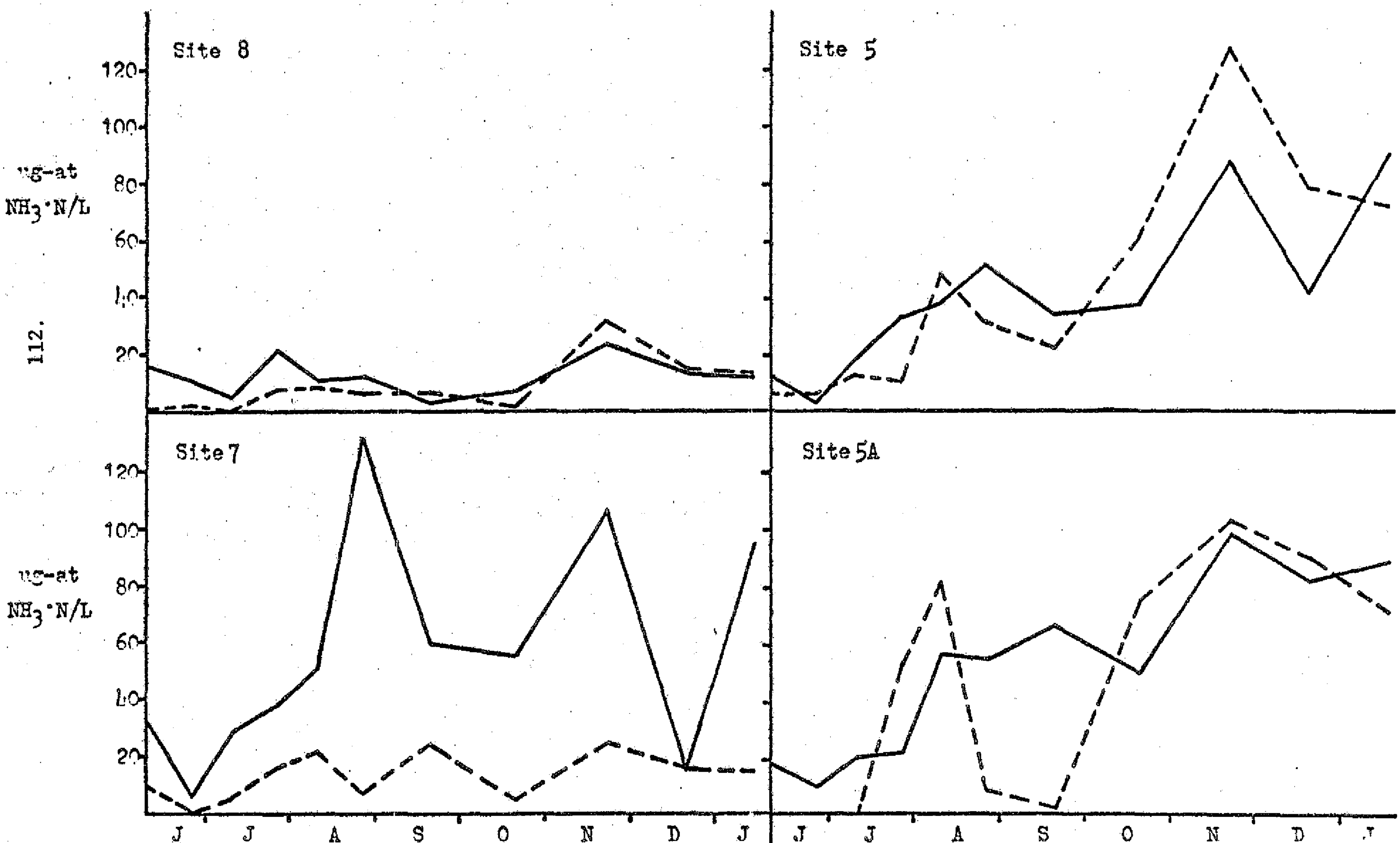


Figure 37. Changes in ammonia-nitrogen (plus some amino-acid nitrogen) from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

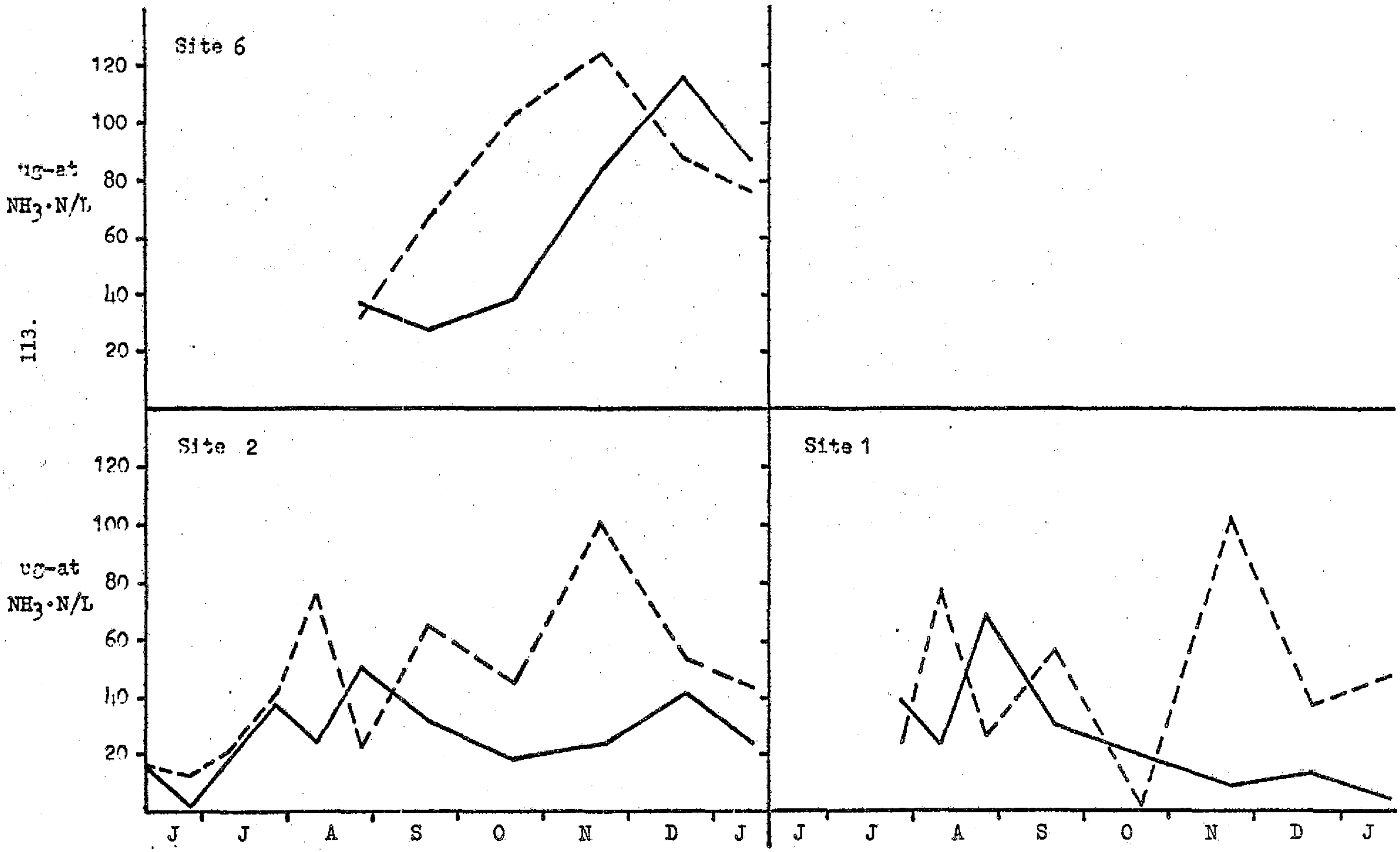
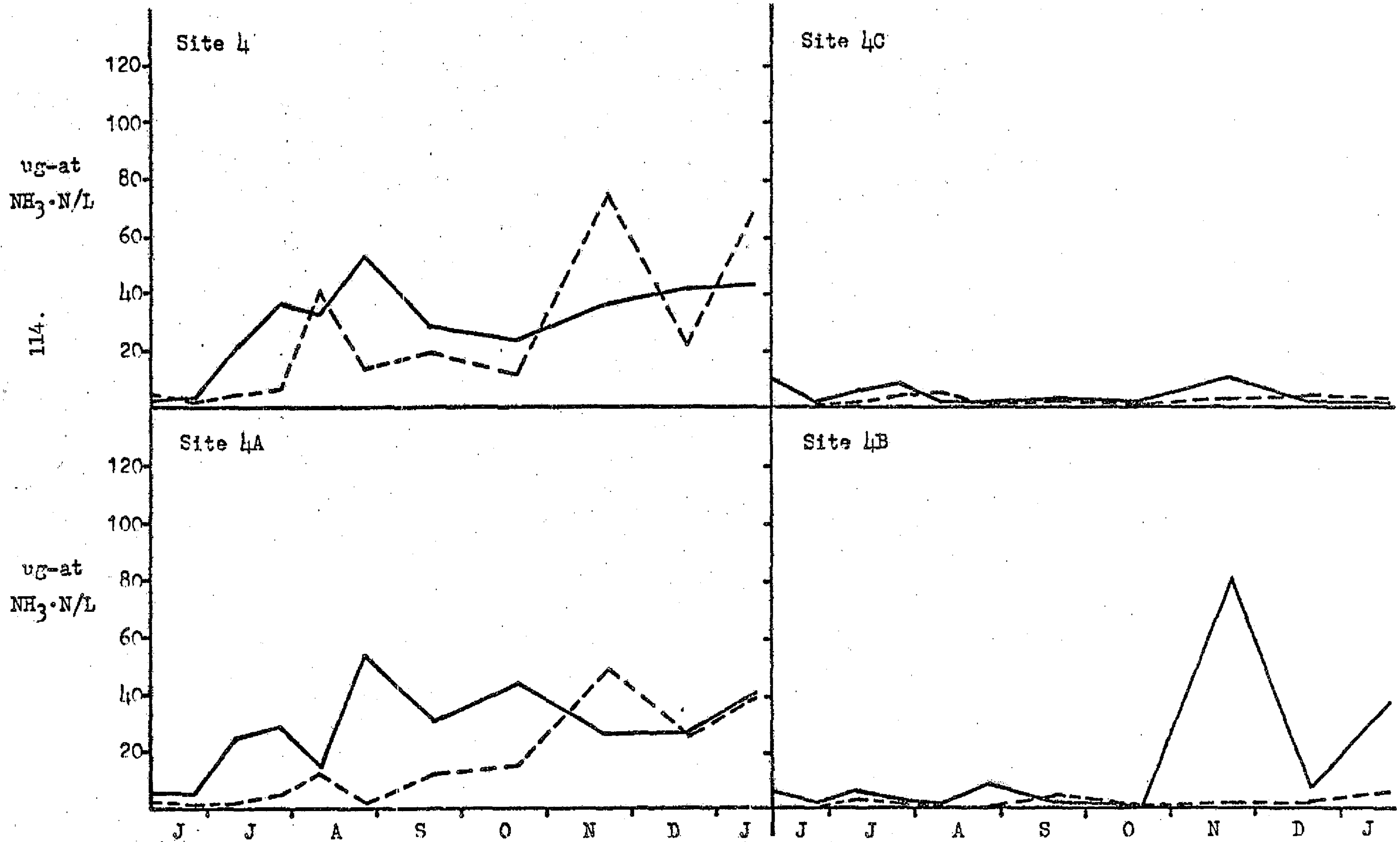


Figure 38. Changes in ammonia-nitrogen (plus some amino-acid nitrogen) from June 1974 through January 1975 at Sites 4, 4A, 4B, & 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



to those found at Site 2. Except for two dates in mid-summer ammonia levels were also very low at Site 5A during the summer at lsw, but rose dramatically in October and have remained at around 80 ug/l since then. Similar trends are also seen at Site 5. Low values (20 ug/l or less) with no obvious differences between hsw and lsw are found at Site 8. Sites 1, 2, and 6 on Crosswick Creek below the effluent pipes for the sewage plant usually had considerably higher ammonia values at lsw than at hsw. The reverse of this pattern with high ammonia values at hsw and much lower levels at lsw are seen at Site 7 upstream from the effluent pipes.

Site 8 located up stream from the marsh on Crosswicks Creek always has little ammonia or nitrate, but it does have fairly high amounts of nitrate. The nitrogen values at this site probably reflect stream conditions as the water enters the marsh. The influence of the Hamilton Sewage Treatment Plant is seen at the sites downstream from Site 8 along Crosswicks Creek. Here changes in ammonia nitrogen with the tide are particularly dramatic. At Site 7 upstream from the effluent pipes ammonia concentrations are markedly higher at hsw than at lsw. Conversely, at Sites 1, 2, and 6 downstream from the sewage plant, the reverse is seen with higher ammonia levels at lsw. A similar, though less dramatic pattern occurs with the nitrate and nitrite at Sites 1 and 2, apparently reflecting the oxidation of ammonia to these forms as it travels downstream at ebb tide.

During the summer, considerably more nitrate, nitrite, and ammonia are present at hsw than at lsw at Site 5A. During the fall and early winter, this difference disappears, but interestingly less nitrate and ammonia are present at lsw than at hsw at Site 5 downstream from Site 5A during this period. It would appear from these data that during the summer, the high marsh areas upstream from Site 5A are assimilating nitrogen and that this is being rereleased during the fall.

In the pond-like areas of Site 4B and 4C, all forms of nitrogen are low through the summer and only nitrate shows any significant buildup during the fall and winter. This buildup appears to occur rapidly as the rooted vascular plants dieback. In fact, the substantial quantities of nitrate and ammonia present at Site 4A downstream from these sites never appear to reach Sites 4B and 4C during the summer. Lsw values at Site 4A are virtually always lower than hsw values reflecting the paucity of nitrogen leaving the pond-like areas of 4B and 4C during the summer. An interesting difference in nitrate levels appears between 4B and 4C during the late fall. At Site 4C nitrate values are about the same at lsw as they are at hsw, but at Site 4C they are much higher at hsw than at lsw. The major difference between the two sites is a lush growth of Rhizoclonium at 4B which develops after the rooted vascular plants have died back. It would appear that perhaps this alga is acting as a sink for nitrate during the winter months.

Reactive Phosphate

Figures 39-41 show reactive phosphate levels during the study period. Sites 1, 2, 6, and 7 on Crosswicks Creek show large differences between hsw and lsw values with hsw values being greater at Sites 1, 2, and 6 below the effluent pipes. The highest phosphate values occur at Site 6 immediately below the effluent pipes. Sites 4 and 5 in major tributary channels of Crosswicks Creek show little fluctuation with the tide. Likewise Site 8 varies little with the tide. Site 5A phosphate levels are considerably higher at hsw than at lsw with the lsw values being much lower than those downstream at Site 5. Phosphate levels at Sites 4B and 4C are always low, even when hsw levels at Site 4A are relatively high.

The major influence on reactive phosphate levels appears to be the Hamilton Township Sewage Treatment Plant. Depending on whether the tide is flooding or ebbing Sites 1, 2, 6, and 7 show markedly higher phosphate levels than other areas of the marsh. The major exception to this rule is Site 5A where phosphate levels are also usually high at hsw. The high values here may be due to leakage for the sludge lagoons near the site since Site 5 downstream from 5A does not show these elevated values at hsw. Elsewhere in the marsh, reactive phosphate levels are generally low and at sites 4B and 4C are often near the limits of detection.

Figure 39. Changes in reactive phosphate from June 1974 through January 1975 at Sites 5, 5A, 7 and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

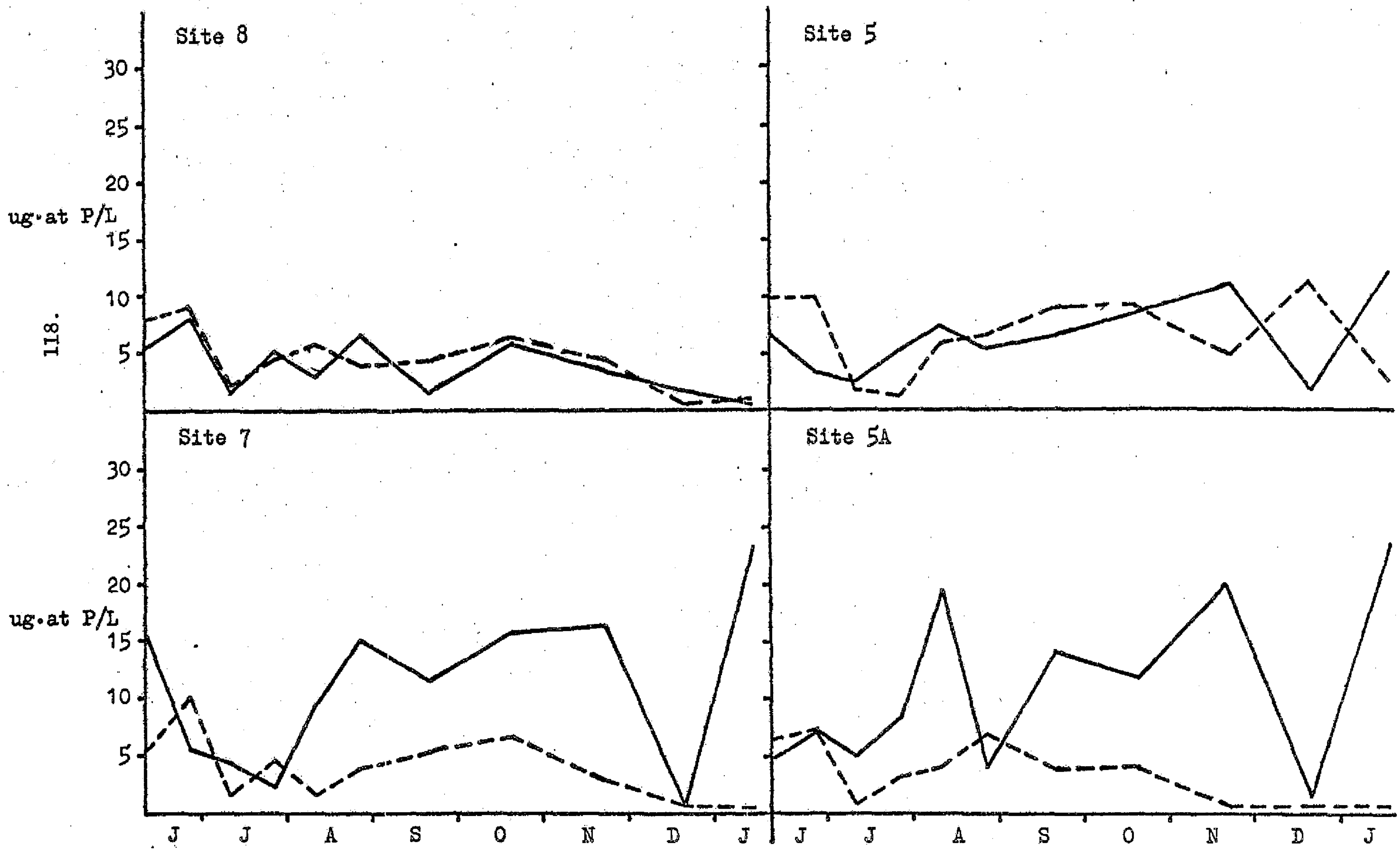


Figure 40. Changes in reactive phosphate from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

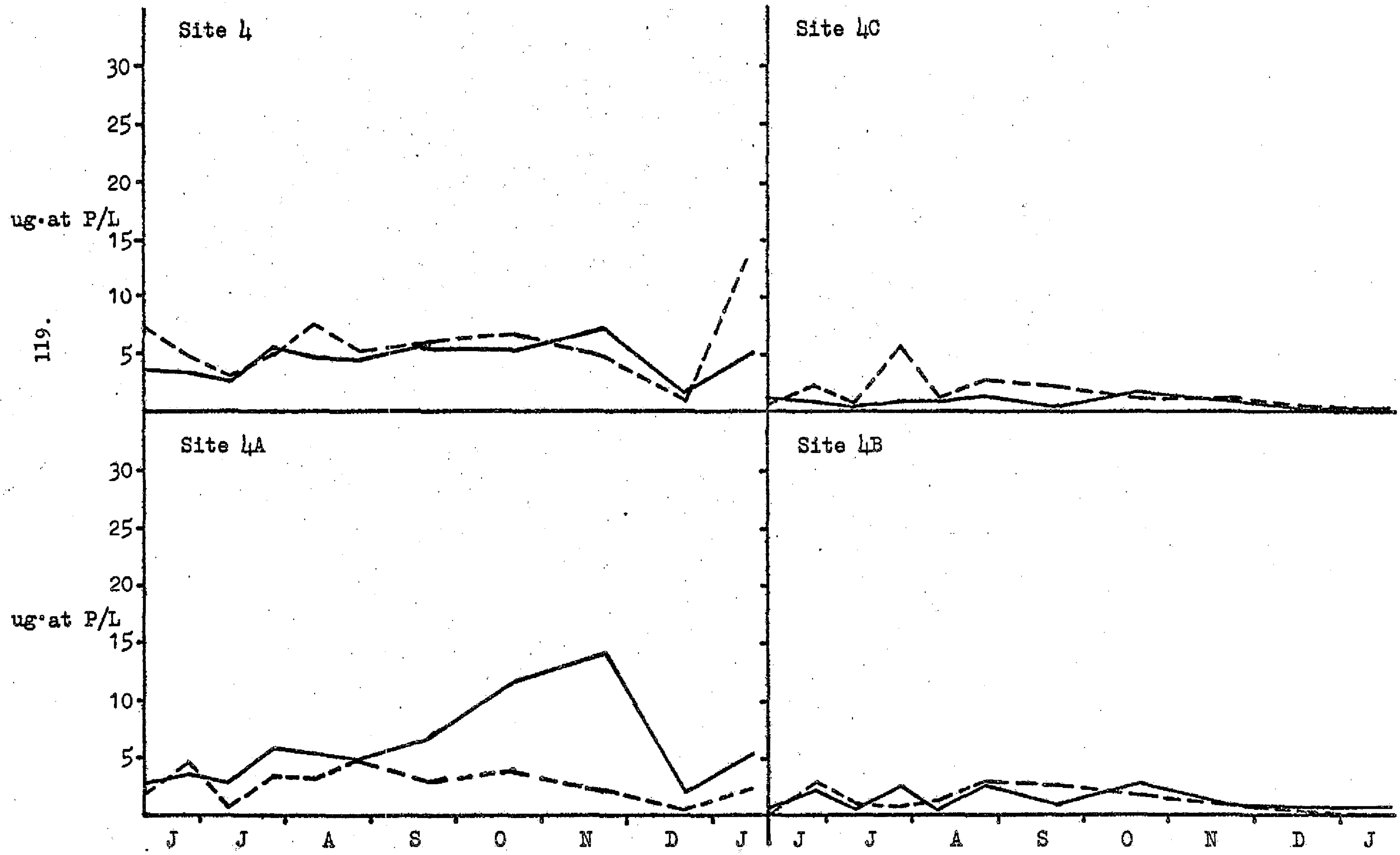
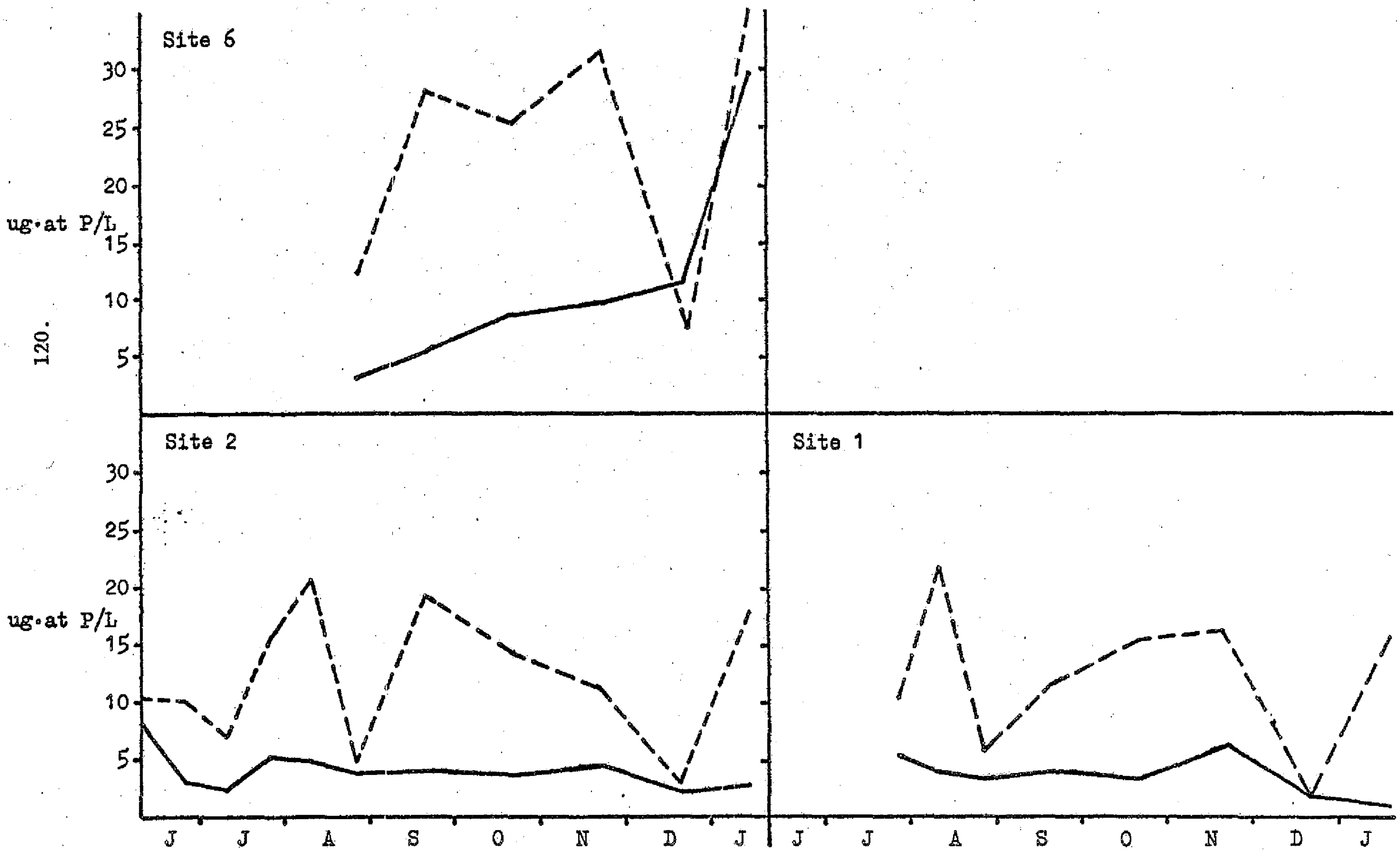


Figure 41. Changes in reactive phosphate from June 1974 through January 1975 at Sites 1, 2, and 6. solid lines represents morning high tide values and dashed lines represent afternoon low tide values.



General Conclusions

The major influence on the surface waters in the Hamilton Marshes is the Hamilton Sewage Treatment Plant. This impact is noticed at hsw at Site 7 above the effluent release point and at Sites 1, 2, and 6 downstream from the release point at lsw. All these sites are on Crosswicks Creek. Site 8 on Crosswicks Creek at the upper end of the marsh is little influence by tidal action and consequently is minimally affected by the sewage effluent. Sites located on major side channels of Crosswicks Creek appear to be largely unaffected by the sewage plant, particularly at lsw. Sites 4B and 4C which experience tidal fluctuations of only 20-50 cm are distinctly pond-like. At these sites water quality parameters behave as they would in very productive non-tidal ponds with summer oxygen and nutrient depletion and high carbon dioxide levels. During the winter, oxygen levels are markedly higher and show siurnal variation due to algal production. At Site 4B this is due to Rhizoclonium and at Site 4C it is due to blooms of mixed diatoms and Spirogyra that develop as the higher vascular plants dieback. Interestingly at these sites nitrate levels increase markedly in the fall, but phosphate levels remain depressed. However, at Site 4B nitrate levels are elevated only at hsw with lsw values being considerably lower suggesting that this site may be acting as a nutrient sink during the winter months.

Site 5A at the confluence of a large high marsh area appears to be able to absorb nitrate nitrogen in the summer and rerelease it during the fall and winter when the vascular plants dieback. Reactive phosphate levels appear to follow a similar pattern except that the source for the phosphate may be the sludge lagoons rather than Crosswicks Creek. Oxygen depletion is not a problem at this site, but during the fall carbon dioxide levels change markedly paralleling the dieback of rooted vascular plants.

Blum (1968, 1969), Aurand and Daiber (1973), Arelrad, Bender and Moore (1974), and others have suggested that brackish water tidal marshes may act as nutrient sinks and Grant and Patrick (1970) have suggested a similar role for freshwater tidal marshes. Our data suggest that the high marsh areas may be acting as a nutrient sink during the summer months and that perhaps pond-like areas of the marsh may be playing a similar role in the winter.

AUTECOLOGICAL STUDIES

A long range objective of our studies is to determine ecological life histories of the dominant marsh plant species. Information of this type will be invaluable whenever decisions are being made concerning the tolerances of those species to perturbations ie: dredging, filling, and other types of management processes. This section of our report deals with three studies that have already been undertaken. The research on wild rice was done by Dennis Whigham and was supported by a Faculty Research Grant-in-Aid from Rider College. The second and third studies are edited reports of independent research projects by Rider College Biology students, David West and Patricia Parkinson.

Autecological Studies of Wild Rice (*Zizania aquatica*)

by

Dennis Whigham

INTRODUCTION

Wild rice is a member of the grass family (Poaceae) that grows in brackish to freshwater marshes, lakes, ponds, and slow moving streams along the coast from southeastern Canada to Florida and Louisiana. Inland it occurs in northern New York State and from western Lake Erie into Wisconsin and southern Illinois (Dore, 1969). In New Jersey, marshlands in which wild rice is dominant or abundant occur mostly in the southern part of the State (Robichaud and Buell, 1973). It is most abundant along streams and rivers that empty into the Delaware Bay and along streams that empty into the Delaware River.

Until recently wild rice was one of the dominant plants in southern New Jersey marshlands. Robichaud and Buell (1973) stated that good stands can now only be found as far north along the Delaware River as Rancocas Creek. A preliminary survey of the northern most freshwater tidal marsh along the River (Hamilton Marshes) (Whigham, 1974) showed that the wild rice was widespread and abundant. The present study was undertaken to determine the distribution, abundance, and primary production of wild rice in the Hamilton Marshes.

METHODS

Wild rice populations were surveyed during the spring, summer, and fall of 1974. Several populations (Figure 2 and Table 1) were selected for intensive study. On each sampling date, 3 quadrat ($\frac{1}{4}m^2$) were harvested from each population. Entire plants were removed by hand and I estimated that our samples contained approximately 95% of the root biomass. Rogosin (1958) and Bray et. al. (1959) had similar experiences in sampling wild rice. Specimens were returned to the laboratory where they were washed and then dried at 105°C for at least 24 hours. Shoot and root portions of each plant were weighed individually. Inflorescences were harvested near the end of the growing season and the number of seeds counted. Between April 15-18, permanent quadrats were established throughout the study areas and counts were made of wild rice seedlings.

RESULTS

Most wild rice populations are located in 3 areas of the marshes. The largest populations occur in the Rowan Lake section. Populations were found along the stream and on the adjacent marsh areas that connect Rowan Lake and Crosswicks Creek. The second area of concentration is near the Hamilton Township Sewage Plant. The third concentration of wild rice is in the area of the marsh upstream from the Route 206 bridge.

Wild rice grows in 3 distinct habitats. Along the banks of Crosswicks Creek and in the channels of small tributaries it grows in association with yellow water lily (Nuphar advena), pickerelweed (Pontederia cordata), water hemp (Acnida cannabina) and water smartweed (Polygonum punctatum). Wild rice also grows in areas that are elevationally the highest marsh sites that are only covered by water at high tide. In addition to wild rice the dominant species are arrow arum (Peltandra virginica), bur marigold (Bidens laevis), Halberd tearthumb (Polygonum arifolium), Tearthumb (Polygonum sagittatum), sweet flag (Acorus calamus), and touch-me-not (Impatiens capensis). Wild rice also grows in small drainage channels that connect high marsh areas with stream channels. Yellow water lily is dominant and associated species are water smartweed, pickerelweed, and waterhemp. The third major habitat of wild rice is areas that are pond-like at high tide and drained at low tide. At high tide the water is approximately 1-2 feet deep and those areas are water covered for much of each tide cycle. Rowan Lake is the largest pond-like area in the Hamilton Marshes. In addition to wild rice the dominant plant species are yellow water lily, pickerelweed, water smartweed, arrow arum, and cattail. Wild rice does not grow in the sections of the marshes that are permanently flooded by water - Spring Lake and a section of the marsh that surrounds Spring Lake (Site 4C in this report is representative of this type of habitat).

Phenology

Wild rice has a relatively long period of vegetative growth followed by a sudden transition to the flowering and fruiting phenophases. Germination occurred during the last week of April at all sites and most individuals senesced in August. The flowering phenophase began during the 4th week of July and continued until mid August. Most seeds were shed by the third week in August with the majority being dislodged by wind and rain in late July and early August. McCormick (1972) has also reported that there is much physical damage done to wild rice populations during summer wind and rain storms. Dore (1969) has also reported that seeds are easily dislodged. Almost all individuals had died by the 3rd week in September and the remainder were killed by the first heavy frosts (October 19-21).

Seed Production

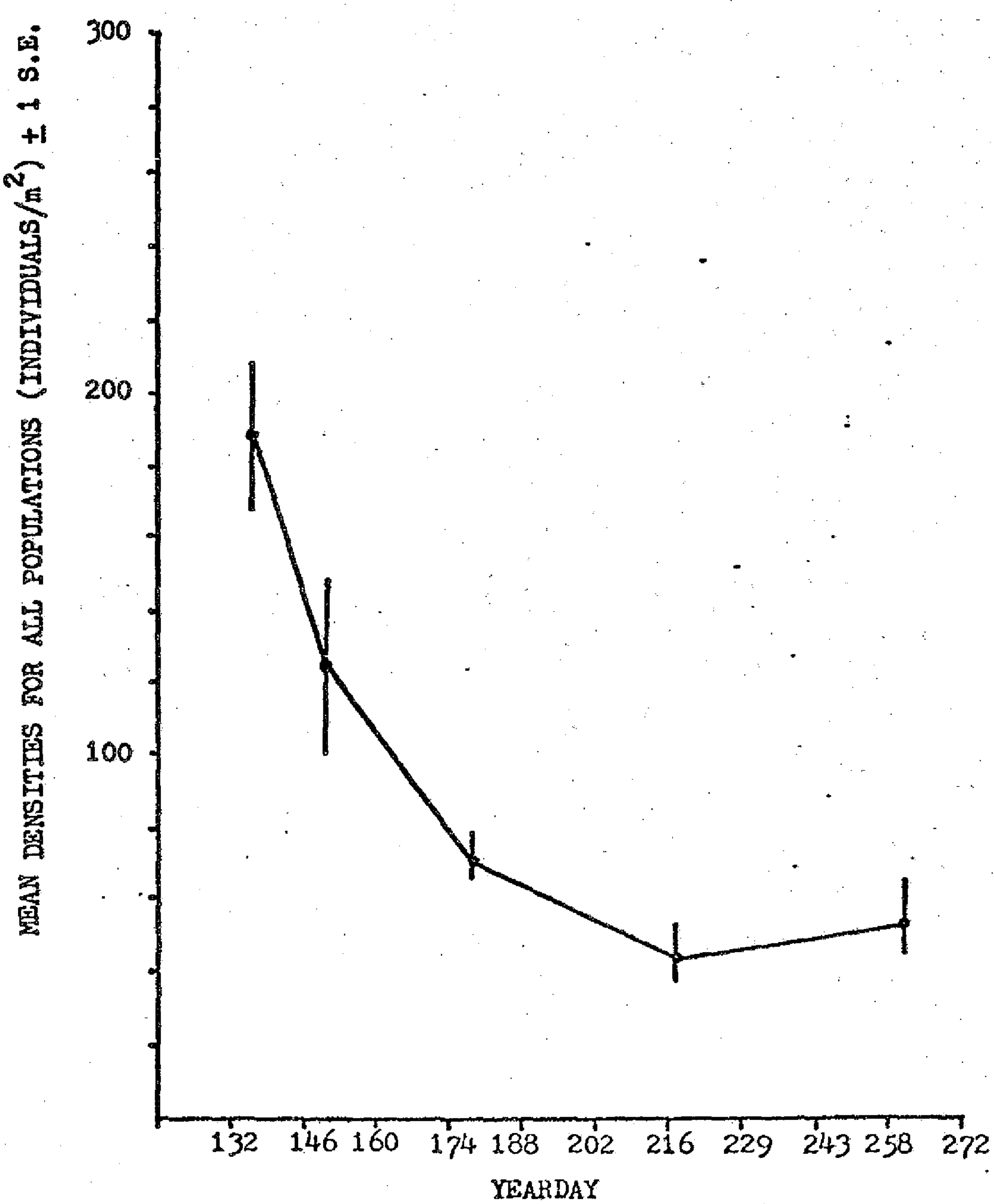
The vast majority of plants (98.7%) produced one inflorescence. The average number of seeds per inflorescence was 655 ± 193 (N=20) and the average density of seed bearing plants was $57 \times 10^4 \pm 28 \times 10^4$ per hectare. Estimated seed production was 373×10^6 seeds/hectare. Wild rice occupies approximately 24 hectares in the Hamilton Marshes (New Jersey Department of Environmental Protection Wetland Maps 1972) and the estimated total seed production was 9 billion.

Seed Mortality and Seedling Establishment

Many wild rice seeds are carried away because they float freely until they become waterlogged (Sculthrope, 1967). Others became lodged near the point of release. Dore (1969) on the other hand has reported that seeds immediately sink and are subsequently lodgednearthe parent plant. Many seeds were consumed by birds, especially redwing blackbirds. When the fruits were maturing the birds were observed to consume wild rice seeds. Sculthrope (1967) has stated that wild rice seeds are valuable food for ducks, coots, geese, and several other types of waterfowl. The net affect of seed predation, removal of seeds by tides, and the covering of seeds by sediment and litter during the winter is that one would expect that only a small percentage of one years seed crop would survive. Seedlings counts made shortly after germination substantiates this assumption. Twenty-four permanent quadrats were sampled between April 15 - 28. Wild rice seedlings averaged 181 ± 69 individuals/m^2. The production of large quantities of seed in order to assure the survival of a few individuals is common among annual plant species (Harper, 1974).

Figure 42 shows seasonal changes in density of wild rice populations. The species has a linear type of survivorship curve which indicates a constant mortality risk. Mortality was most likely due to competition, herbivory, and the destruction of plants by objects that lodged on top of them during the daily course of tidal

Figure 42. Mortality data in wild rice (*Zizania aquatica*) populations. All values represent mean number of individuals/$m^2 \pm$ 1 standard error.


MEAN DENSITIES FOR ALL POPULATIONS (INDIVIDUALS/m2) ± 1 S.E.
300
200
100
132
146
160
174
188
202
216
229
243
258
272
YEARDAY

activities. Rice plants at Site 5C were eaten by the end of June. It is most likely that the plants were eaten by muskrats that are plentiful in the marshes. Mortality late in the growing season was due to destruction of the large reproductive plants by wind and rain. In some cases the plants were not killed but simply lodged onto the ground where they continued to grow in the prone postion. McCormick (1972) has reported a similar phenomenon in the freshwater tidal marshes along Oldmans Creek in Gloucester County. Plants at Site 5B (2 populations) were destroyed by a storm in July. The size of the wild rice populations in the marshes appears to be controlled primarily by seed mortality and by mortality during the vegetative and reproductive periods.

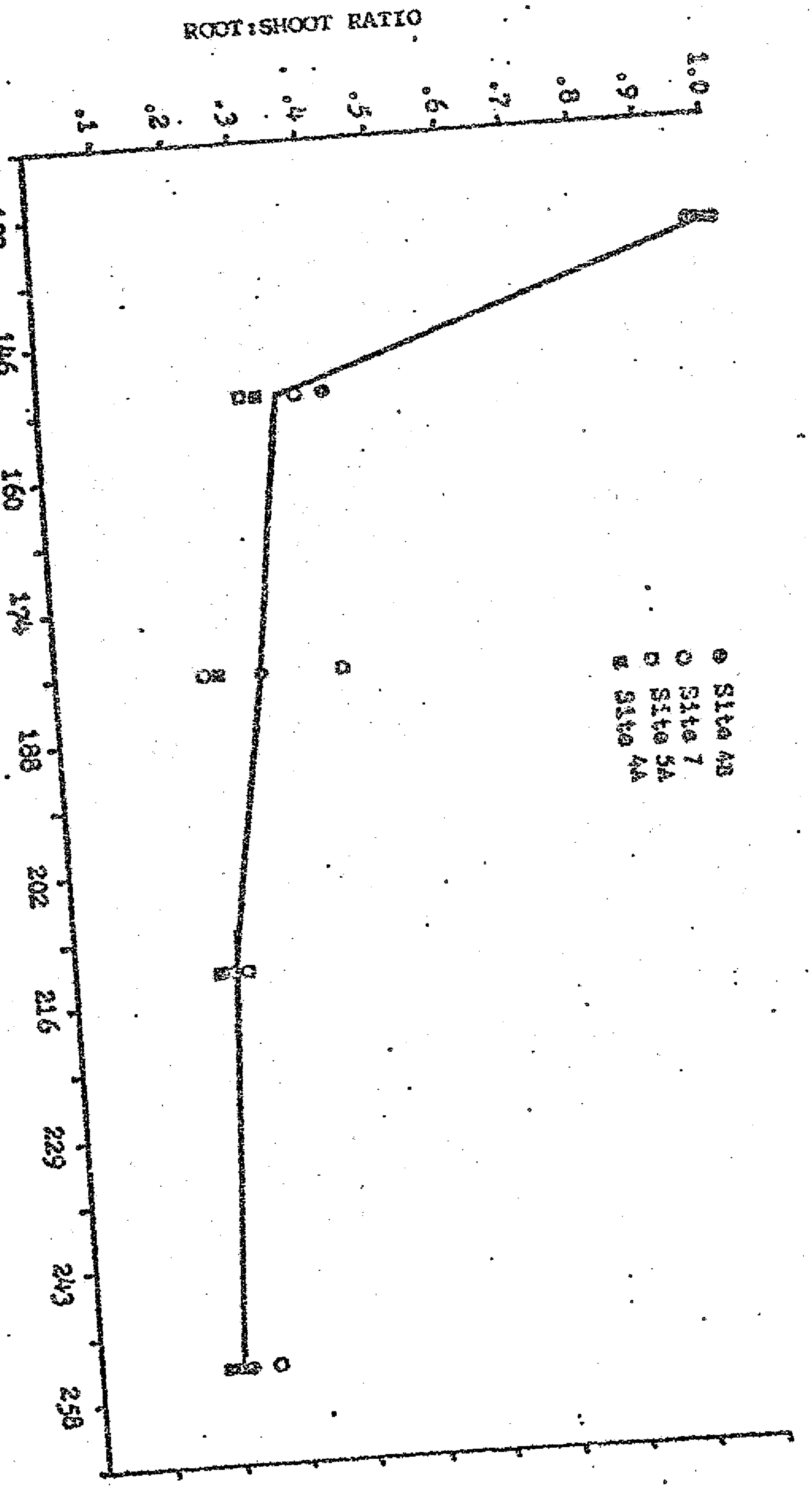
PRIMARY PRODUCTION

A second objective of this study was to determine levels of primary production.

Initial biomass samples were collected approximately 2 weeks after the seeds had germinated and sampling continued until the majority of individuals had senesced in September.

Much of the initial production was used in seedling establishment (Figure 43). The root:shoot ratios were all approximately 1 on May 15 which indicates an equal partitioning of the net primary production. By June 1, root:shoot ratios started to drop indicating that after the initial establishment of the seedlings

Figure 43. Seasonal patterns of the partitioning of net primary production between roots and stems in wild rice (Zizania aquatica). Refer to Figure 2 for site locations.


ROOT:SHOOT RATIO
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
132
146
160
174
188
202
216
229
243
258
Site 4B
Site 7
Site 5A
Site 4A

most of the net production went into shoot growth. Root:shoot ratios remained approximately 1:3 during the remainder of the growing season. Bray et al (1962) also found low root biomass for wild rice. They ascribed the low root biomass to be due to weak root development characteristic of many aquatic plants. This is probably true only of annual species for Dykyjova (1972) has shown that perennial species of marsh habitats have higher root:shoot ratios for wild rice were very consistant even though there was considerable difference in substrate conditions between the populations (see description of substrate properties on pages 8 - 26 of this report).

Figure 44 shows the pattern of biomass accumulation in individual plants. Growth averaged .07 g/ind/day during the period May 15 - June 29 and .44 g/ind/day during July. Toward the end of July the growth rate slowed. This coincided with the onset of flowering and fruiting phenophases. By the end of the growing season an average individual weighed 25.2 $\pm$ 3.5 g (Figure 44.)

Net primary production on an area basis is shown on Figure 45. Overall biomass accumulation followed a pattern similar to the accumulation of biomass in individual plants. Total net primary production for all sites was 2.2 g $\pm$ .6 on May 15, 41.5 g $\pm$ 6.7 on May 30, 346.3 g $\pm$ 48.4 on June 26, and 1453.4 g $\pm$ 225.1 on September 10. Net primary production data for four of the

Figure 44. Net primary production of individual wild rice (*Zizania aquatica*) plants in the Hamilton Marshes. All values are means (g/ind.) ± 1 standard error.

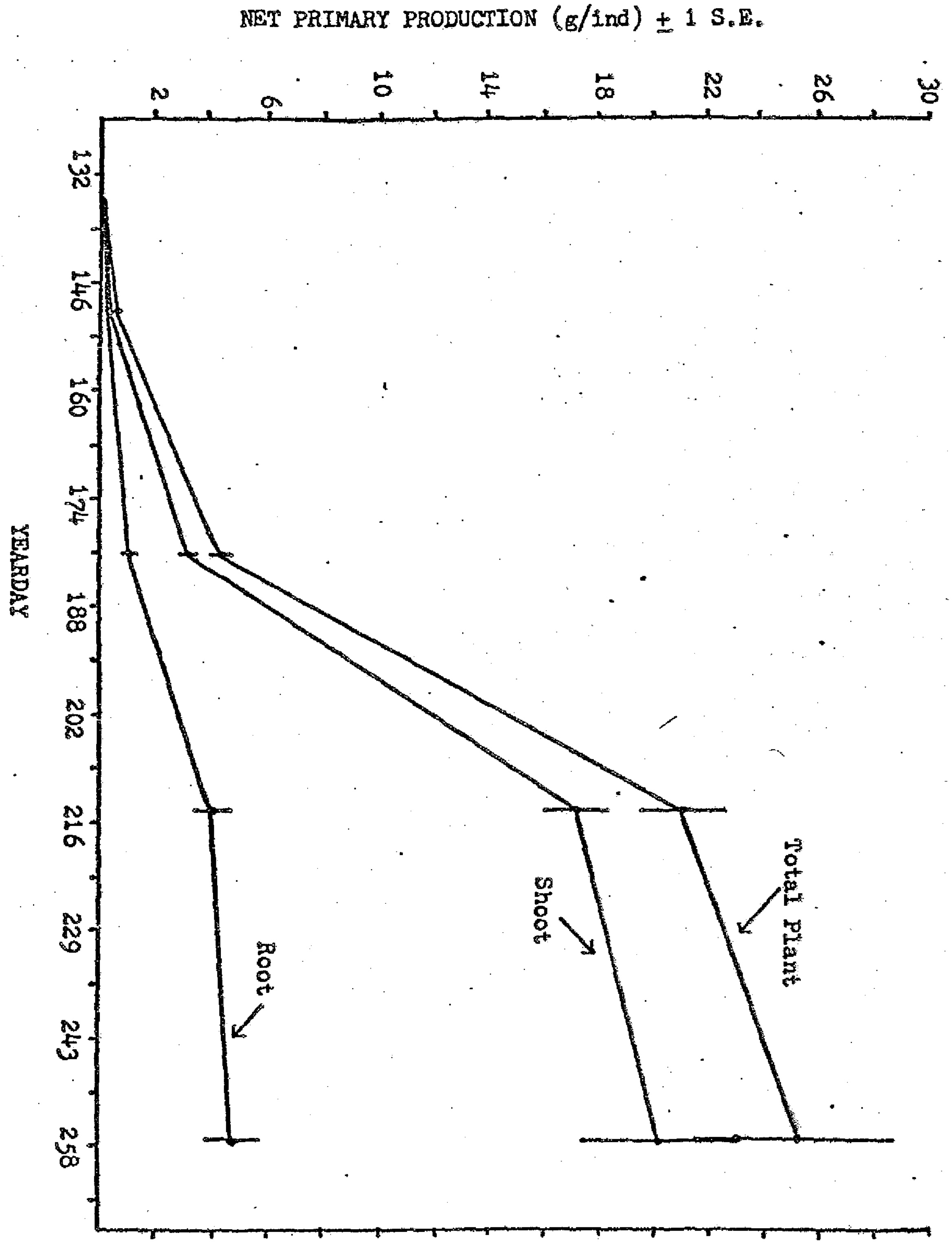

NET PRIMARY PRODUCTION (g/ind) ± 1 S.E.
2
6
10
14
18
22
26
30
132
146
160
174
188
202
216
229
243
258
YEARDAY
Total Plant
Shoot
Root

Figure 45. Net primary production of wild rice (*Zizania aquatica*) in the Hamilton Marshes. All values are means (g/m^2) ± 1 standard error. ($g/m^2 \times 10^{-2}$ = T/Ha)

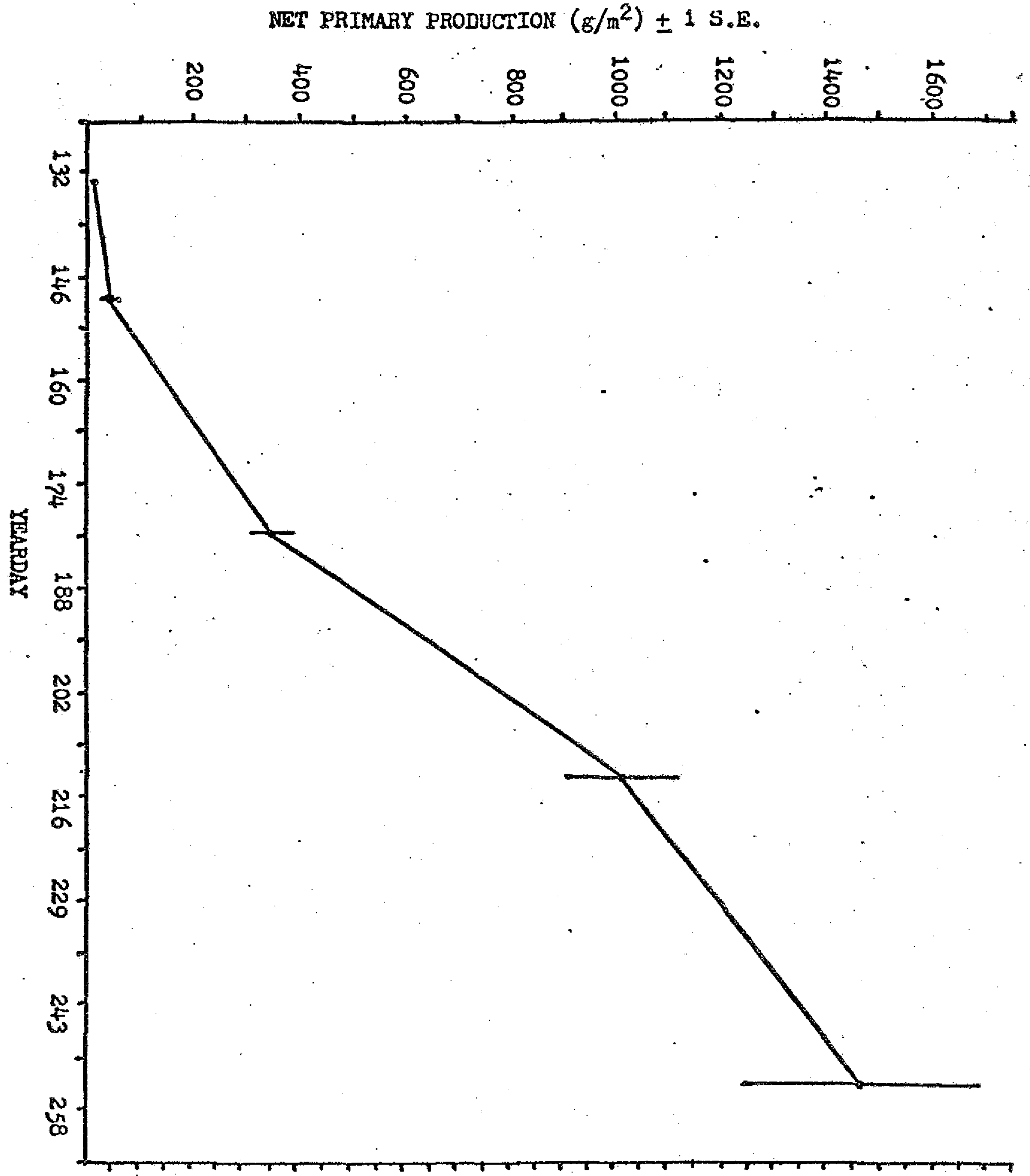

NET PRIMARY PRODUCTION (g/m2) ± 1 S.E.
200
400
600
800
1000
1200
1400
1600
YEARDAY
132
146
160
174
188
202
216
229
243
258

Table 10

Density changes in wild rice populations. Values are mean number of plants/m^2.

Yearday	Sampling Site (see Figure 1) Site 1	Site 1A	Site 2	Site 3	Site 3A	Site 6	Site 7
150	211	250	N.S.	134	N.S.	216	168
155	172	N.S.	N.S.	N.S.	N.S.	212	N.S.
170	76	132	30	86	114	182	148
184	52	74	18	52	80	72	90
210	N.S.	N.S.	X	56	16	64	92
238	69	24	X	36	X	59	44

N.S. = Not sampled

X = All plants destroyed (Site 3A) or eaten (Site 2) sites are shown in Figure 5 (Page 44). Production was similar for the four sites until July but there were differences afterward. Site 4B has the highest net annual primary production (2163.2) ± 663.2 g/m^2). Production at Sites 4B, 5A and 7 was 1619.1 ± 489.5, 823.8 ± 58.9 and 1234.2 ± 187.2 respectively.

DISCUSSION

Net primary production of wild rice in the Hamilton Marshes differed between sample areas. Total production at Sites 7 and 5 were probably least because of competition and mortality. At Site 5B there were fewer individuals that survived (Table 10) and thus production on an area basis was less than that of any other site. Many individuals at Site 5B were killed during a storm in July. Net primary production was lower at Site 7 than at Sites 4B and 4A because the individual plants were smaller. At area 4A wild rice maintained dominance throughout the growing season and individual plant size was the greatest.

There is not apparent correlation between production of wild rice and location of populations with regard to the amount of tidal activity. Based upon the greatest length of time that each area would be covered by water during a tide cycle, the areas would be ranked as follows: 4B, 5B, 7, 5A, 4A, and 5.

Table 11 compares production data for wild rice in other

Table 11. Comparison of production values for wild rice in fresh water tidal marshes.

NET PRODUCTION (g/m^2)	STATE	SOURCE
605 - 1547	Pa.	McCormick (1930)
1390	N. J.	McCormich and Ashbaugh (1972)
659 - 1125	N. J.	Present study
1699	N. J.	Jervis (1964)

geographic locations. Net primary production appears to be extremely high in tidal areas. Production in two other Delaware River freshwater tidal marshes was 605-1547 g/m^2/yr (McCormick, 1970; McCormick and Ashbaugh, 1972). Jervis (1964) has measured rice production at 1699 g/m^2/year in another New Jersey freshwater marsh. In fact, primary production of wild rice in New Jersey's freshwater tidal marshes is comparable to annual net production of salt marsh plants. Good (1965) measured a net production of 300 g/m^2 for *Spartina alterniflora* in New Jersey and Potera and MacNamara (1972) measured values of 191 g/m^2 for the same species in a polluted estuary. Although there is little comparable data for wild rice in inland areas of New Jersey, it appears that primary production is equal to or greater in the freshwater tidal marshes than it would be in non-tidal environments. Bray measured wild rice production at 630 g/m^2 in Minnesota (Bray et. al., 1962).

CONCLUSION

Robichaud and Buell reported that wild rice is sensitive to pollution, dredging, etc. and that, as a result of such actions, the distribution and abundance of wild rice in the Delaware River Basis has been drastically reduced. They stated that it was abundant as far north as Rancocas Creek. This study has proved that wild rice is still abundant and doing well in the Hamilton Marshes. This may be due to the fact that these marshes have not been filled or dredged recently. Other data presented in this report have shown that the waters of the marshes are not polluted beyond acceptable standards. This study has also shown that wild rice is an invaluable component of the marsh ecosystem. We have estimated that communities of dominated by wild rice produce more than 200 tons of material per year. Future management of the marshes should include planning that will insure the existence of this valuable species.

A STUDY OF VARIOUS ASPECTS OF THE ECOLOGICAL LIFE HISTORY OF PONTEDERIA CORDATA (Pickerelweed)

by

Patricia Parkinson

INTRODUCTION

Pontederia cordata is a common aquatic plant which grows in marshy areas and on the shores of streams (Fairbrothers and Moul, 1965). Although other genera of the family Pontederiaceae have been studied, there is little literature available on Pontederia (Sculthorpe, 1967).

NOMENCLATURE AND DESCRIPTION

Pontederia cordata (*P. sagittata* Seubert) is an aquatic macrophyte of the family Pontederiaceae (Muenscher, 1944 and Stodola, 1967). It is a perennial with thick, creeping root-stocks and clusters of erect leaves which have fleshy petioles and heart-shaped to lanceolated blades. Leaves are borne singly on a simple stem. It is an emergent species, but can grow entirely submerged. The leaves of the submerged form, forma *taenia*, are ribbon-like with little or no differentiation of a blade. *P. cordata* also has a leaf sequence from the linear or spatulate first-formed leaves of the seedling to the mature leaf form described above (Sculthorpe, 1967). The perfect, irregular, trimerous flowers are borne on a spike, They are violet-blue, funnel-shaped, two-lipped, and hairy on the outside. There are six stamens and the ovary is three-celled, but two of the cells are sterile. Pontederiaceae is one of only three angiosperm families in which tristyly is known to occur, and is the only monocotyledonous family exhibiting this type of floral heteromorphism (Hazen, 1918; Ornduff, 1966). In pickerelweed, the three forms are: (1) those having flowers with long styles and anthers at two levels below the stigma; (2) those having flowers with mid-length styles and one set of anthers above the stigmas, the other set below; and (3) those having flowers with short styles and anthers at two levels above the stigmas. This system promotes cross-pollination, since self-pollination or cross-pollination between stigmas and anthers not at equivalent levels is much less productive of seeds than pollination between stigmas and anthers at equivalent levels (Ornduff, 1966). Representation of the floral forms in populations is unequal. This is because, once an area is colonized, too few sexually produced generations succeed to allow equilibrium to be established. This species is insect pollinated. Nectar accumulates in the perianth tube. The lower lip of the flower serves as a landing platform for smaller insects. The upper lip is erect and has a large double blotch of bright yellow on the posterior petal segment, which probably serves as a nectar guide. Hazen (1918) observed ten species of Lepidoptera and many Hymenoptera visiting the plant in a marsh in New Jersey. <u>Dufourea novea-angliae</u>, a bee, visits no other plant and its emergence coincides with the onset of flowering of pickerelweed (Sculthorpe, 1967).

The fruit, an achene bearing one seed, has crested ridges running lengthwise and a "beak" at the end, which is a persistent style base. The seeds are 3-4 mm long, ovoid ellipsoid in shape, and contain a pure white endosperm. The fruits have a period of bouyancy due to large intercellular spaces in the pericarp which allow them to be carried well away from the parent plant, which is a very competitive environment (Sculthorpe, 1967).

P. cordata is a geophyte and the stout, spongy rhizome is the organ of perennation. Vegetative reproduction by extension of the rhizomes predominates over sexual reproduction (Ornduff, 1966).

Pickerelweed is native to the Americas and its distribution is from the eastern United States south to Argentina. It was observed in several locations in the Hamilton Marshes (Whigham, 1974). It was most common along the banks of Crosswicks Creek and in the Rowan Lake, Spring Lake, and Sturgeon Pond sections of the marshes. It is, however, not restricted to those areas and populations are scattered throughout. Pickerelweed is not one of the dominant species in the Marshes. Whigham (1974) listed it as the 13th most important species. It is most commonly associated with yellow water lily, arrow arum, and water smartweed. Its contribution to the overall productivity of the marshes was studied in 1973 and 1974 (Table 12). The differences between the 1973 and 1974 data were due to the sampling methods employed. In 1973 the sampling at each site was random and because the species is primarily concentrated in certain communities there was much variation in the harvest data. In 1974, having determined what community types exist in the marshes, the vegetation was sampled systematically. Pickerelweed appeared in many of the samples collected at several sites where is was part of the communities found there. The 1974 data shows an increase in aboveground biomass throughout the growing season with a beak biomass of approximately 592 g/m^2.

PHENOLOGY

Pontederia cordata was in flower when phenological data was first collected on June 25, 1973. In 1974 flowers were first noted on June 21. During both years the flowering phenophase lasted for the remainder of the growing season. Fruits were first seen on July 6 and on August 3 it was first noted that some had been shed from the stalks.

TRANSPLANT EXPERIMENT

Most perennial species in the marshes appear to grow whenever temperature conditions are favorable. Dormancy thus appears to be maintained by low temperatures throughout the winter. In order to determine what factors controlled dormancy in pickerelweed, a transplant experiment was performed.

Table 12

Productivity (g/m^2) of Above-ground Portions of *Pontederia cordata* in the Hamilton Marshes.

			Sample Date (1973)			
Site No.	June 14	June 26	July 11	August 3	August 17	Average
4C	-	19.7	10.0	28.8	38.0	24.1
4B	25.6	32.4	8.3	-	-	22.1
4A	13.6	1.9	-	-	-	7.8

			Sample Date (1974)			
Site No.	May 30	June 20	July 8	July 31	August 27	Average
4C	6.2	-	-	-	-	-
4B	-	56.3	71.2	129.9	328.	
4A	48.2	-	163.1	-	-	
3	-	161.5	484.9	353.8	592.1	

Rhizomes were collected in the field in early November, 1973 after leaves began to senesce. The rhizomes were planted in soil in 5-gallon plastic pots lined with plastic bags to retain water. Larger rhizomes were cut and planted separately, with at least one growing tip present on each. They were stored outdoors until all leaves had completely died back and were then placed in a cold room (2-4^{o}C). At the same time, 5 plants were placed in the greenhouse as controls. Rhizomes were removed ten at a time from the cold room to the greenhouse at two-week intervals after 8 to 16 weeks of cold storage. Results of this experiment are given in Table 13 .

Eighty percent of the plants that had received no cold treatment had broken dormancy after 15 days. There were not significant differences in the percentages of plants that had broken dormancy after varying periods of cold storage. The results of this experiment show that Pickerelweed will grow as long as temperature and moisture conditions are favorable. The effect of photoperiod was not studied.

SEED GERMINATION EXPERIMENTS

Seeds were collected on six occasions between September 28 and November 9, 1973. The fruits mature from the bottom of the stalk upward and drop off while still green. In order not to lose seeds between collection dates, net bags were placed over the stalks and tied below the fruits. The stalks were collected when all fruits had dropped off into the bag. The fruits were

Table 13
Percents of rhizomes
that had broken dormancy after various periods of cold storage.

Length of Cold Storage of 2-4°C	Day Number after transfer to Greenhouse		
	5	10	15
None	0	60	80
8 weeks	0	70	90
10 weeks	20	70	80
12 weeks	10	50	60
14 weeks	10	50	80
16 weeks	50	60	90

stored moist in plastic bags at room temperature until the germination experiment was begun. During this time, the fruit coats turned from green to brown and only those with dark brown coats were used for the experiments. The average number of fruits per stalk was 178 ± 97.3.

Germination pretreatments were begun 2-3 weeks after collection of the seeds. Seeds were subjected to the following treatments:

Treatment	
Stratification (2-4°C) for	31 days
Dry storage (2-4°C) for	31 days
Stored moist (20°C) for	32 days
Stored dry (20°C) for	31 days
Scarification	
Gibberellic Acid, 0.1mM	23 hours
Gibberellic Acid, 0.01mM	23 hours

As a control, 90 untreated seeds were placed in a germination chamber at 15°C. Scarification consisted of removal of the fruit coat and scratching the soft seed coat with forcepts. Each treatment consisted of three replicates of 15 seeds per replicate.

Germination was attempted at the following temperatures: 10°C, 15°C, 20°C, and 30°C. At each temperature, one group of seeds was maintained on moist filter paper (approximately 3 ml distilled water) and another group was kept in approximately 30 ml. Of the 2600 seeds used in this experiment, only 8 germinated. It was concluded that the pickerelweed seeds were in a state of deep dormancy imposed by one or both of the following factors:

(1) immaturity of the embryo or (2) a requirement for leaching of an inhibitor.

Seed ripeness, or readiness for harvest, occurs at different stages of the embryo's development in different plants; some are of considerable size and a high degree of differentiation, and in others the embryo may consist of a few undifferentiated cells. The latter type is incapable of germination without a period during which the development of the embryo is completed within the dormant seeds.

A stratification requirement is most often associated with the presence of germination-inhibiting substances in the embryos. If such embryos are excised and washed with water, frequently they will germinate; if they are simply excised and held in a humid atmosphere where leaching could not occur, the embryos remain dormant. Production of germination stimulating substances can also overcome the effects of the inhibitors.

A second series of germinations experents were initiated between 6 and 11 weeks after harvest. Fruits were washed in running water for one hour, soaked for one hour in 1.0% sodium hypochlorite, and washed again in running water for one hour. They were then stored moist in covered bowls for two to three weeks, during which time a few seeds germinated. Fruits were then placed 25 each in petri dishes on moist filter paper and placed in a cold room (2-4°C) for various stratification periods (Table 14). Three hundred of the fruits were stored dry at 2-4°C for

Table 14

Percent Germination of Seeds of *Pontederia cordata*.

Pretreatment	15°C Moist	15°C Wet	20°C Moist	20°C Wet	30°C Moist	30°C Wet
Control	0	0	0	0	4	4
Stratified 6 weeks	22	46	34	52	92	90
Stratified 8 weeks	54	64	54	44	92	88
Stratified 10 weeks	54	58	54	50	90	82
Stratified 12 weeks	46	30	56	66	82	88
Dry, 2-4°C, 8 weeks	10	2	4	4	22	14

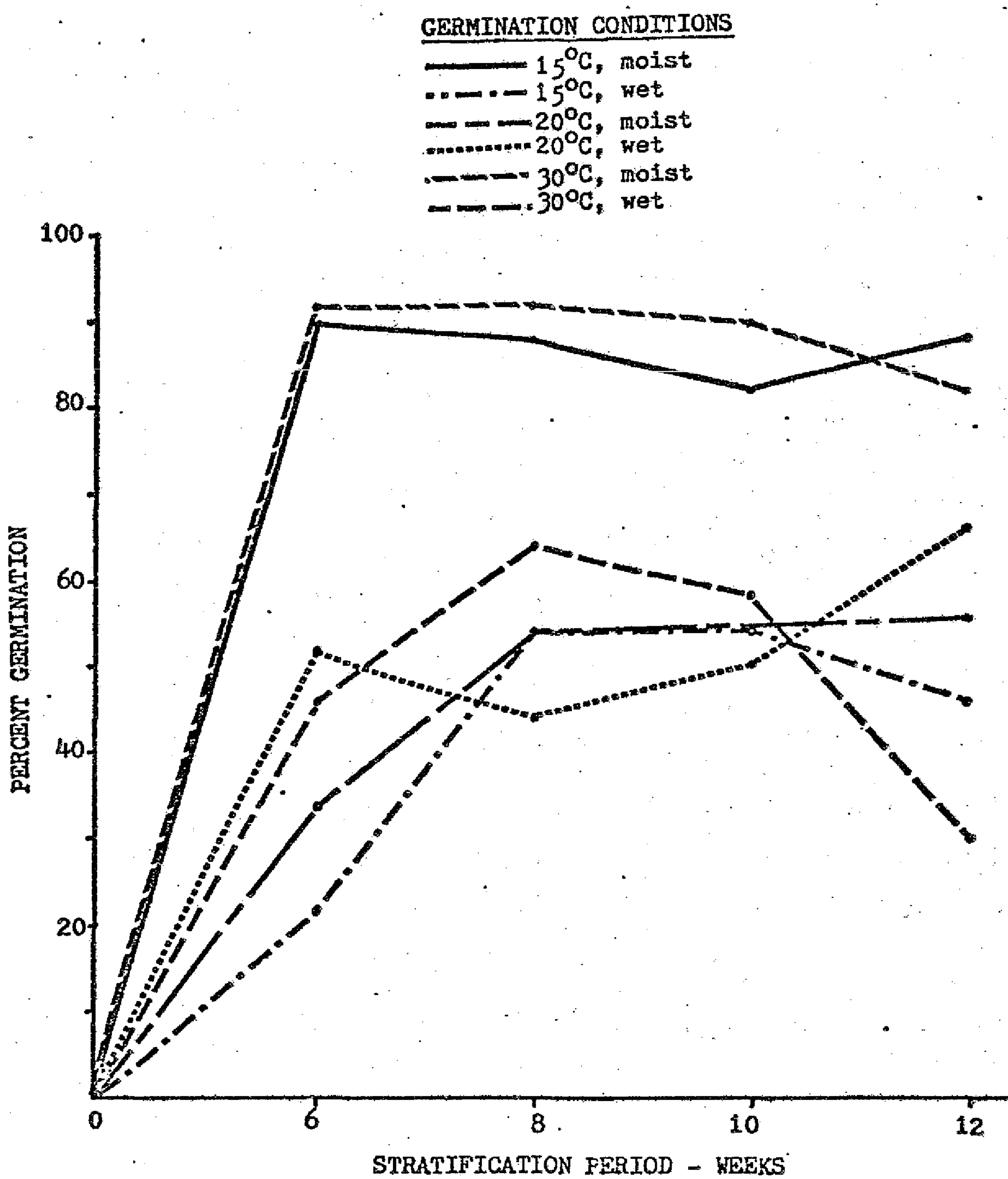
eight weeks and 300 were placed in a germination chamber at 20°C for eight weeks as a control. After the prescribed stratification periods, the fruits were transferred to germinators at 15°C, 20°C, and 30°C under both moist (3 ml) and wet (30 ml) conditions. Results of those experiments are given in Table 14 . Very few seeds in the control group germinated. Similarly, seeds that were stored dry at 2-4°C did not have high germination percentages. Under a cold moist stratification regime, high germination percentages occurred for each of the four stratification periods.

A significantly greater percentage germination occurred at 30°C. There was no significant difference between seeds germinated at 15°C and 20°C. Neither were there any large differences between fruits germinated on moist filter paper and fruits submerged in water.

At 30°C germination temperature there is little difference among the various stratification periods (Figure 46). At 20°C there is a considerable difference between the 6 and 12-week stratification periods with the highest percent germination occurring in seeds that were stratified for 12 weeks and germinated wet.

At 15°C the best germination was obtained with seeds stratified for 8 and 10 weeks and the lowest with those stratified 6 weeks. Overall, the best stratification period is 8 weeks, followed by 10, 12 and 6 weeks, in that order.

Figure 45. The effects of temperature and moisture on the germination of pickerelweed (Pontederia cordata) seeds that had been stratified for periods of 6-12 weeks.


GERMINATION CONDITIONS
15°C, moist
15°C, wet
20°C, moist
20°C, wet
30°C, moist
30°C, wet
100
80
60
40
20
PERCENT GERMINATION
0
6
8
10
12
STRATIFICATION PERIOD - WEEKS

Seeds germinated rapidly at 30°C for all treatments. Maximum germination was obtained within 3 days or shortly thereafter. Germination was also more rapid at 20°C than at 15°C for all stratification periods.

Lack of germination in the first experiment may have been due to seed immaturity, a requirement for leaching of a germination inhibitor, or for production of a germination stimulator. Seeds were not washed in running water or sterilized in the first experiment. In the second experiment, a few seeds germinated while being stored in the bowls and also in the control group. The washing procedure may have removed a germination inhibitor. The second experiment was carried out three months later than the first, which allowed considerable time for maturation of the embryos. However, if dormancy were due to immaturity alone, there would have been germination in the control group. It can be concluded that the seeds of pickerelweed require at least an 8 week period after harvest for the embryo to mature before germination will occur under any circumstances. In addition, they must be stratified in order to overcome the effects of a germination inhibitor. The minimum period of stratification required was not determined in this study.

CONCLUSIONS

Pickerelweed is not a dominant plant species in the Hamilton Marshes. It occurs sporadically throughout but is common along the banks of Crosswicks Creek and side channels leading into it and the Spring Lake, Rowan Lake, and Sturgeon Pond sections of the marsh. It occurs in all habitats throughout the marshes and thus appears to be able to withstand a wide range of environmental conditions. Along the stream banks and in the Rowan Lake section it is exposed at low tide which is always covered by water in other areas. It is most commonly found growing with yellow water lily, arrow arum, and water smartweed. Although it produces a large number of seeds, few seedlings are encountered throughout the marshes. Many are undoubtedly consumed by animals. Sculthorpe (1967) has stated that they are readily consumed by ducks and muskrats. Because of the high mortality rate of seeds, the species is most successful in spreading by asexual means. As a result, one frequently encounters the species growing in clones. The mature plants have no internal dormancy mechanism and will start to grow as soon as the water and substrate temperatures begin to warm in the spring. The seeds, on the other hand, possess an internal germination inhibitor that must be removed by stratification. In addition, the embryo is immature at the time that the seeds are shed. Both of these mechanisms insure that the seeds do not germinate before the onset of cold weather.

STUDIES OF THE SEED GERMINATION AND SEED MUCILAGE OF PELTANDRA VIRGINICA L. (Arrow Arum)

by

David West

Introduction

Peltandra virginica (L.) Kunth. is a perennial herb arising from a thick fibrous rootstock. The species is commonly seen growing along muddy shores or advancing into shallow water of streams and ponds. Distribution is from Maine to Florida, west to Michigan, Montana and Louisiana (Gleason, 1963).

Peltandra is a member of the Araceae, a family of about 2,000 species most abundant in the tropics (Gleason, 1963). The dominant family characteristic is the typical aroid inflorescence of numerous flowers on a fleshy spadix subtended by a spathe (Fassett, 1969).

Whigham (1974) in his study of a fresh water tidal marsh in New Jersey, found the species to be widespread throughout the marsh. He also showed the species to be the fourth most important species of the open marsh vegetation. The study also indicated that Peltandra, unlike the yellow water lily (Nuphar advena), does not do well under conditions of continual complete submergence. Thus, Peltandra grows on the relatively higher ground adjacent to the stream channels in which Nuphar thrives.

Peltandra begins to flower from June to late July. Fruiting lasts from August to early September at which time the fruit, a head of green berries begins to swell. By late November, all of the multiple fruits have been dispersed.

Peltandra seeds will not germinate in their intact condition after dispersal. Seed dormancy of many species have been extensively studied with Vegis (1964) giving a general definition of seed dormancy as being a condition under which germination and establishment are possible only within a narrow range of environmental conditions. Barton (1965) states that there are basically two kinds of dormancy: ectogenous, influenced by external factors such as light, temperature, water, etc., and endogenous, conditioned by the internal physiology of the seed. Furthermore, Sculthorpe (1967) reports that the overwhelming majority of aquatic angiosperms exhibit ectogenous dormancy. Sculthorpe also states that in most species this dormancy is simply due to containment of the embryo within the pericarp. Hart (1928) suggests in her germination studies of _Peltandra_ that dormancy was due to the containment of the embryo within the pericarp. One purpose of this study was to determine the dormancy mechanism in seeds of _Peltandra_ _virginica_. The second objective of the study was to determine the purpose of the mucilage found in each _Peltandra_ seed. The muscilage is located between the embryo and the seed coat.

Materials and Methods

Peltandra seeds were collected between early September and November from the Hamilton Marshes. The seeds were then stored in distilled water at room temperature.

The seeds, on the average, consist of a large, well developed and slightly curved embryo whose plumule is about eight millimeters long, lying in a groove along a large mass of endosperm. A translucent pericarp surrounds the entire embryo with a two to three millimeter thick layer of mucilage surrounding the pericarp. A dark green to black seed coat encloses the mucilage and embryo.

Experiments were conducted to determine relative germination rates of seeds which had various components of the fruit removed, effects of temperature and stratification on germination, and effects of the seed mucilage on seedling development and seed dessication. For each of the above experiments the methodology was as follows:

I. Effects of Removal of the Fruit Components

All germination tests were conducted in petri dishes filled half way with distilled water and kept at room temperature. Twenty intact fruits were washed and placed in petri dishes. Seed coats were removed from a second set of 20 seeds. From a third set of twenty seeds, the seed coats and mucilages were removed. Seed coats and mucilage were removed from the next three sets of fruits (20 seeds per set) followed by partial or entire removal of the pericarp. From one set, about one half of the pericarp was removed from the end of the embryo nearest the tip of the plumule. A second set was prepared by removing about one half of the pericarp on the opposite end of the embryo, thus exposing the embryonic root nodules. The entire pericarp was removed from the final set of 20 fruits. There were three replications of each of the above experiments. Germination was considered to have occurred when the tip of the plumule rose above its groove in the endosperm.

II. Stratification Experiments

Two stratification experiments were performed. In the first experiment the seed coats, mucilage, and pericarp were removed from each fruit leaving only the bare embryo. Twenty embryos were stored at each of the following temperatures: 0^{o}, 5^{o}, 10^{o}, 20^{o}, and $24^{o}C$. Germination, percentages were determined after two weeks of stratification at the above temperatures. The second experiment involved the effects of various periods of stratification on germination. Forty seeds were prepared in each of the following categories: intact fruit, seed coat removed, seed coat and mucilage removed, and seed coat, mucilage, and pericarp removed. All of the seeds were then placed in water at $5^{o}C$. Ten seeds from each of the above categories were removed weekly and placed in water at room temperature. After two weeks at room temperature, germination percentages were recorded for each category.

III. The Effects of Seed Mucilage on Seedling Development and Seed Dessication

The seed coats were removed from 40 seeds and, in addition, mucilage was removed from 20 of those seeds. The two sets of 20 seeds were then placed in water at room temperature. The day that each seed germinated was recorded.

Experiments were designed to determine if the mucilage had any effect on seed desiccation and thus any effect on germination. Three categories were established: entire fruits, fruits with the seed coat removed, and fruits with the seed coat and mucilage removed. One hundred seeds were used in the first category and 40 in the following two. All of the seeds were placed on dry filter paper at room temperature. Periodically (weekly for the entire fruits, daily for the other two categories), several dry seeds from each category were removed. If the seed coat or mucilage were present, they were removed and the seeds placed in water at room temperature. Two weeks after being placed in water, the total germination for each time period of dryness and each category was recorded.

RESULTS

I. Effect of Removal of Fruit Components

Significant differences in germination rates were obtained through removal of various parts of the fruit. Results are given in Table 15 . After 2 weeks, 3.3 percent of the intact fruits had germinated and 10% had germinated after four weeks. With removal

Table 15

Germination rates of Peltandra virginica seeds after removal of various parts of the fruit. Each treatment consisted of 60 seeds. All germination tests were conducted at room temperature.

Time (Days)	Entire fruits	Seed coat removed	Seed coat and mucilage removed	Seed coat and mucilage removed, pericap removed from plumule and of embryo	Seed coat and mucilage removed, pericap removed, from radicle and of embryo	Seed coat, mucilage, and entire pericap removed
1	0	0	0	0	0	25
2	0	0	0	0	21.7	45
4	0	0	0	20	40	56.7
5	0	0	40	55	70	70
7	0	50	46.7	63.3	80	80
10	0	70	81.7	88.3	81.7	80
14	3.3					
15	-	75	83.5	88.3	96.7	81.7
21	8.3					
28	10.0					

of the seed coat, germination had occurred in 50% of the seeds in only seven days (Table 15). Seventy-five percent had germinated within 15 days. When the seed coats and mucilage were removed 40% of the seeds germinated within five days and 83.3% germinated in 15 days.

Partial or entire removal of the pericarp reduced the time required for germination. With partical removal of the pericarp near the radicle, 21.7% of the seeds germinated after only two days while 96.7% had germinated after 15 days (Table 15). With the entire pericarp removed, 25% of the seeds germinated after 1 day, 45% after two days, and 81.7% after 15 days. The slowest germination occurred when the pericarp was partially removed from near the plumule end of the seed. In four days 20% of the seeds had germinated (Table 15). After 35 days, there was no significant difference between this and any other treatment.

II. Stratification Experiments

Cold temperatures greatly reduced germination of Peltandra seeds. Bare embryos failed to grow after two weeks at 0°C and 5°C (Table 16). As temperature increased there was a corresponding increase in germination. Ten percent of the embryos germinated at 10°C, 75% at 20°C, and 95% at 24°C.

Although embryos will not grow below 5°C, it appears that the length of exposure to cold temperatures or the condition of the

Table 16

Germination of seeds of _Peltandra virginica_ after 2 weeks in water at temperatures ranging from 0 to 24 degrees centigrade. The seed coat, mucilage, and pericarp were removed from all seeds. There were 20 seeds at each temperature.

TEMPERATURE (C)	% GERMINATION
0	0
5	0
10	10
20	75
24	95

fruit exposed to those temperatures has little effect on the ability of the seed to germinate when placed at room temperature. Eighty percent of the entire fruits kept at 5°C for one week germinated after two weeks at room temperature (Table17). Fruits kept for four weeks at 5°C also had high germination percentages (Table 17). High germination percentages were recorded for the other classes of seeds which were stored at 5°C for periods of 1-4 weeks (Table 17.).

III. Seed Mucilage effects on germination and dessication

Results of the experiment to determine the effects of desiccation on germination appear in Table 18. The data indicates that entire fruits are not affected by drying. Germination significantly decreases with dry storage when the seed coat is removed. All seeds germinate after one day of dry storage. Germination percentages started to drop after 5 days of dessication and all seeds fail to germinate after eight days. A similar pattern occurred when both the seed coats and mucilage were removed.

DISCUSSION

Seed dormancy in Peltandra virginica is primarily imposed by the seed coat. The thick seed coat is extremely resistant to mechanical damage and to microbial decomposition. As evidence of the seed coats impermeability, water had penetrated only 10% of

Table 17

Germination of seeds of *Peltandra virginica* at room temperature following periods of cold, wet treatment ranging from one to four weeks. The seeds were divided into four classes depending on how much of the fruit was removed. Each class contained 40 seeds, with 10 removed weekly. All parts of the fruit were removed from the 10 seeds before being placed in water at room temperature for two weeks.

Time (weeks)	Entire fruit	Seed coat removed	Seed coat and mucilage removed	Seed coat, mucilage and entire pericarp removed
1	80	90	100	90
2	90	90	76	80
3	100	70	60	90
4	90	80	90	80

Table 18

The effects of various periods of desiccation on the germination of seeds of *Peltandra virginica*. Three classes of seeds were placed on dry filter paper at room temperature: entire fruits, fruits with the seed coat removed, and fruits with the seed coat and mucilage removed. Periodically some of the dry seeds were removed, the remaining parts of the fruit removed and then placed in water at room temperature for two weeks.

Length of dry period (Days)	Entire fruits	Seed coats removed	Seed coats and mucilage removed
1	90	100	80
2		80	80
3		80	80
4		80	60
5	80	40	20
6			0
7	90	20	0
8		0	
9		0	
14	70		
21	80		
28	90		
42	80		

the intact seeds (Table 15). Mucilage may also serve to inhibit germination somewhat since, with its removal, germination was initiated in 5 instead of 7 days (Table 15). The pericarp also appears to inhibit germination. Twenty-five percent of the seeds with the entire pericarp removed germinate in only one day and 80 percent after five days (Table 15). Partial removal of the pericarp was only effective in initiating germination earlier when it was removed from near the root end of the embryo. Partial removal of the pericarp near the roots resulted in a 21.7% germination rate of within the first two days. These results agree with Hart (1928) who suggested that partial dormancy was due to containment of the embryo within the pericarp. Edwards (1933) also reported the pericarp to be an obstacle to germination.

Temperature can also serve to hold seeds in a dormant condition. Seeds only germinated at temperatures above 10^{o}C. In the marshes, the onset of the growing season corresponds with that temperature threshold. In the field, if seeds are to successfully survive they must be able to survive long periods of cold. Seeds stratified for periods varying from 1-4 weeks at 5^{o}C all had high germination percentages once they were placed at room temperatures and the seed coats, if present, were removed. This is true regardless of the condition of the fruit since even seeds with the entire pericarp removed show high germination percentages following the cold treatment. These results differ from those found by Adams (1927) from studies on Crataegus mollis. He found that after-ripening at 5°C was greatly influenced by the structures surrounding the embryo, namely the testa and carpel. Parkinson (1973) has shown that Pickerelweed, a common plant in the marshes, also requires a period of after-ripening before the seeds will germinate. Mucilage has virtually no effect on germination or in protection of the embryo from cold temperatures.

Mucilage does not provide protection from dessication damage. Gutterman (1967) suggested this for the mucilage of Blepharis persica seeds. However, the data indicates that such is not the case for Peltandra (Table 18.). When the seed coat is removed, the mucilage quickly dries out and flakes off the embryo. The seeds continue to dessicate and the germination fails to occur after seven days. With the mucilage removed prior to the drying period, the seed appears to dry out slightly faster with no germination occurring five days. With the seed coat intact, seeds remained viable after six weeks of dry storage. Examination of those seeds showed that the seed coat remained pliable and that the mucilage had shrunk but was still in the gel state. This suggests the possibility that the mucilage is capable of keeping both the seed coat and embryo from drying out if the seed coat is intact.

Kozlowski (1972) has reported that seed mucilages may reduce the specific weight of seeds in water. This does not seem to be true for <u>Peltandra</u>. The intact fruit is bouyant in water, however, with removal of the seed coat, the embryo losses its bouyancy as the mucilage absorbs water. The embryo itself is not bouyant, therefore the fruits' bouyancy is probably due to air trapped between the mucilage and seed coat. In the winter the mucilage freezes to the marsh surface when the temperatures are below $0^{o}C$. This serves to hold the seeds in place and prevent them from being washed away.

Both Kozlowski (1972) and Ferry (1959) state that seed mucilages have a large capacity to absorb water and swell. This is especially true for <u>Peltandra</u> where, on the average, the seed mucilage is capable of absorbing better than twice its weight in water. Preliminary field studies also indicate that about ten percent of the seeds collected during early December have some amount of mucilage exuding through the seed coat. This is indicated by the observation that through swelling, the mucilage is able to enlarge a small tear in the seed coat into an area large enough for the embryo to escape. Once this is accomplished, the seeds will be held in a dormant state by low temperatures. When substrate temperatures rise above $5\text{-}10^{o}C$, the seeds will germinate because the muscilage will have caused a break in the seed coat. On January 16, 1975, we collected a number of arrow arum seeds from the marshes. All of the seeds that had had the seed coat removed or otherwise broken germinated within 2 days of being returned to the laboratory and placed at room temperatures. None of the seeds that we collected which had the seed coats intact germinated.

The following ecological strategy has evolved in Peltandra virginica. When the seeds are shed from the parent plant, most of the seed coats are intact and the seeds are buoyant. Thus the seeds are able to be dispersed throughout the marshes. As one would expect, arrow arum seeds are ubiquitous and are found in habitats where the species doesn't grow. Seeds are held dormant as long as the seed coat is intact. During the late autumn, the muscilage expands and causes a break in the seed coat. It has not been determined whether or not the muscilage expands because water had moved across the seed coat or whether the water was generated internally via respiration. Preliminary studies of seed metabolism have shown that there is an increased respiration rate just prior to germination. Since respiration is strongly temperature dependent, some metabolic water would be generated prior to the onset of cold temperatures. The seeds could germinate in the marshes whenever the seed coats are broken but water and substrate temperatures are low enough to hold the seeds in a dormant state. A few germinated seeds were observed prior to the onset of cold weather. The seeds are able to withstand extended cold periods and are viable once substrate and water temperatures reach 5 - 10^{o}C in the spring. These temperatures coincide with the beginning of the growing season for mature arrow arum plants and with the onset of germination of arrow arum seeds. Evidence to support much of these conclusions was seen in the field in the fall of 1974. The seed coats of a number of seeds were broken before the onset of cold weather and those seeds germinated. Thus, the seed coat and muscilage appear to be the most important components in the ecology of arrow arum seeds.

ENVIRONMENTAL EDUCATION

Another goal of our work was to consider the feasibility of using the marshes as an outdoor educational facility. It is our opinion that the marshes can be used for that purpose and that serious thought should be given to the development of a township outdoor environmental education program utilizing the Hamilton Marshes as a focal point.

We feel that the most appropriate site for an outdoor educational facility is an island and adjacent marshland located near the Hamilton Township Sewage Treatment Plant (Fig. 46). We consider this to be the best site for the following reasons:

1. All major marsh habitats are in close proximity to the island.
2. Its proximity to the sewage plant would make it easier to provide security if any permanent facilities were to be constructed.
3. The sewage plant could be used as an integral part of educational programs that would be developed.
4. It is close to Crosswicks Creek, Watsons Creek and other unnamed channels which can all be used for canoe trails.
5. The island is large and is covered with mature forests. There is enough additional area for the establishment of fields and plantations of other trees, etc.
6. We have seen no evidence that the island is regularly flooded.
7. The entire area is owned by the township.
8. Figure 46 also shows that the island is horseshoe shaped and that it encloses a section of marsh. It would be feasible to dike that area, dredge it, and create a ground water fed fresh water lake. The lake could be used for boating, fishing, attracting birds, etc.

We propose that the Township seriously consider establishing an environmental study center in the Hamilton Marshes and recommend the following timetable to accomplish its development:

Fiscal Year 1976

1. The Hamilton Township Environmental Commission working with Township schools (including teachers, students, and administrators) should establish the need for a Township environmental education facility.

2. A comprehensive plan for the environmental education center should be developed. This plan should consider alignment of nature trails and catwalks in the marsh and forest areas, placement and design of facilities including museum and interpretive buildings, and location of fields and plantations. The Delaware and Raritan Canal Commission should be contacted during this phase regarding their plans to develop the first lock area of the Delaware and Raritan Canal at Bordentown. It would be entirely feasible to link the Hamilton facility with the canal facility.

3. Grant funds should be sought for the development of the center.

Fiscal Year 1977

1. Build trails, catwalks, and clear island areas for plantations, fields, etc.

2. Develop curricular materials for grades K-12 (this should be done by Township educators).

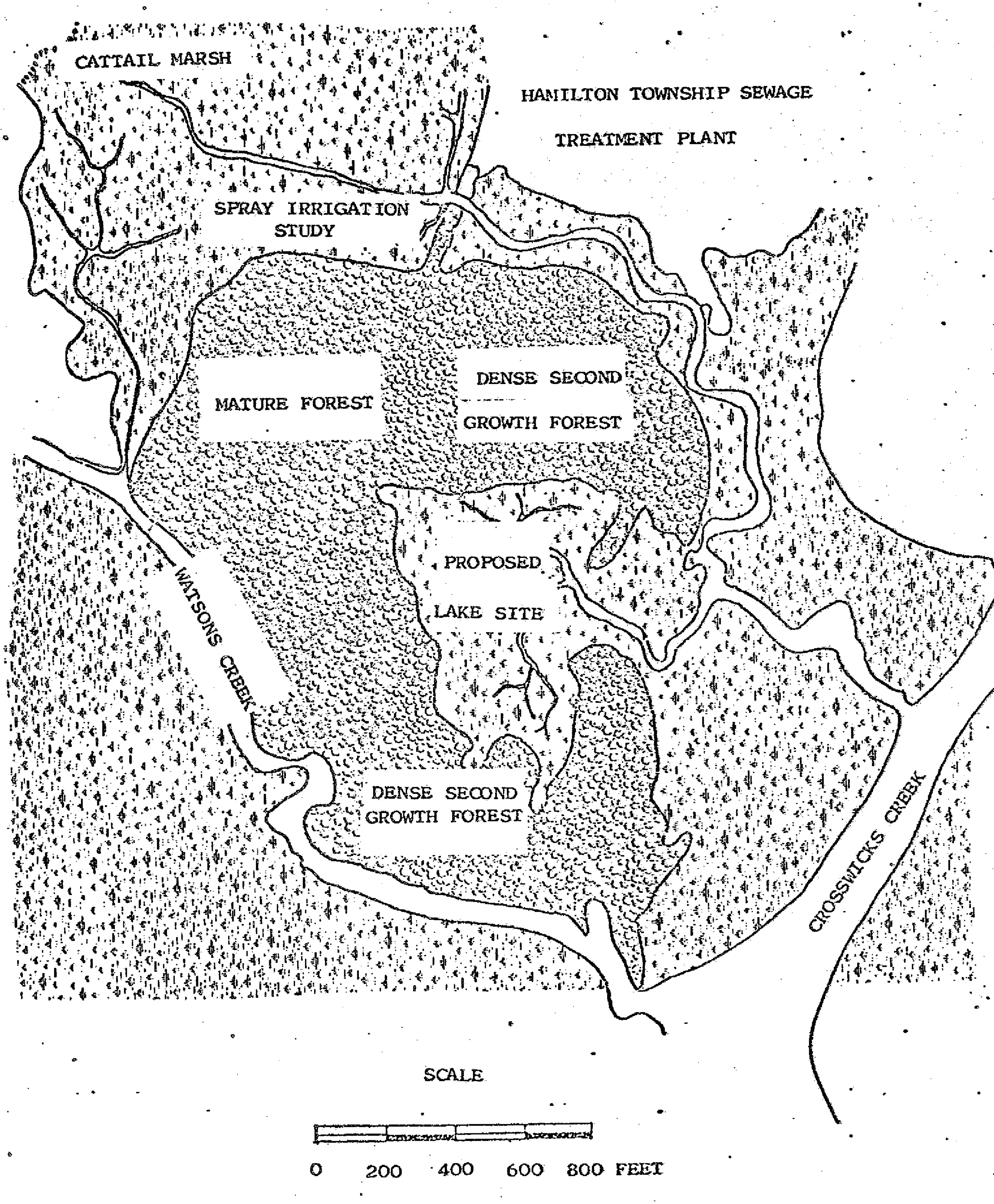
Fiscal Year 1978 and beyond

1. Build museum and interpretive buildings. An environmental education facility involves people, land, and buildings. As described in the National Audubon Societies bulletin on A Nature Center for Your Community, "to run a nature center efficiently, one must have a place where people can meet. An education building, then with an orientation-assembly room, exhibits, displays, book store, offices, restrooms, and a workshop, is essential". This phase of development would be the most expensive and should be

undertaken after the center is established and its future assured. The area has a rich pre and posteuropean history that should be included in the planning of the center.

2. Plans should be formulated for the creation of the proposed lake. We recommend that this project be given early consideration because it would be feasible to use the dredged material to fill, completely or in part, the sludge lagoons at the sewage plant. The latter will apparently be drained and filled whenever construction begins on the expansion of the sewage plant. This fill would save the Township money and it would then be economically feasible to construct the proposed lake.

PROPOSED SITE FOR HAMILTON TOWNSHIP ENVIRONMENTAL STUDY CENTER



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