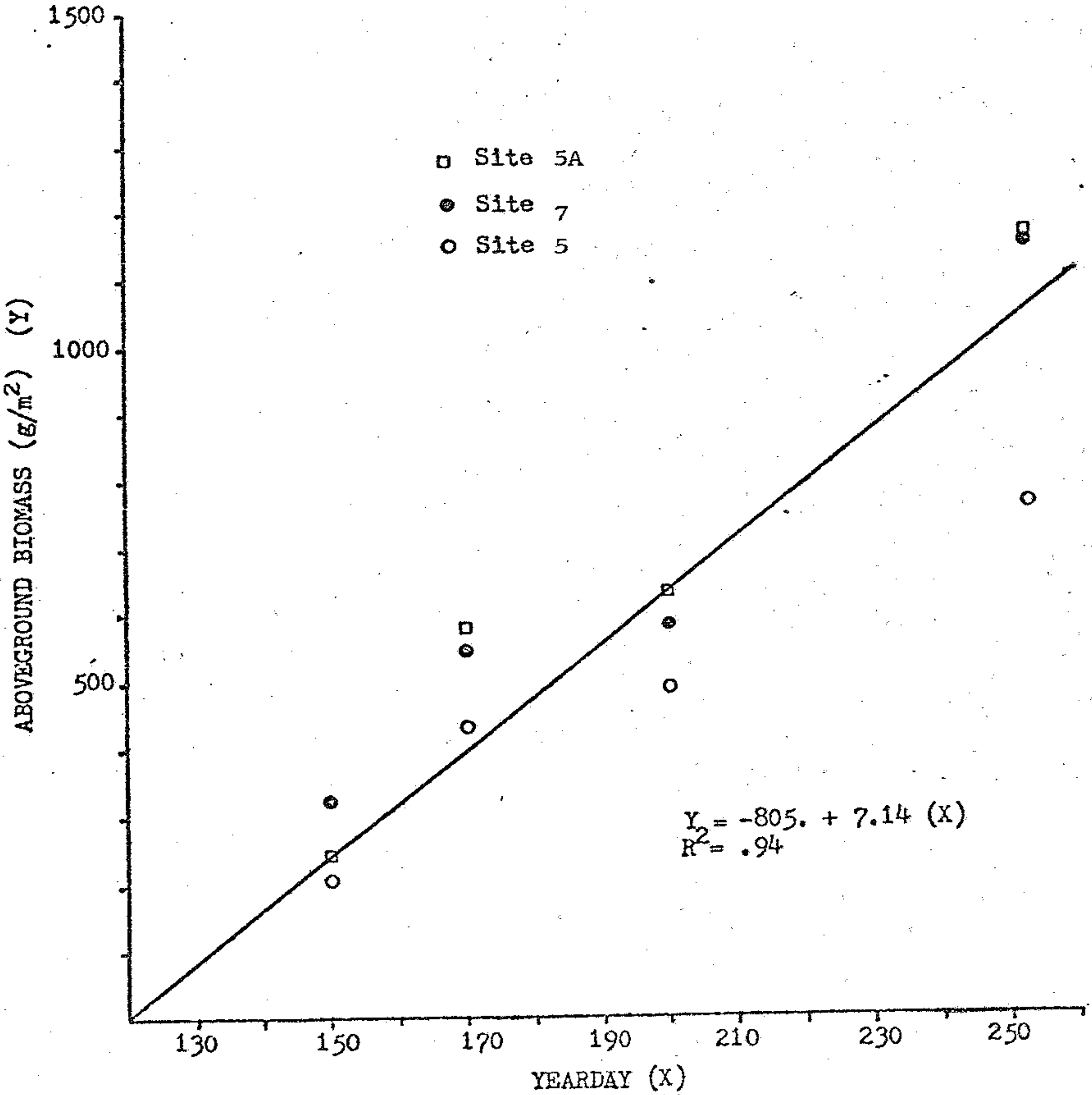
V. Aboveground production in Swamp loosestrife (*Lythrum salicaria*) areas. Values are means of 3 replicate samples ± 1, S.E. See Figure 2 for site locations.

	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 ($r^2 = .99$).

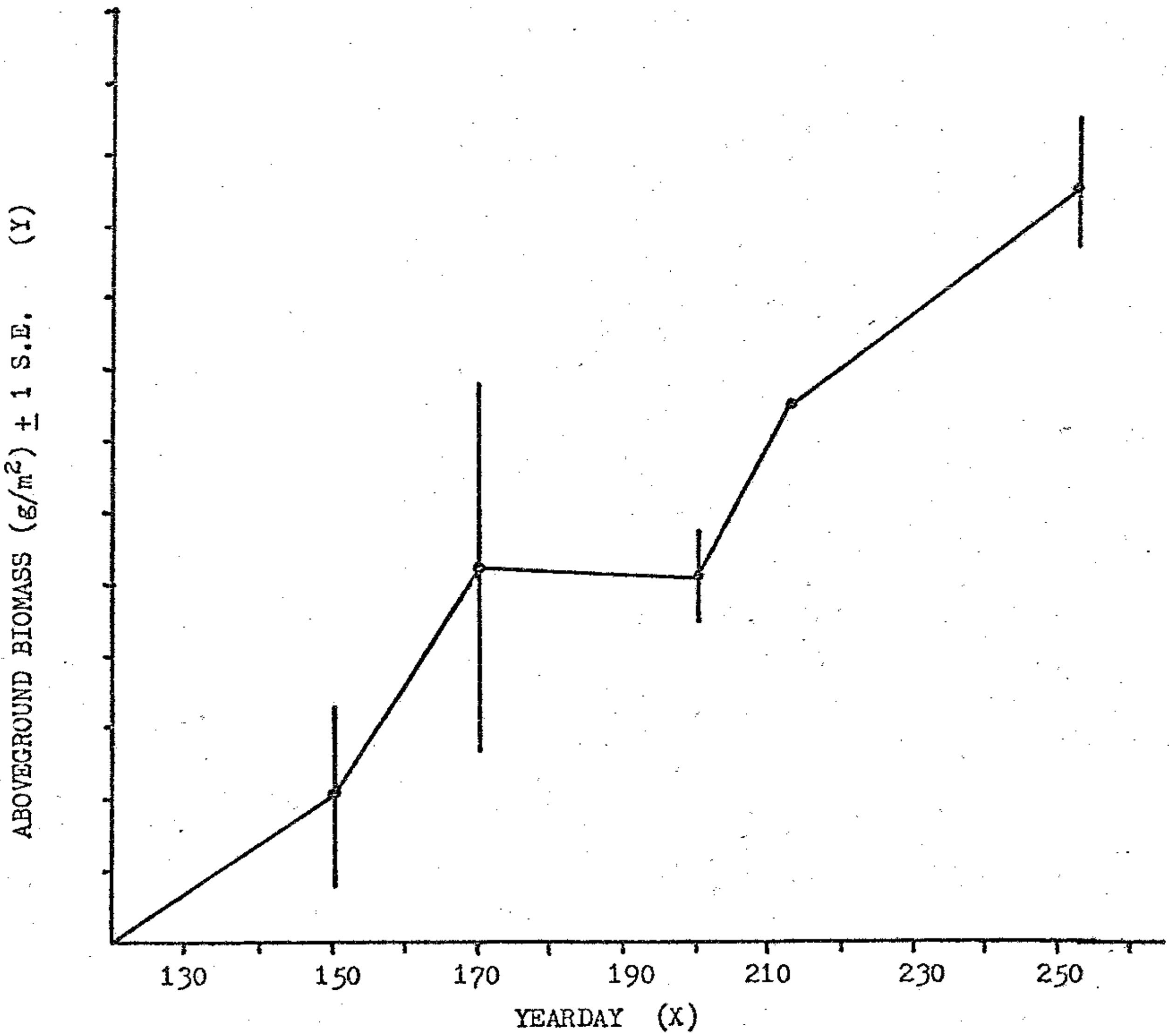
Figure 6. Aboveground primary production of mixed vegetation dominated by bur marigold (*Bidens laevis.*) All values are means (g/m^2) $\pm$ 1 standard error of the mean. Refer to Figure 2 for site locations ($g/m^2 \times 10^{-2}$ = T/Ha)


1500
1000
500
ABOVEGROUND BIOMASS (g/m^2) (Y)
Site 5A
Site 7
Site 5
$Y = -805. + 7.14 (X)$
$R^2 = .94$
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) ± 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 (<u>Typha</u> sp.) dominated areas. All values are means (g/m^2) $\pm$ 1 standard error of the mean. Refer to Figure 2 for site locations.

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

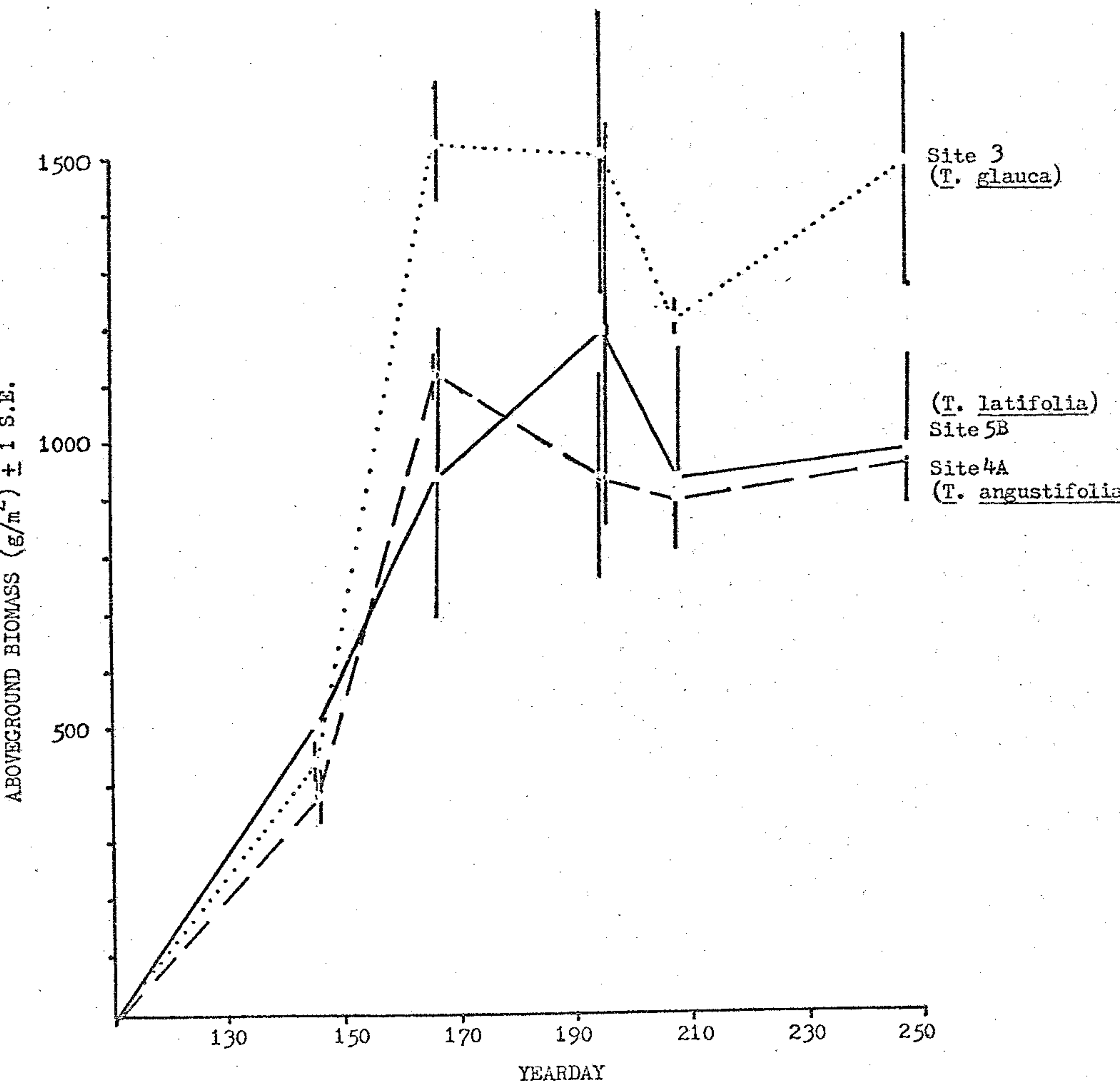
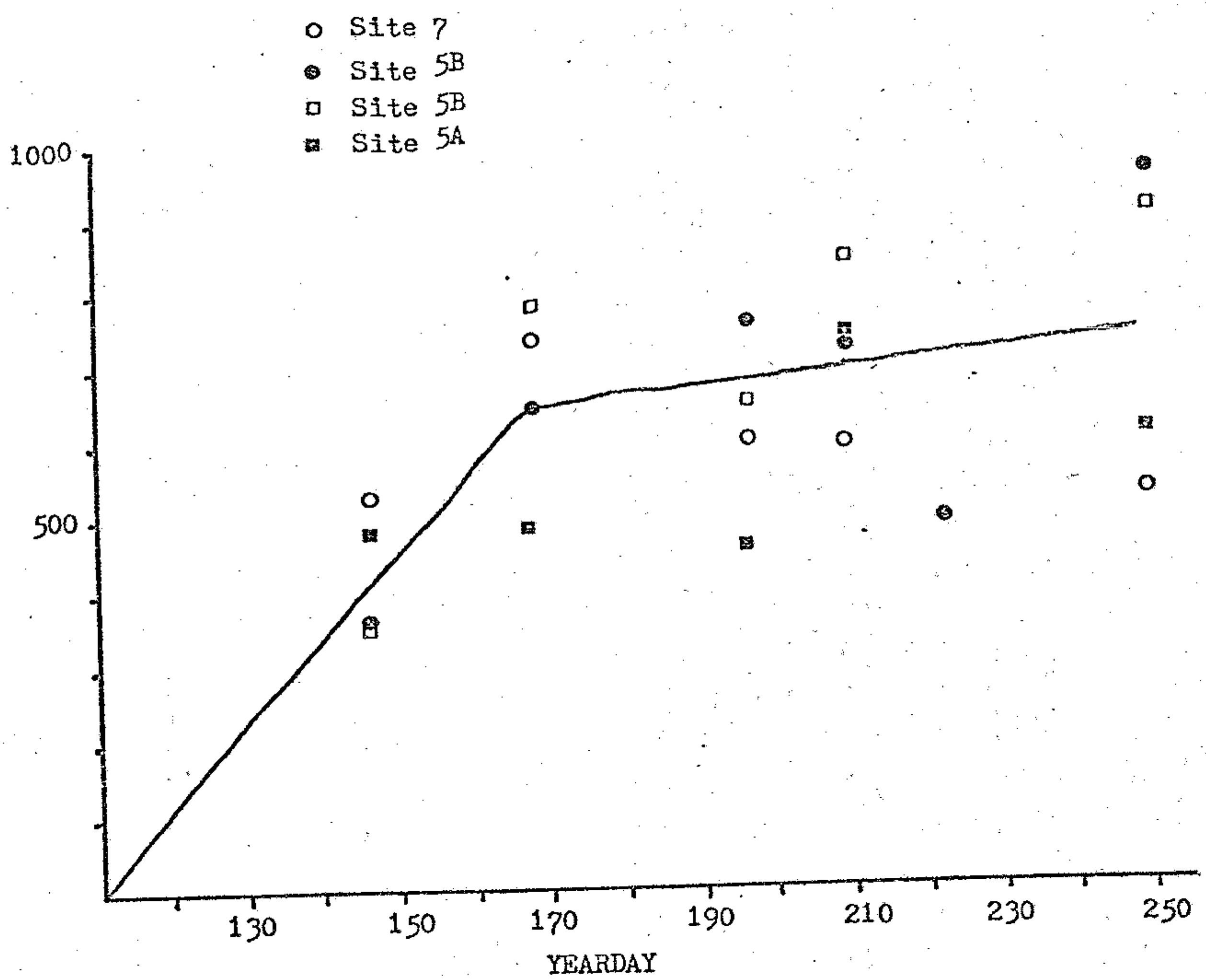

1500
1000
500
ABOVEGROUND BIOMASS (g/m2) ± 1 S.E.
130
150
170
190
210
230
250
YEARDAY
Site 3
(T. glauca)
(T. latifolia)
Site 5B
Site 4A
(T. angustifolia

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)


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 <u>Nuphar</u> dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

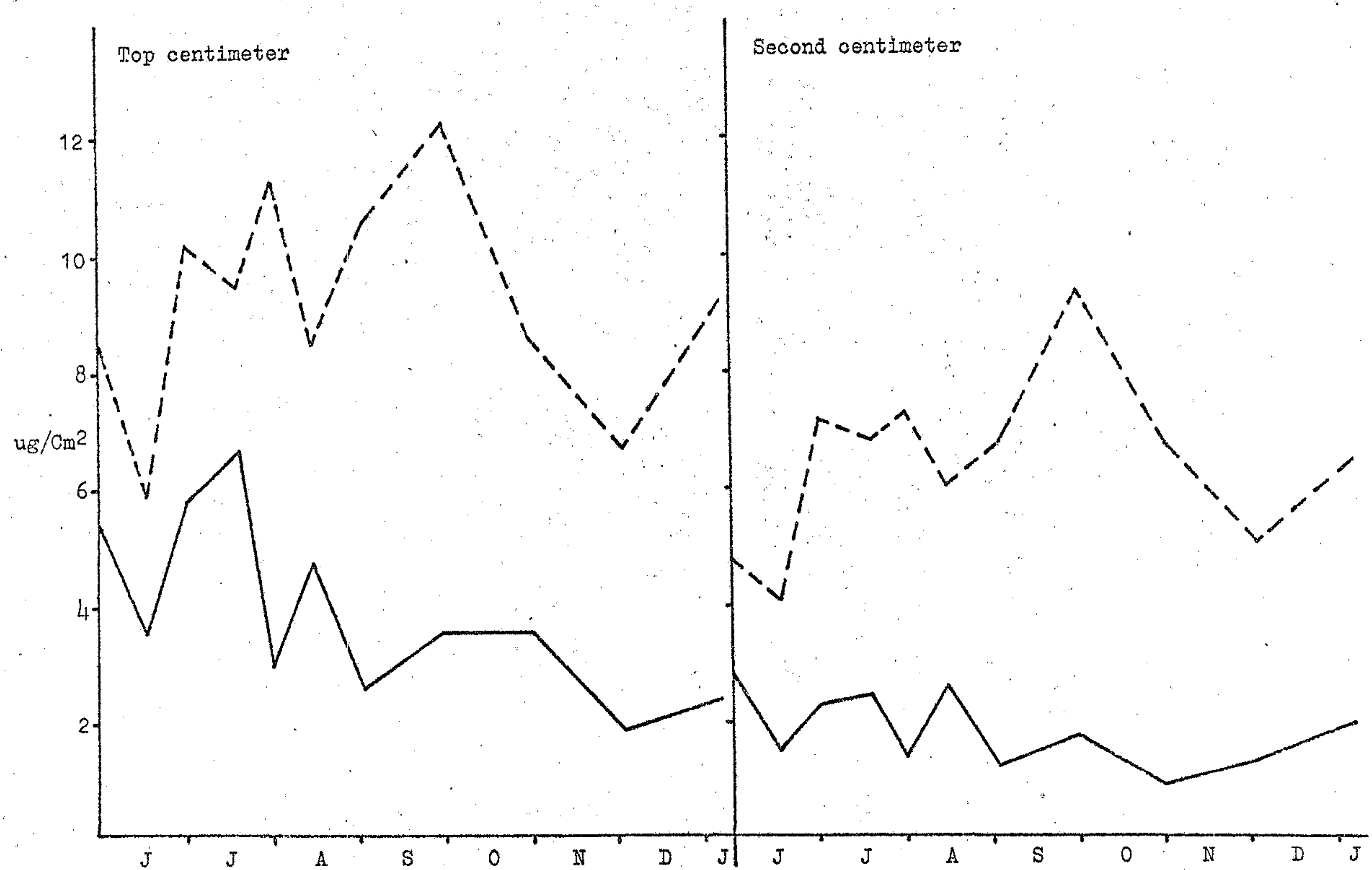


Figure 11. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in Peltandra-Nuphar dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

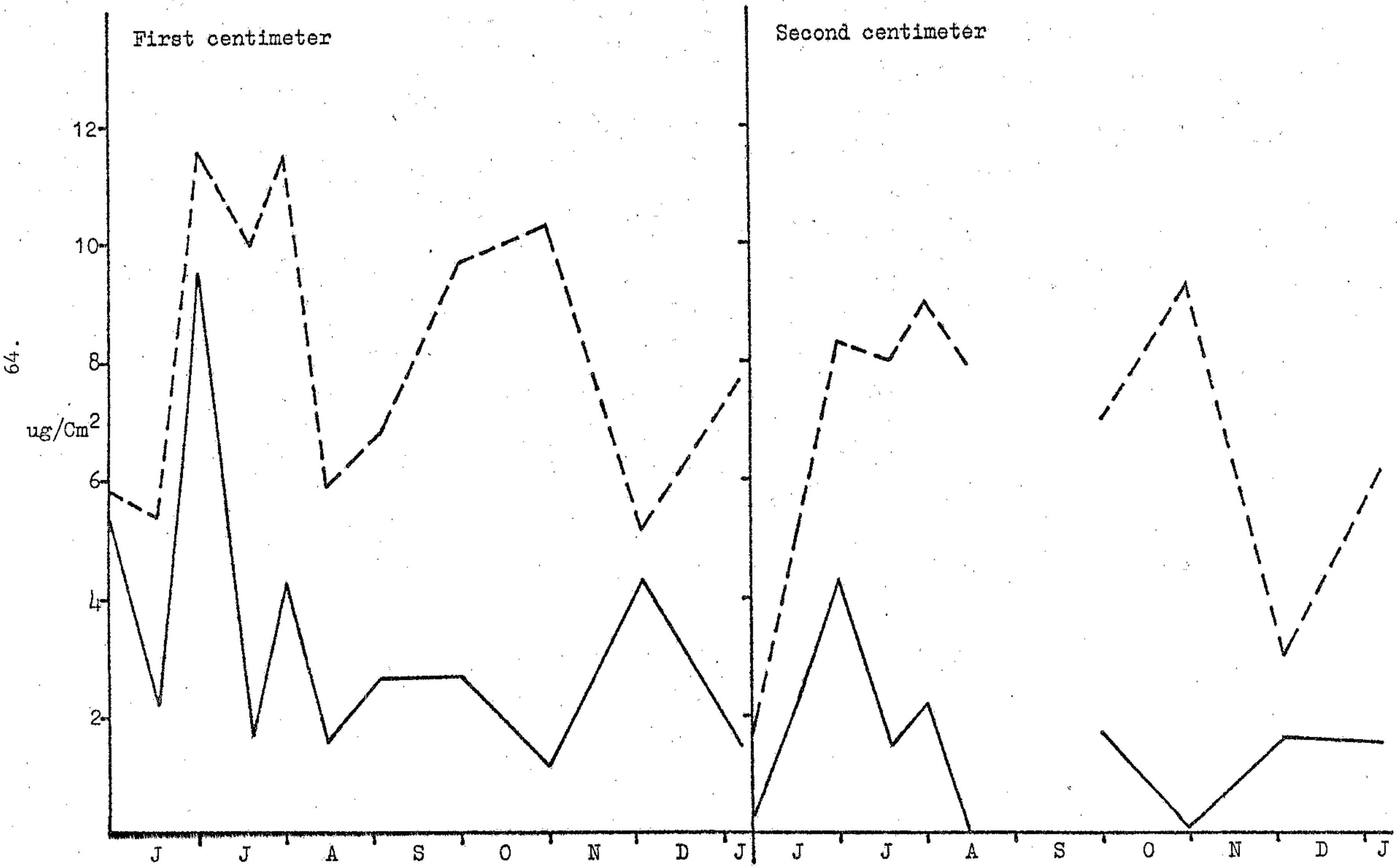


Figure 11. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in Peltandra-Nuphar dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

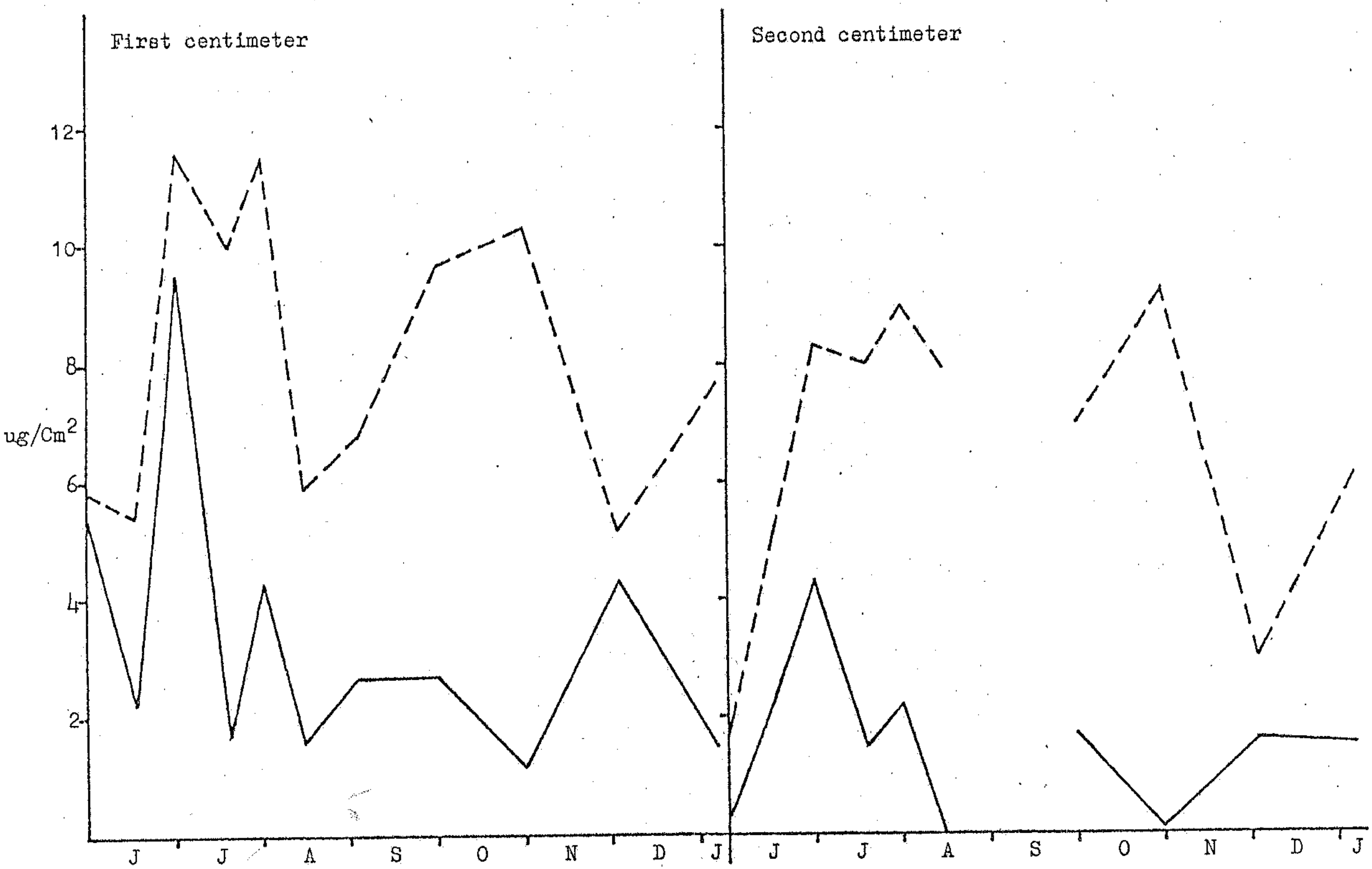


Figure 12. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in stream bank areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

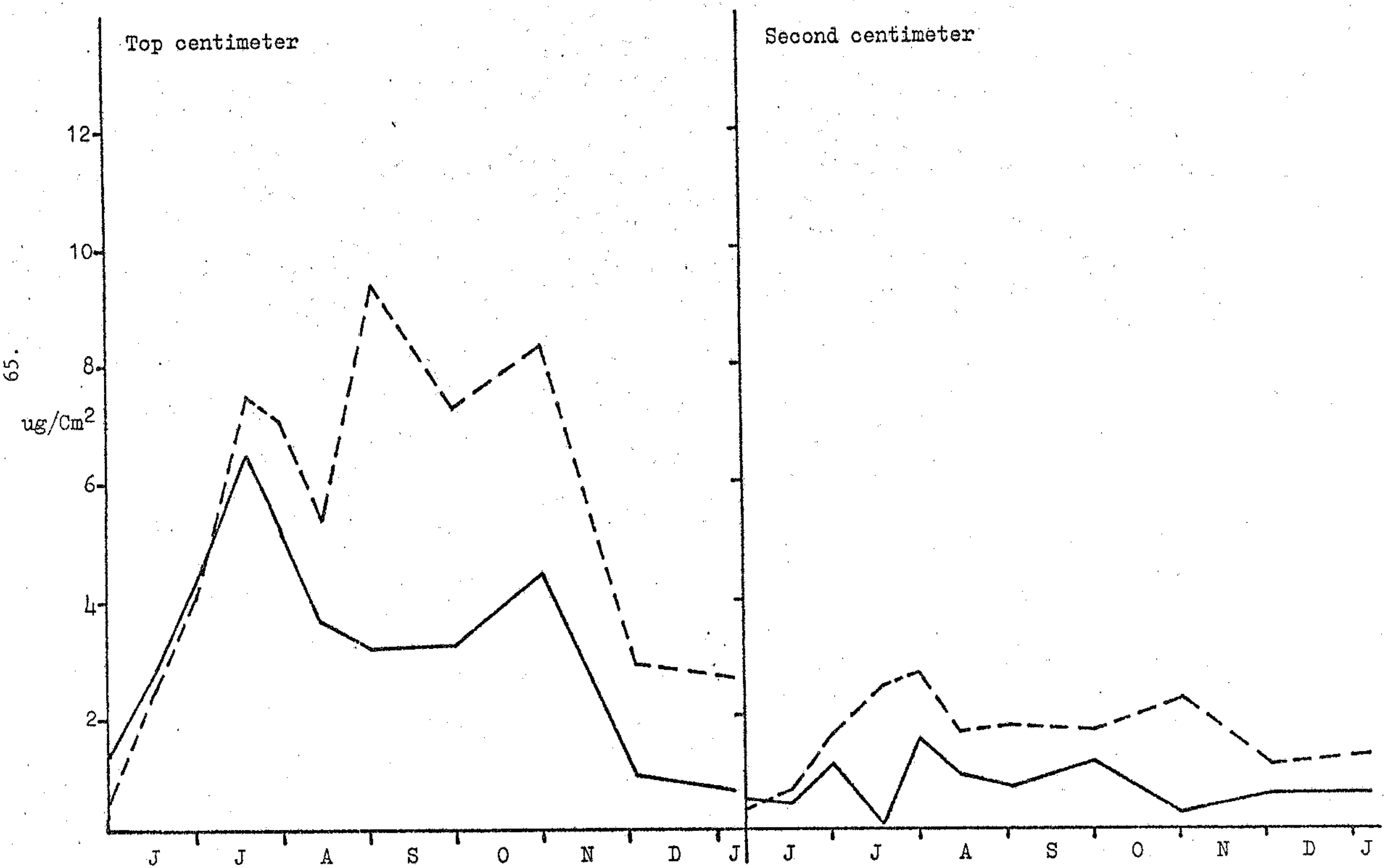


Figure 13. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in _Typha_ dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

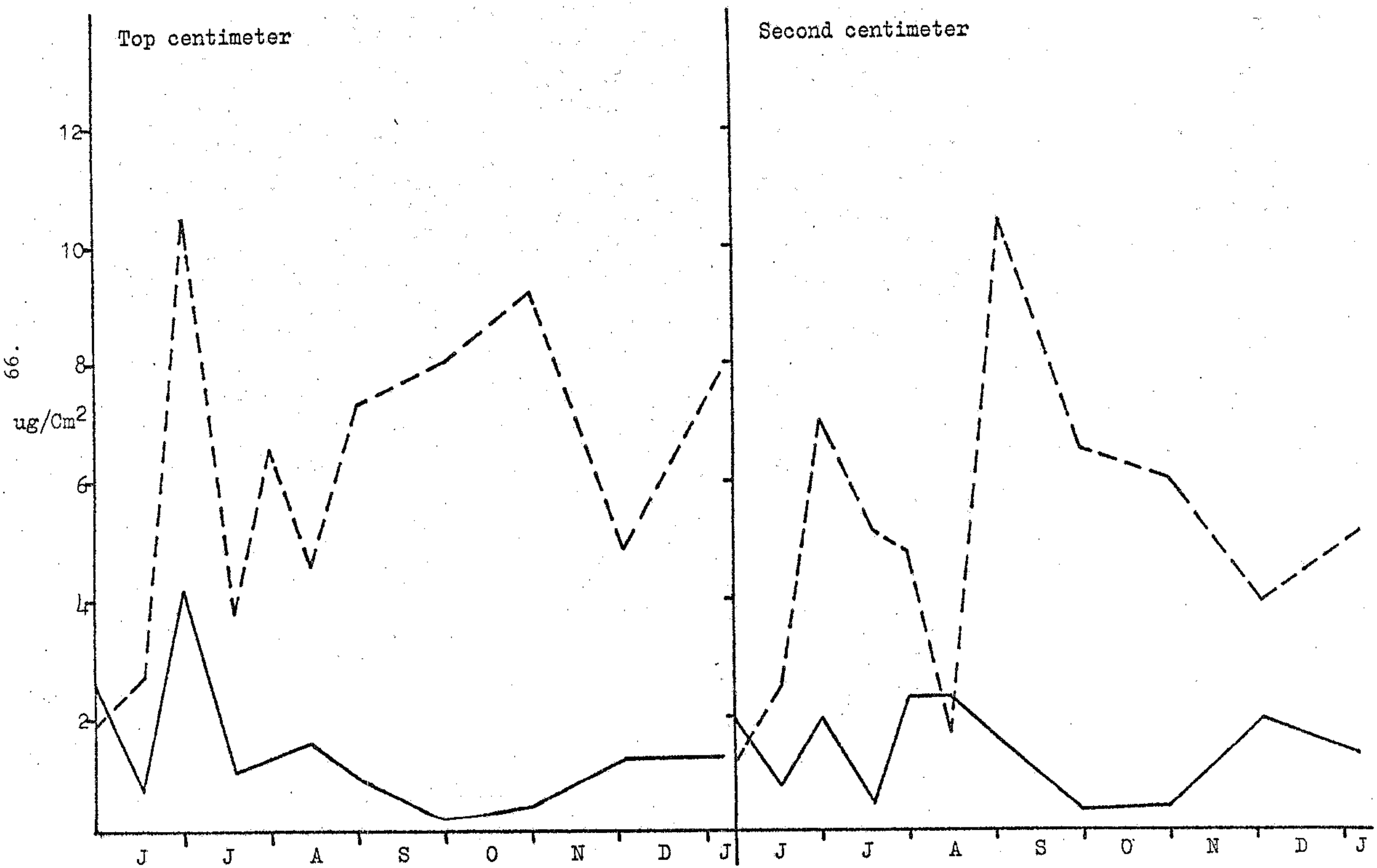


Figure 14. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in Zizania dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

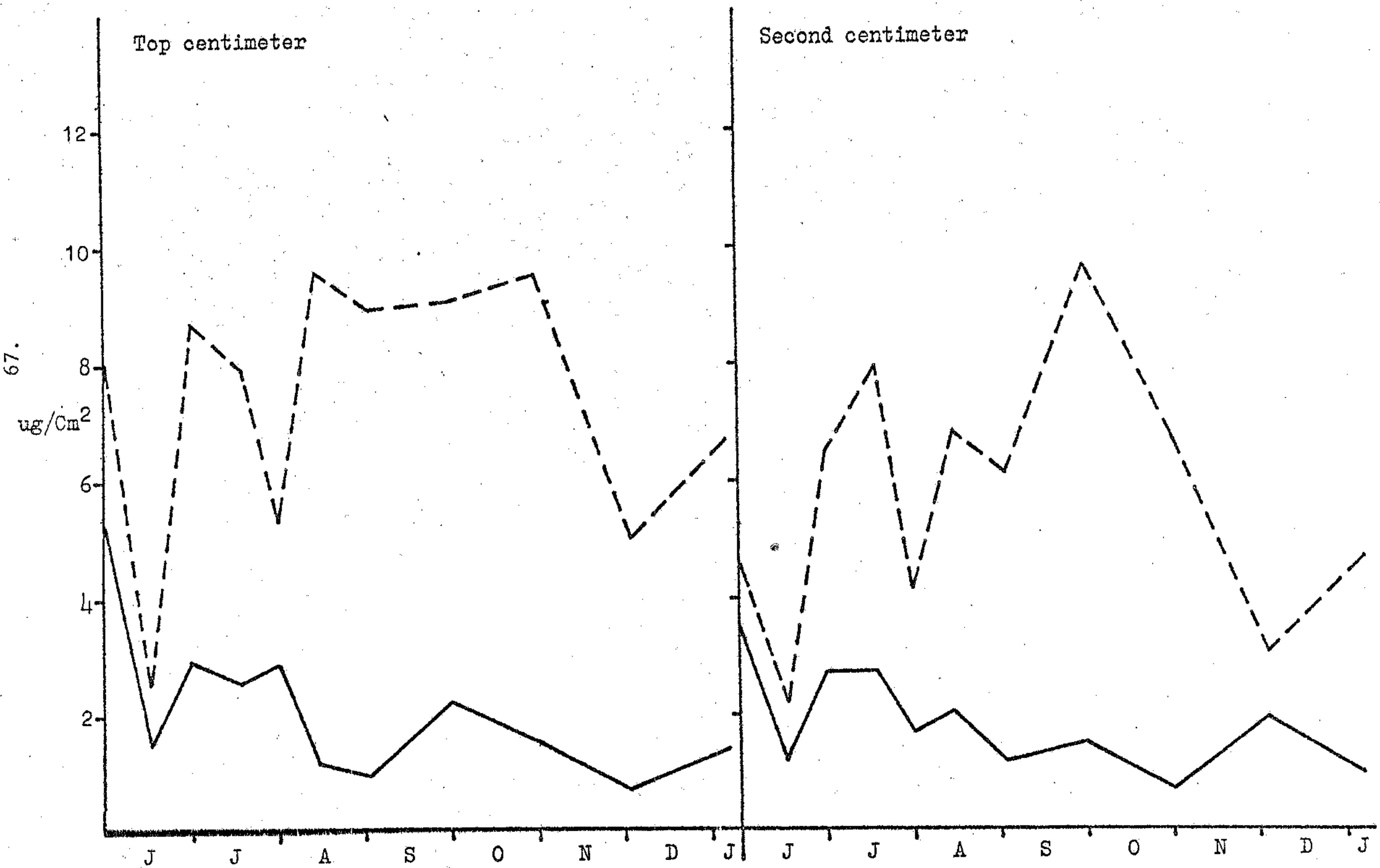


Figure 15. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in mixed vegetation dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

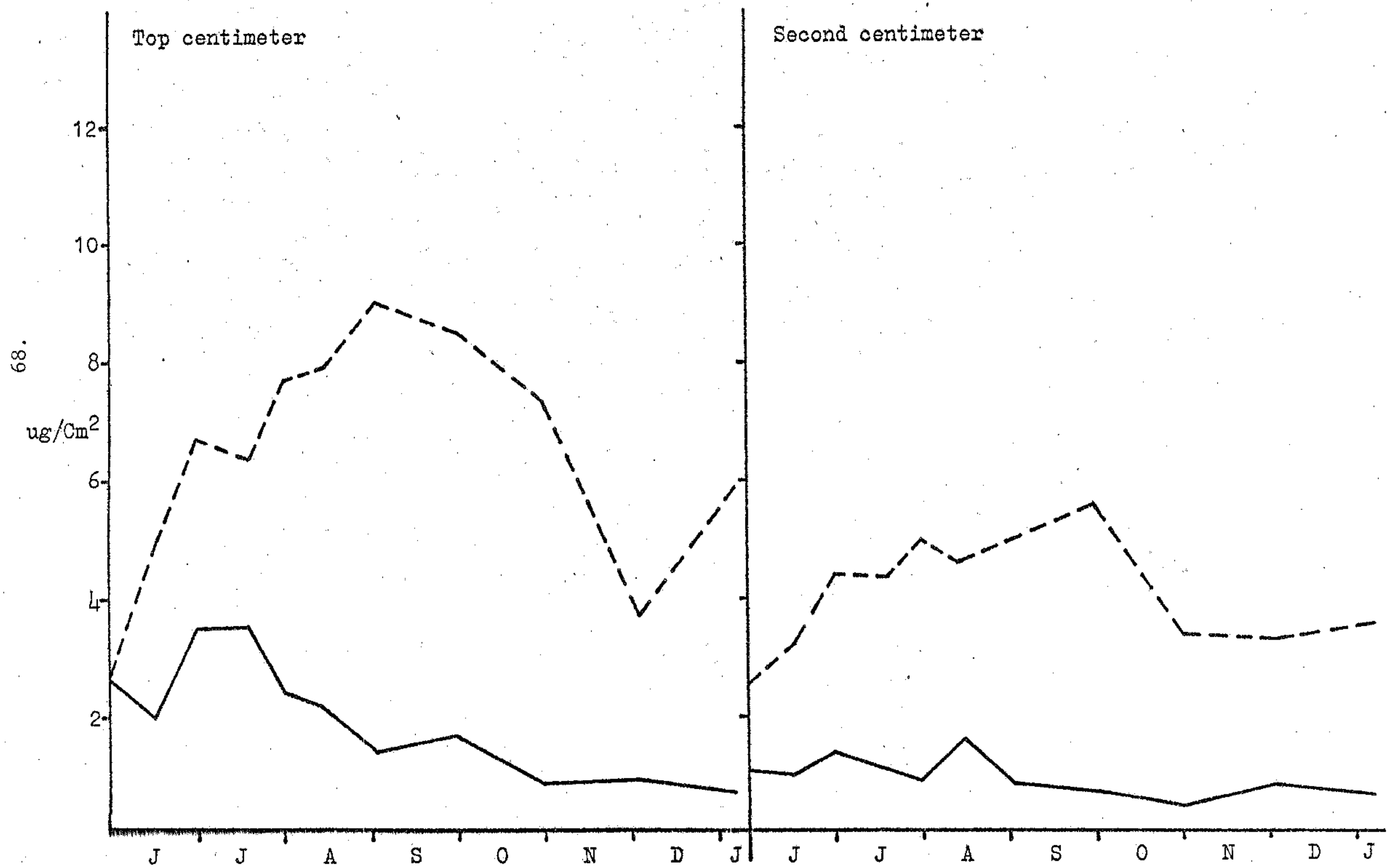


Figure 16. Changes in chlorophyll a and phaeophytin in the first and second centimeters of marsh soil in <u>Lythrum</u> dominated areas from June 1974 through January 1975. The solid line represents chlorophyll a and the dashed line represents phaeophytin.

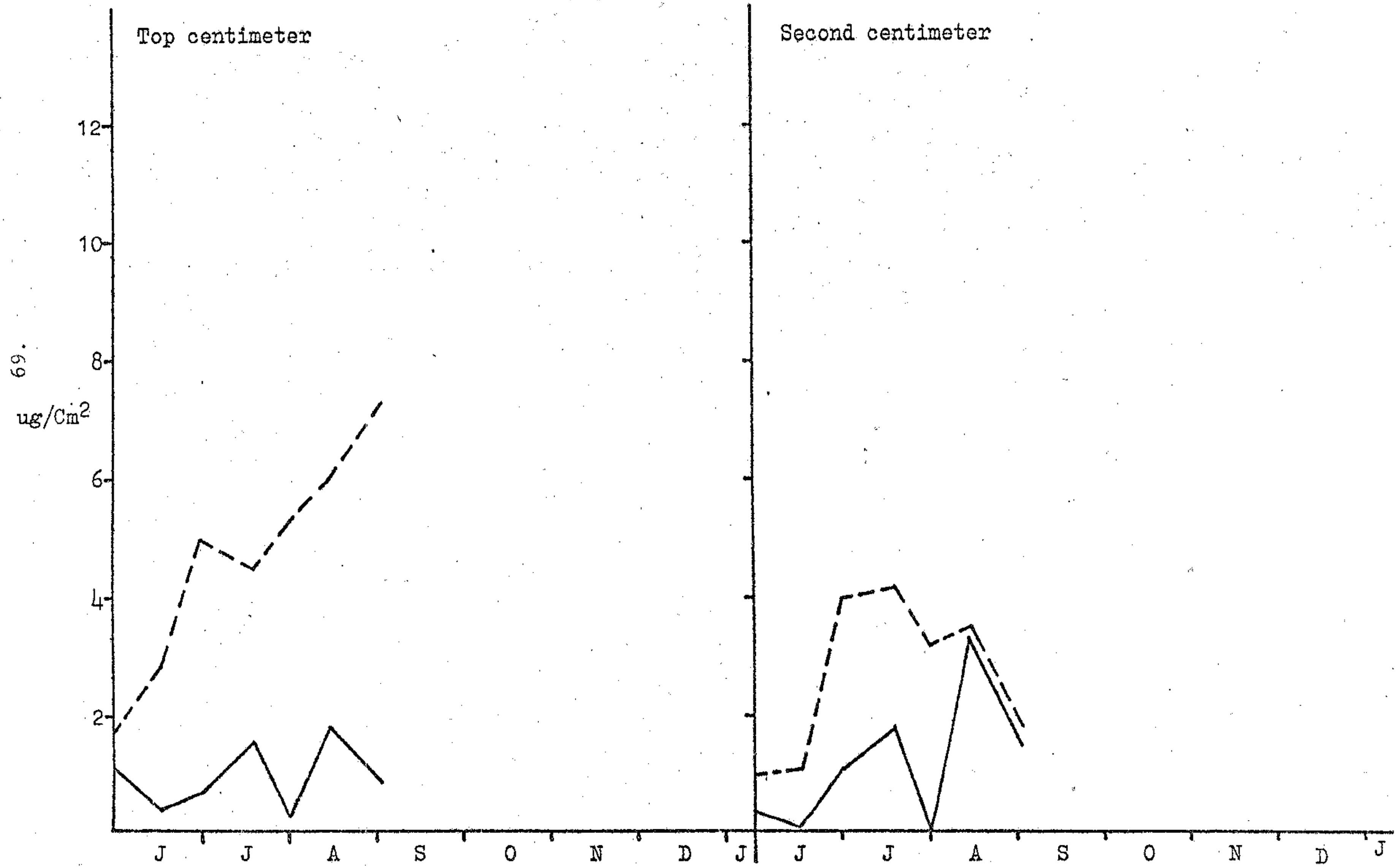
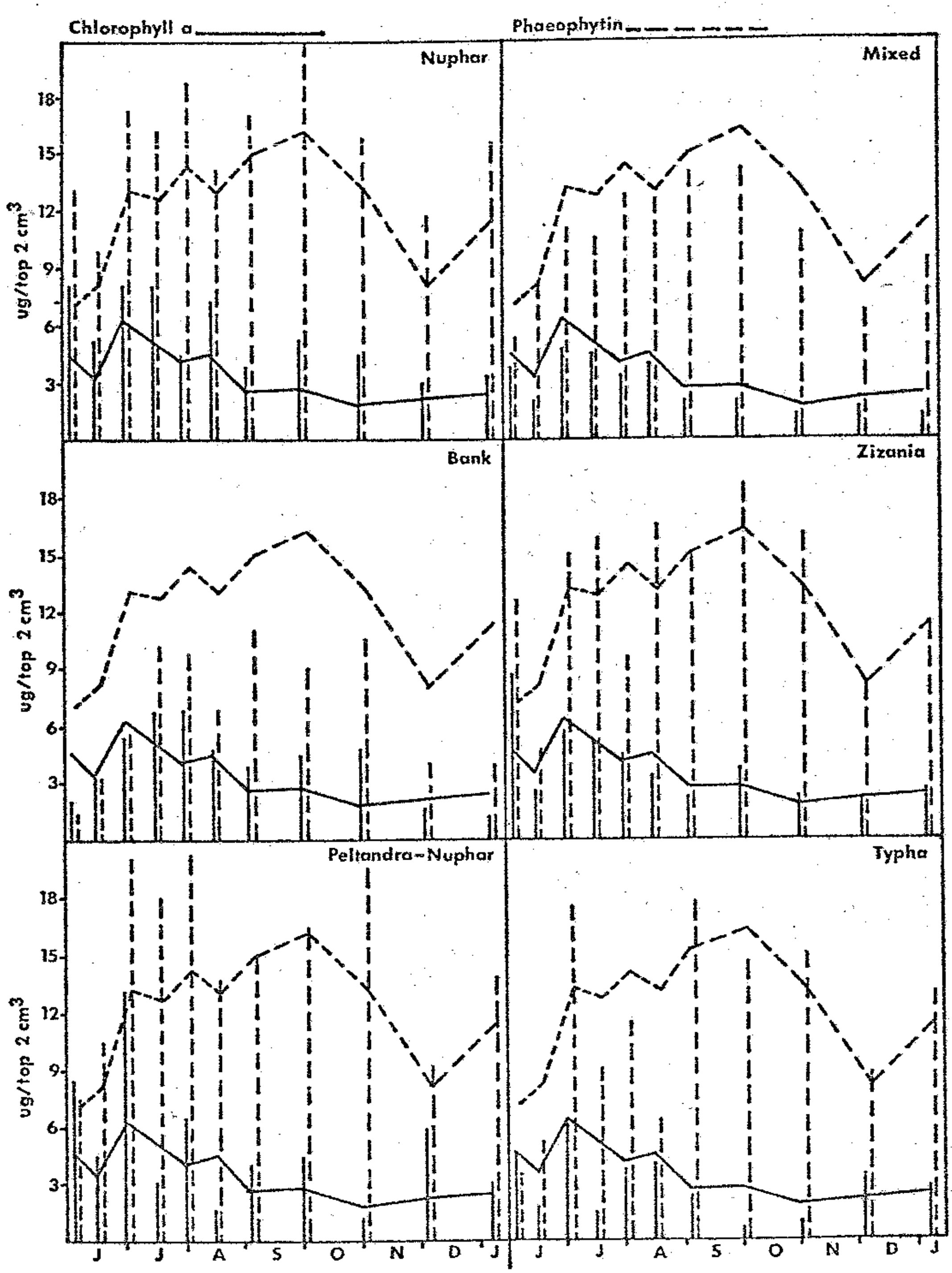


Figure 17. Changes in chlorophyll a and phaeophytin concentrations in the top two centimeters of the marsh soil from June, 1974 through January 1975. Vertical lines represent values for each dominant vegetation type sampled. Horizontal lines give mean chlorophyll a and phaeophytin values for the entire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



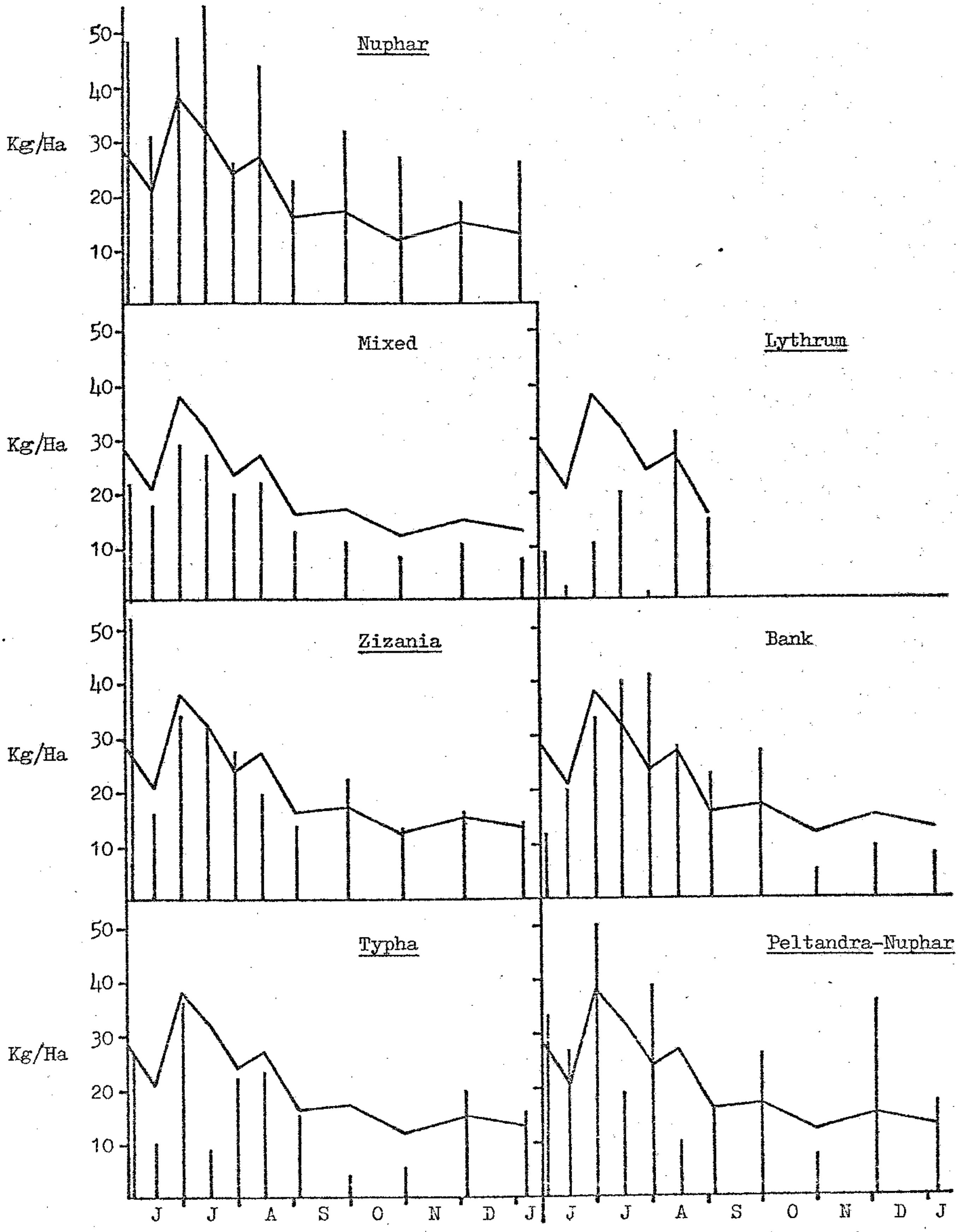
Chlorophyll a
Phaeophytin
Nuphar
Mixed
Bank
Zizania
Peltandra-Nuphar
Typha
ug/top 2 cm3
18
15
12
9
6
3
J
J
A
S
O
N
D
J

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

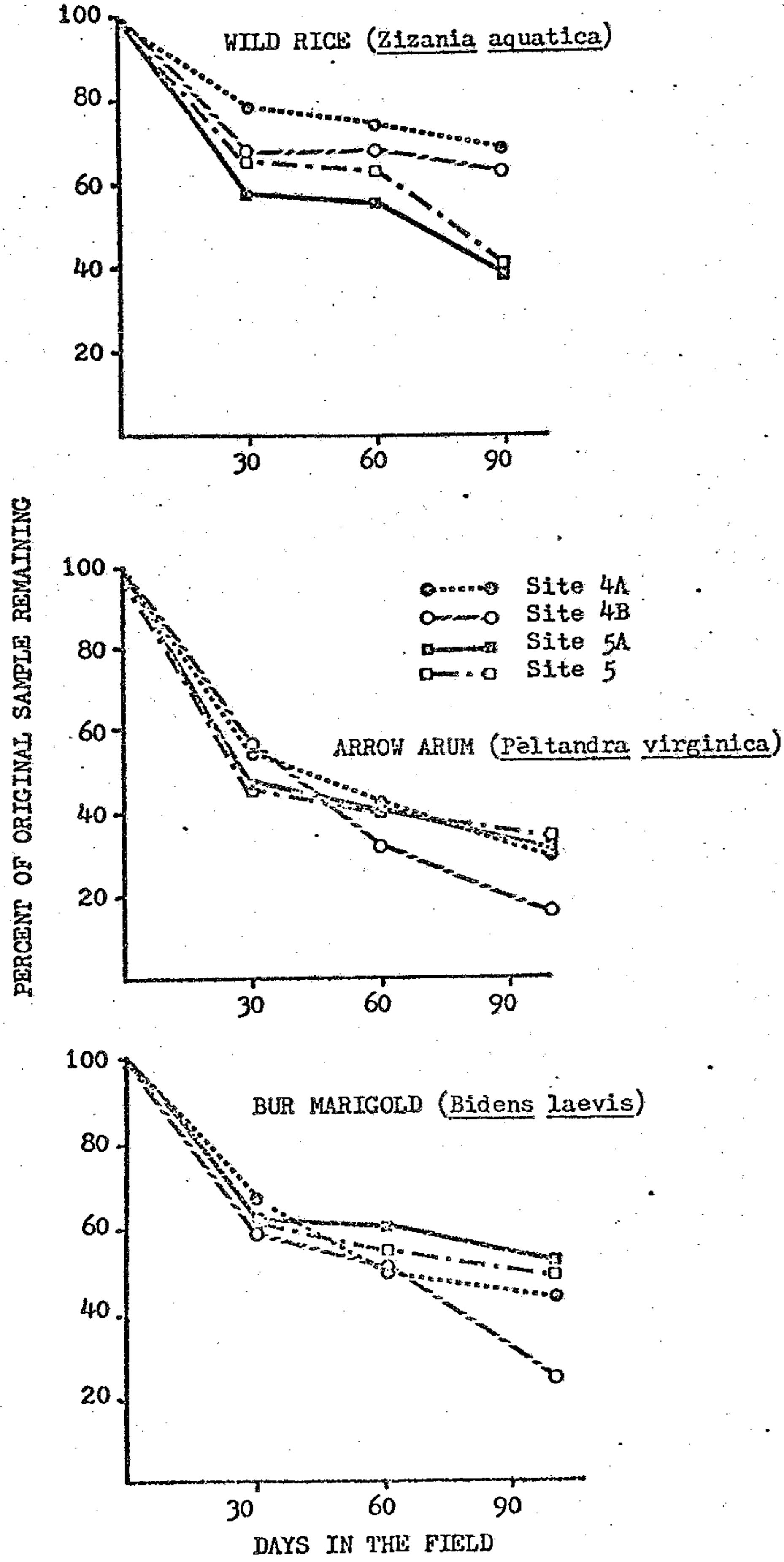
Decomposition is being measured by setting out nylon bags that contain measured amounts of dried plant material. The bags are collected monthly and the amount of material remaining is determined. We are studying decomposition rates of three species. Wild rice is an example of a dominant annual species 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)
100
80
60
40
20
30
60
90
PERCENT OF ORIGINAL SAMPLE REMAINING
Site 4A
Site 4B
Site 5A
Site 5
ARROW ARUM (Peltandra virginica)
100
80
60
40
20
30
60
90
BUR MARIGOLD (Bidens laevis)
100
80
60
40
20
30
60
90
DAYS IN THE FIELD

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.

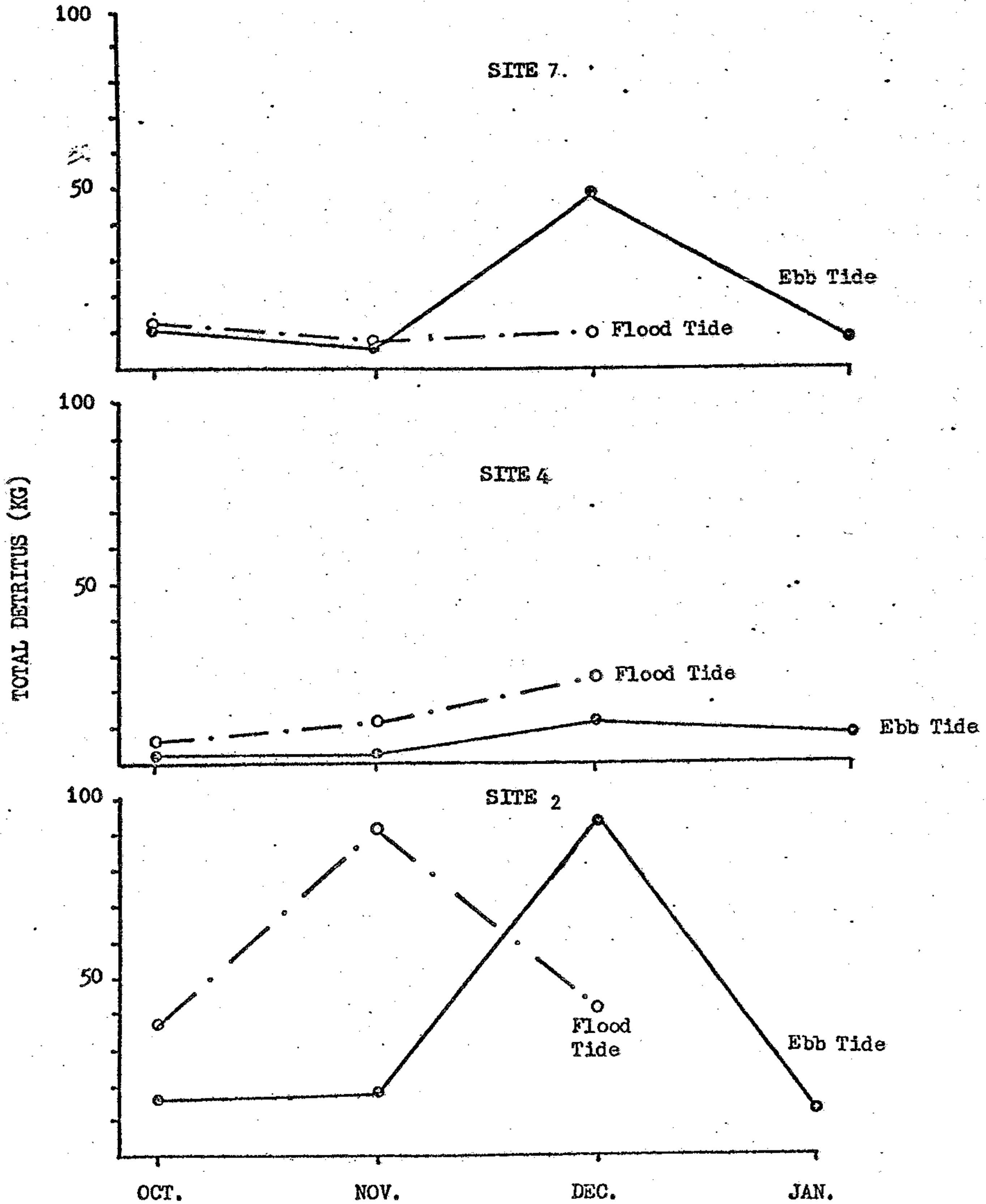
RESULTS

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
TOTAL DETRITUS (KG)
50
Flood Tide
Ebb Tide
100
SITE 2
50
Flood
Tide
Ebb Tide
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.

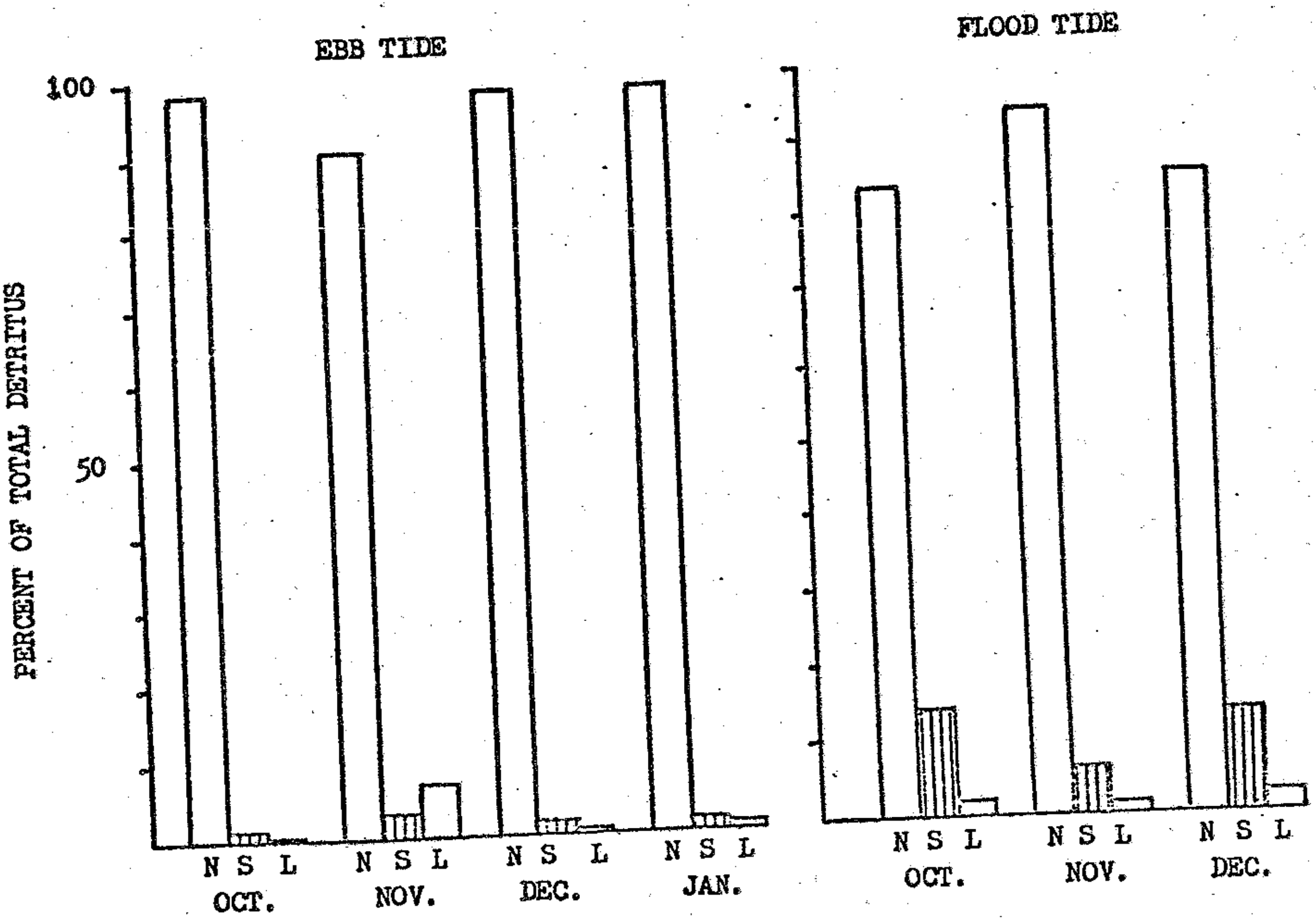
No conclusion can be made concerning the yearly balance of material moving into and out of the marsh, but if the present trend continues, it appears that much of the decomposing litter is mineralized in the marshes.

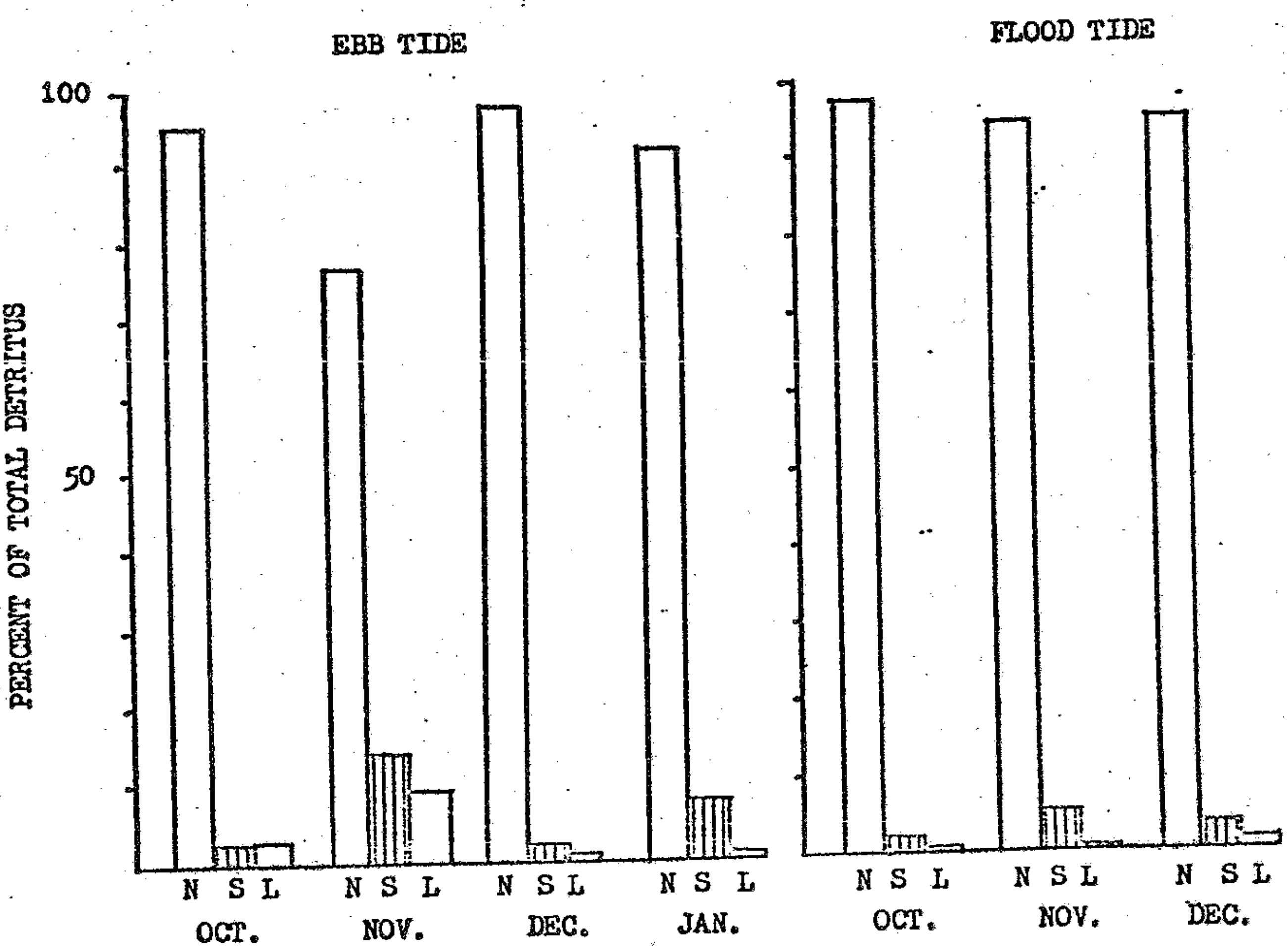
We also hesitate to draw conclusions until we compare the data on an ash-free basis. A portion of the suspended materials that we measure contains phytoplankton and zooplankton and inorganic sediment. We especially need to know how much of the detritus is in the inorganic fraction. We are presently working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

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

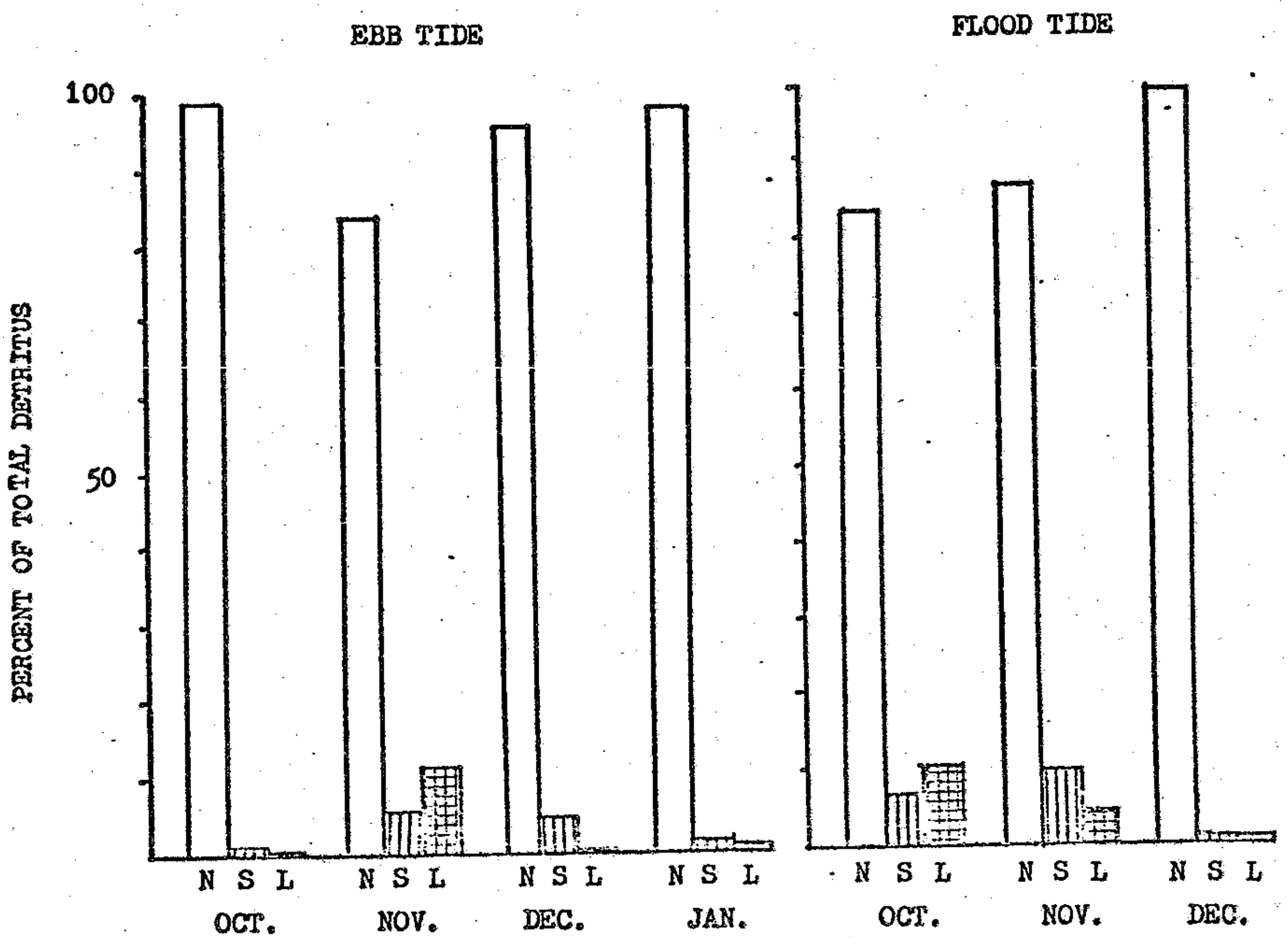
The size fractions are:

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


EBB TIDE
FLOOD TIDE
PERCENT OF TOTAL DETRITUS
100
50
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.


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

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.

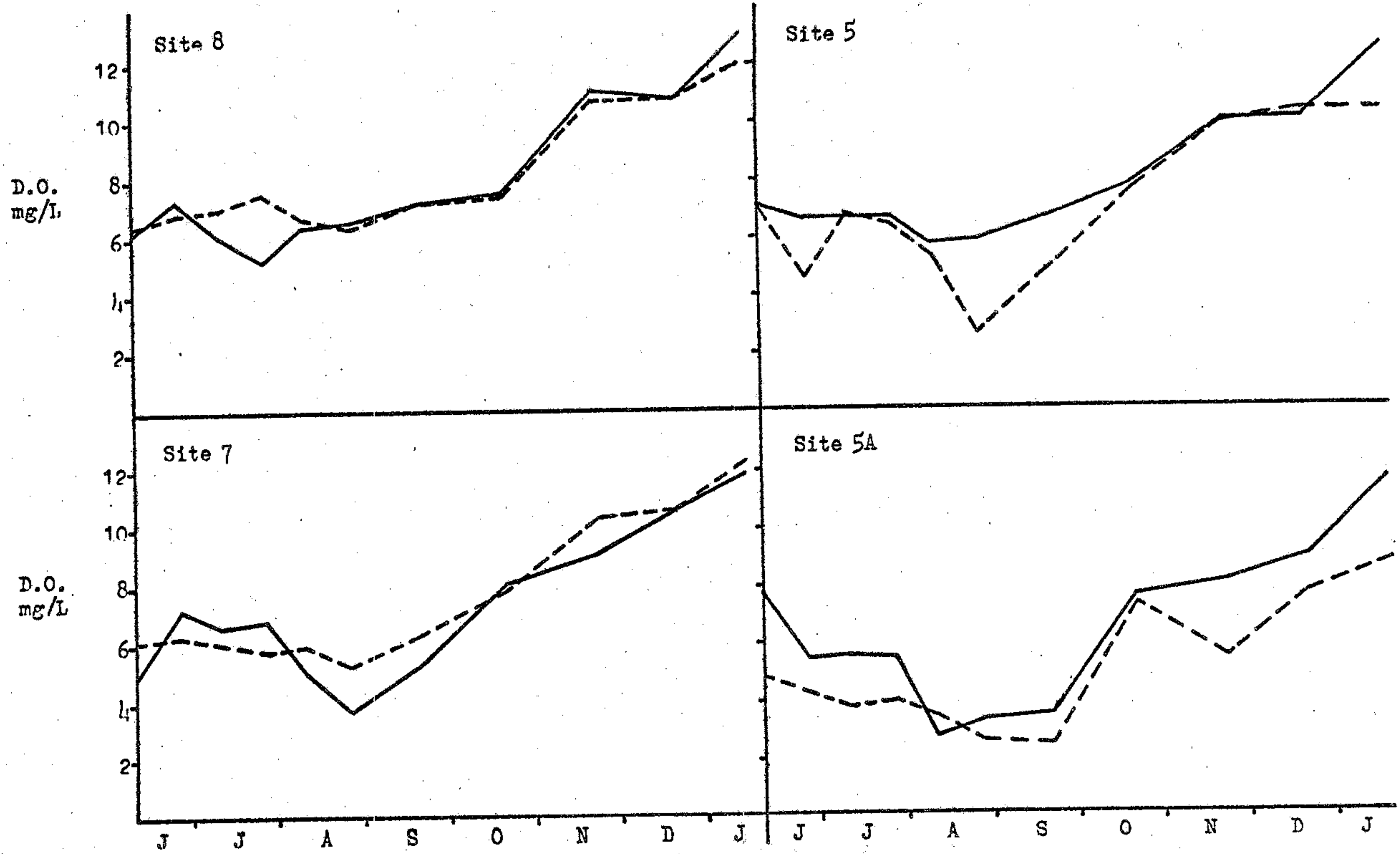


Figure 25. Changes in dissolved oxygen from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

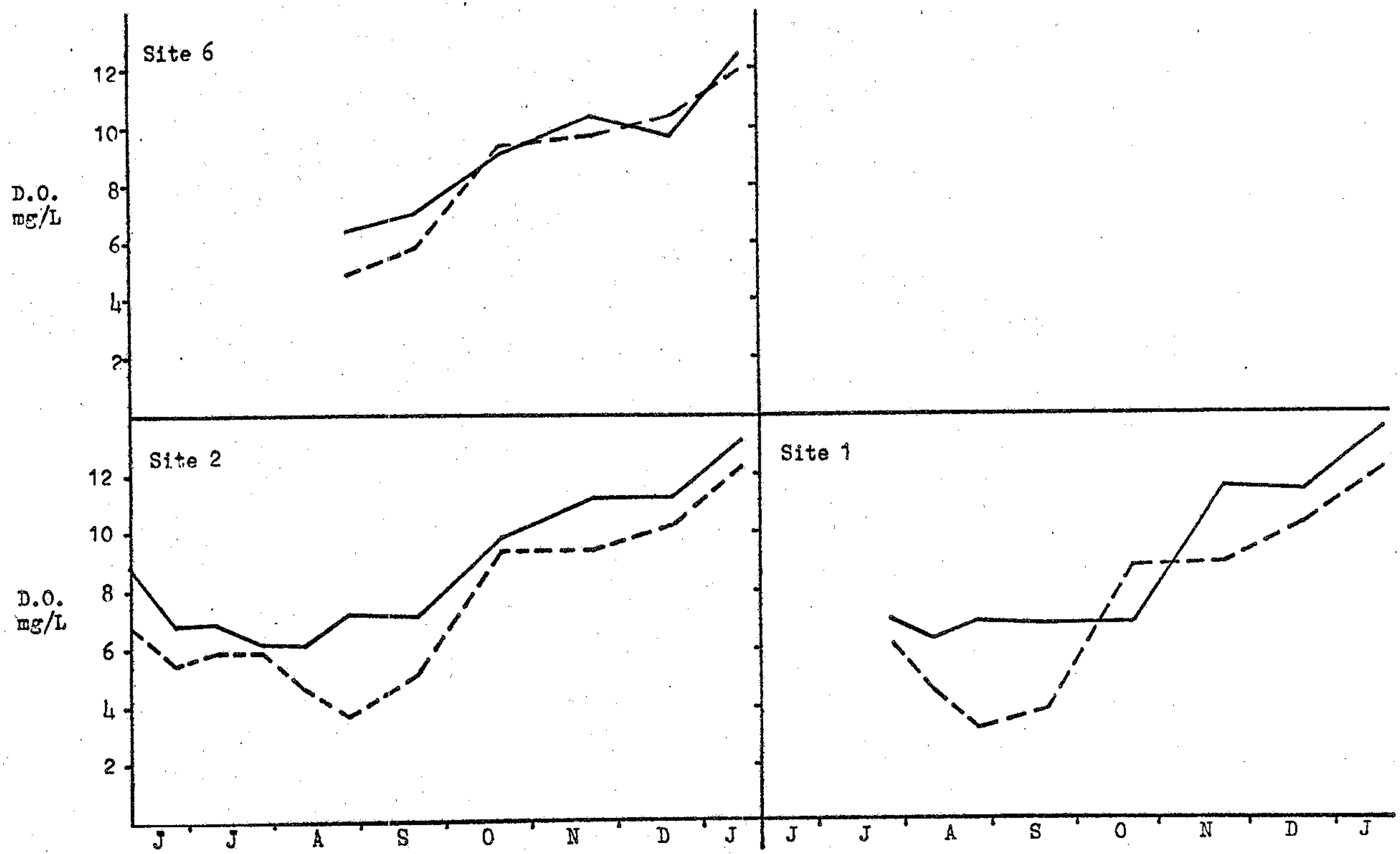
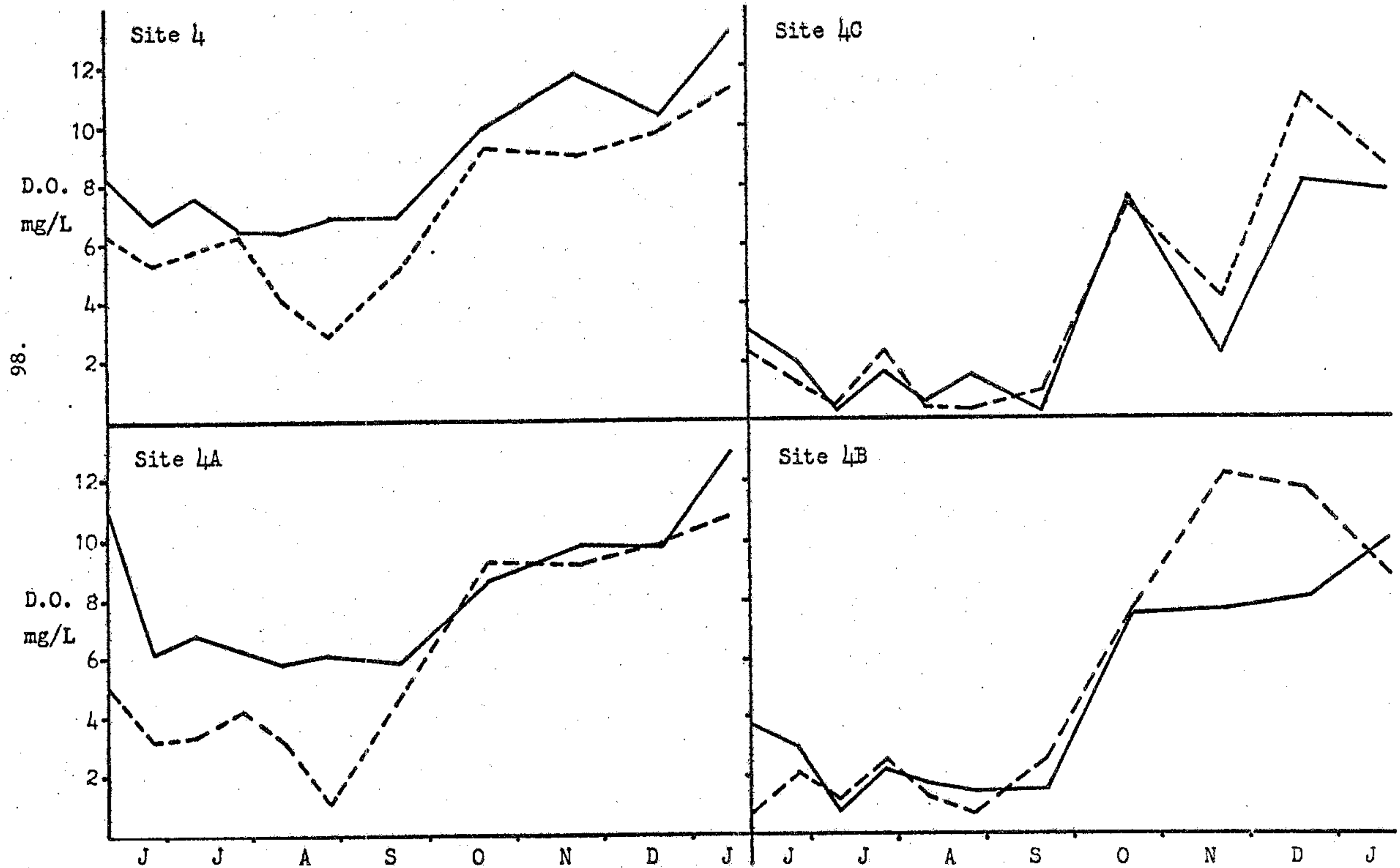


Figure 26. Changes in dissolved oxygen from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



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.

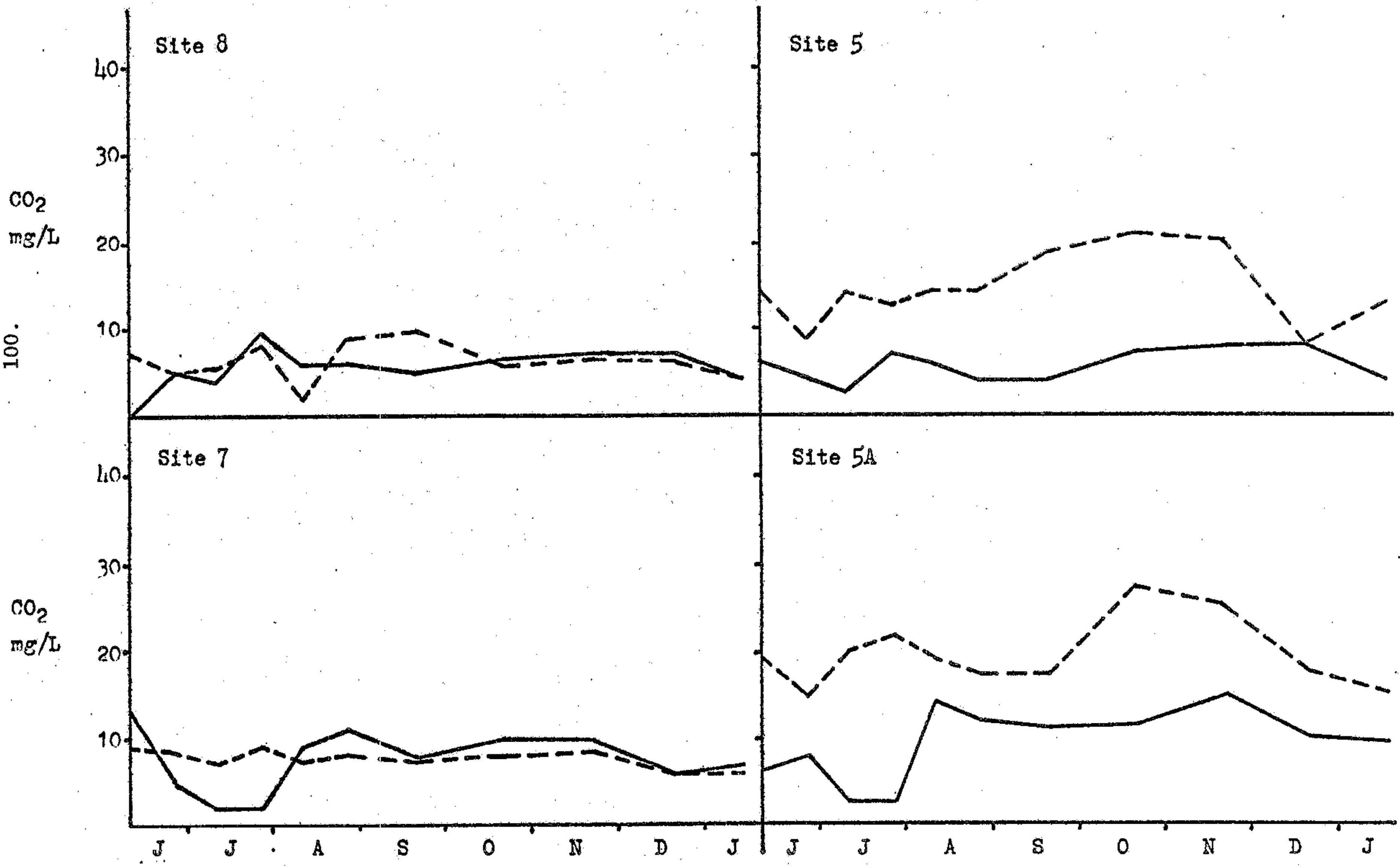


Figure 28. Changes in carbon dioxide from June 1974 through January 1975 at 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

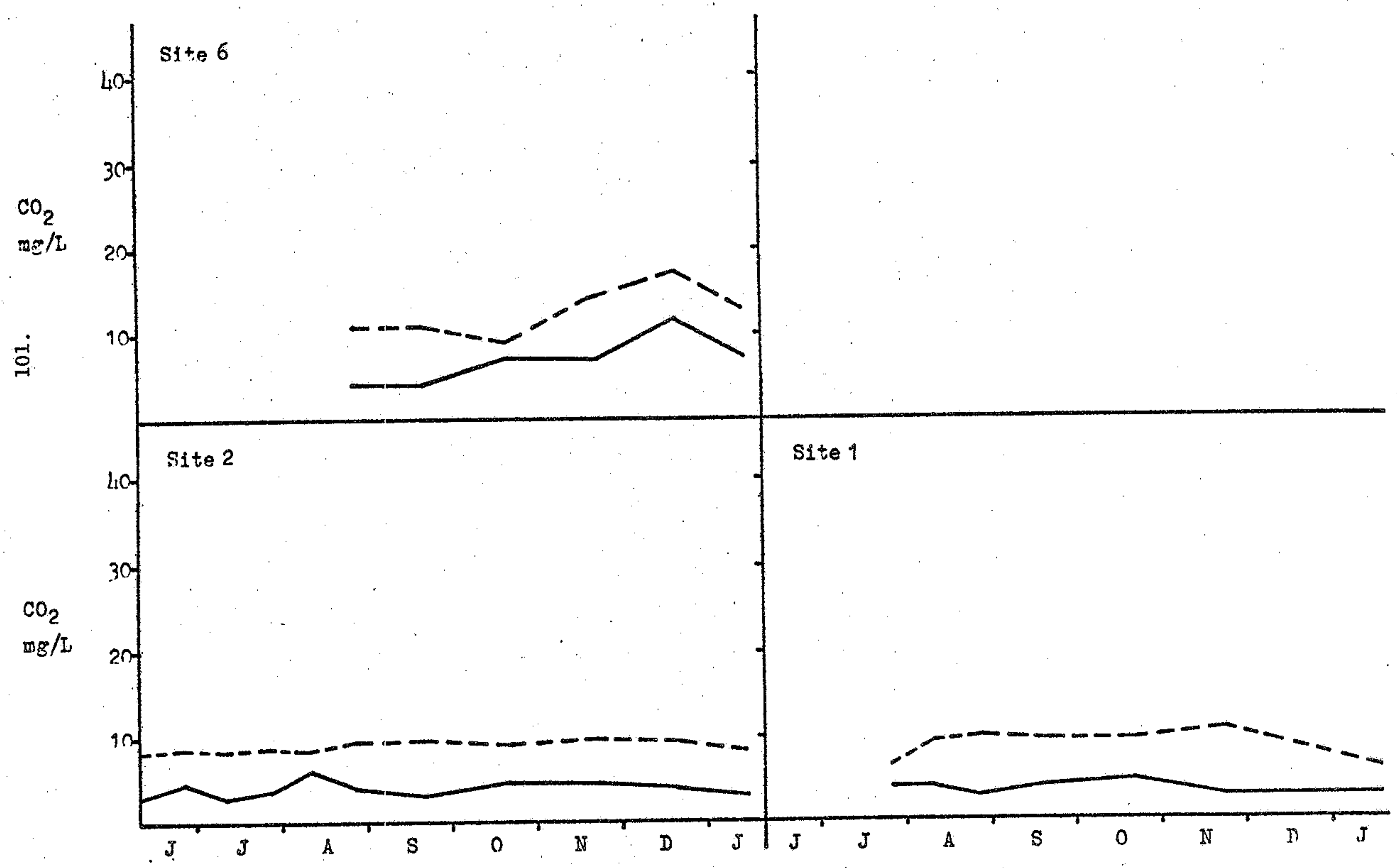
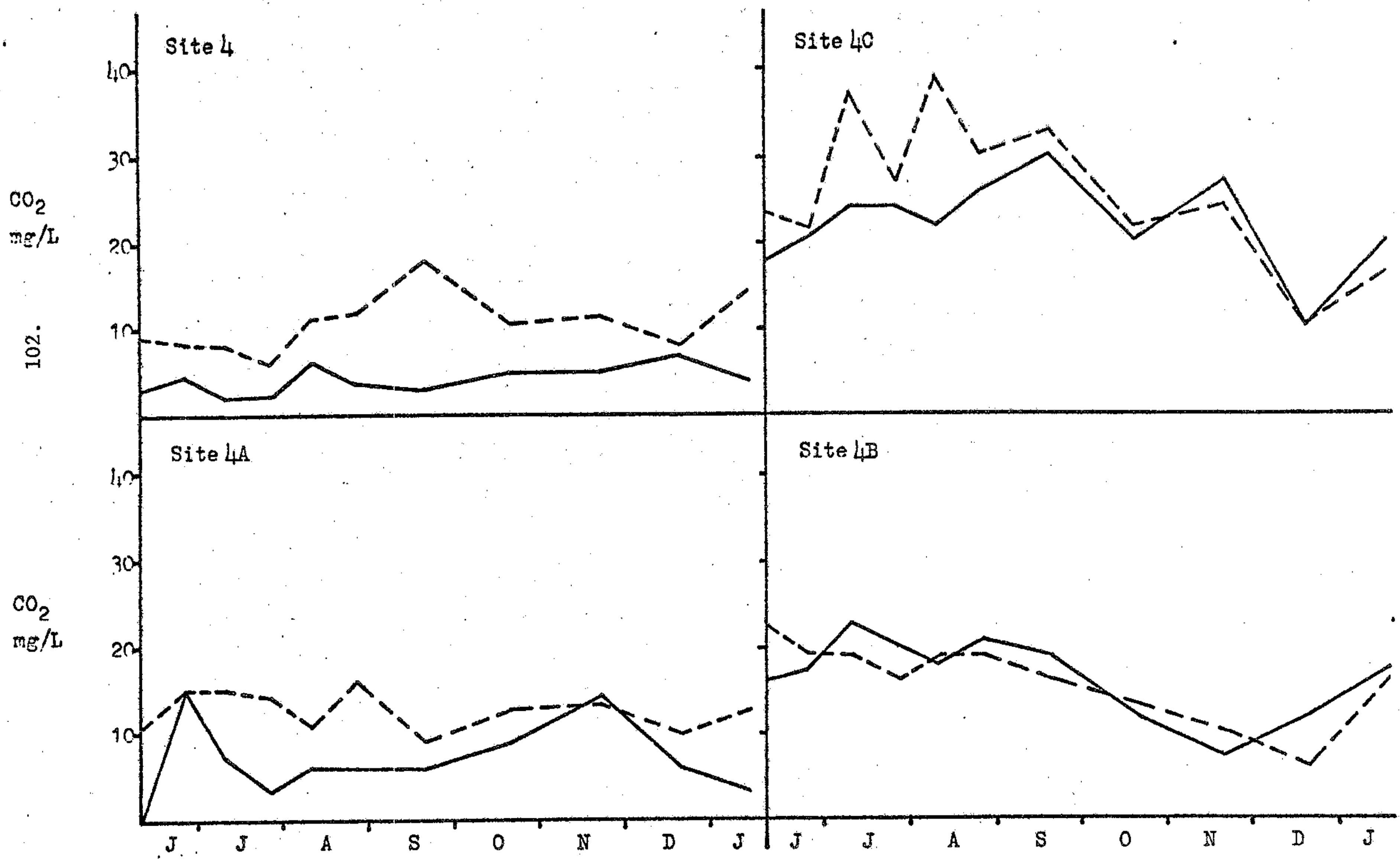


Figure 29. Changes in carbon dioxide from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



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 Rhizoclomium that develops after the rooted plants dieback and at Site 4C it is due to blooms of diatoms and Spirogyra. 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.

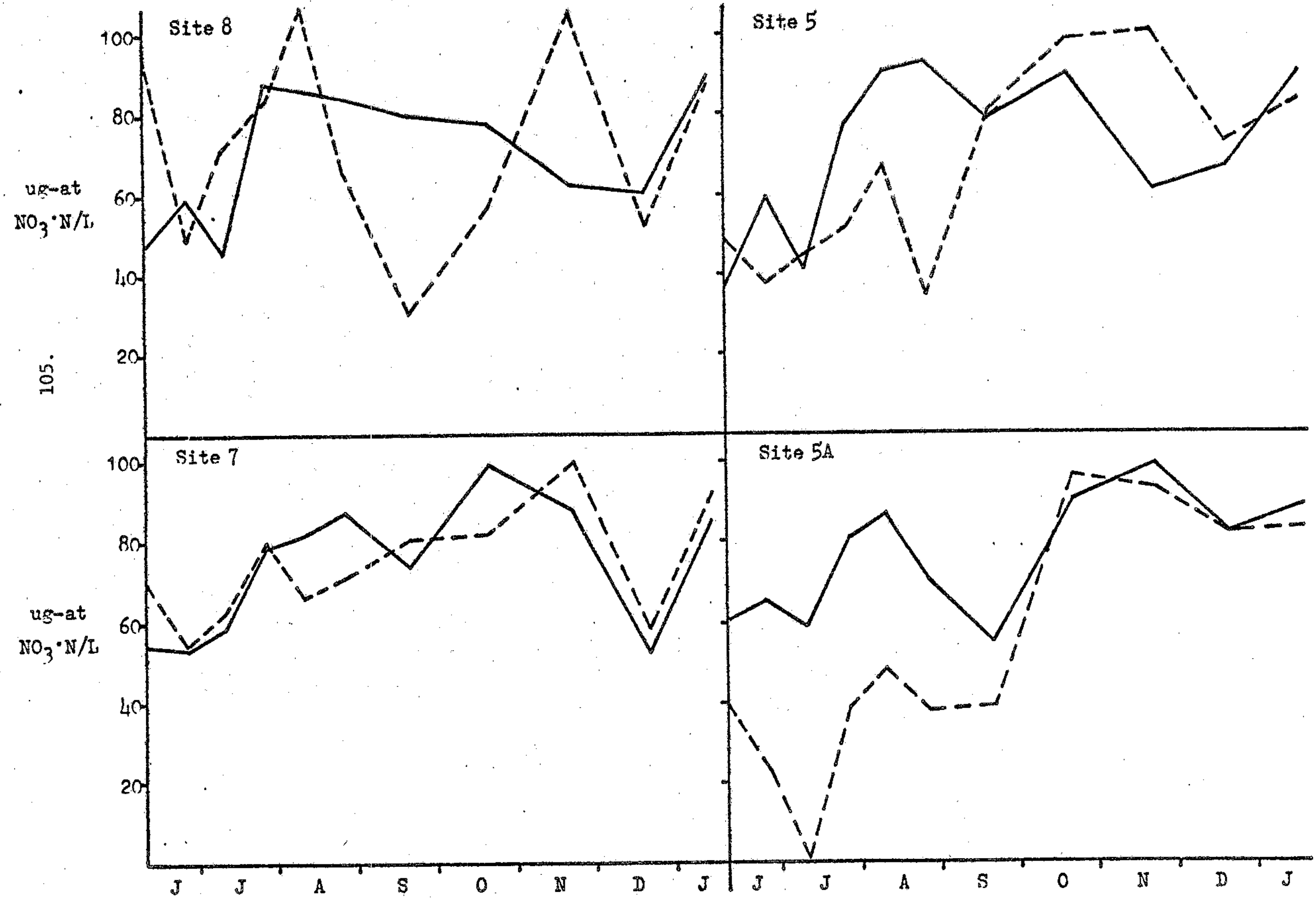
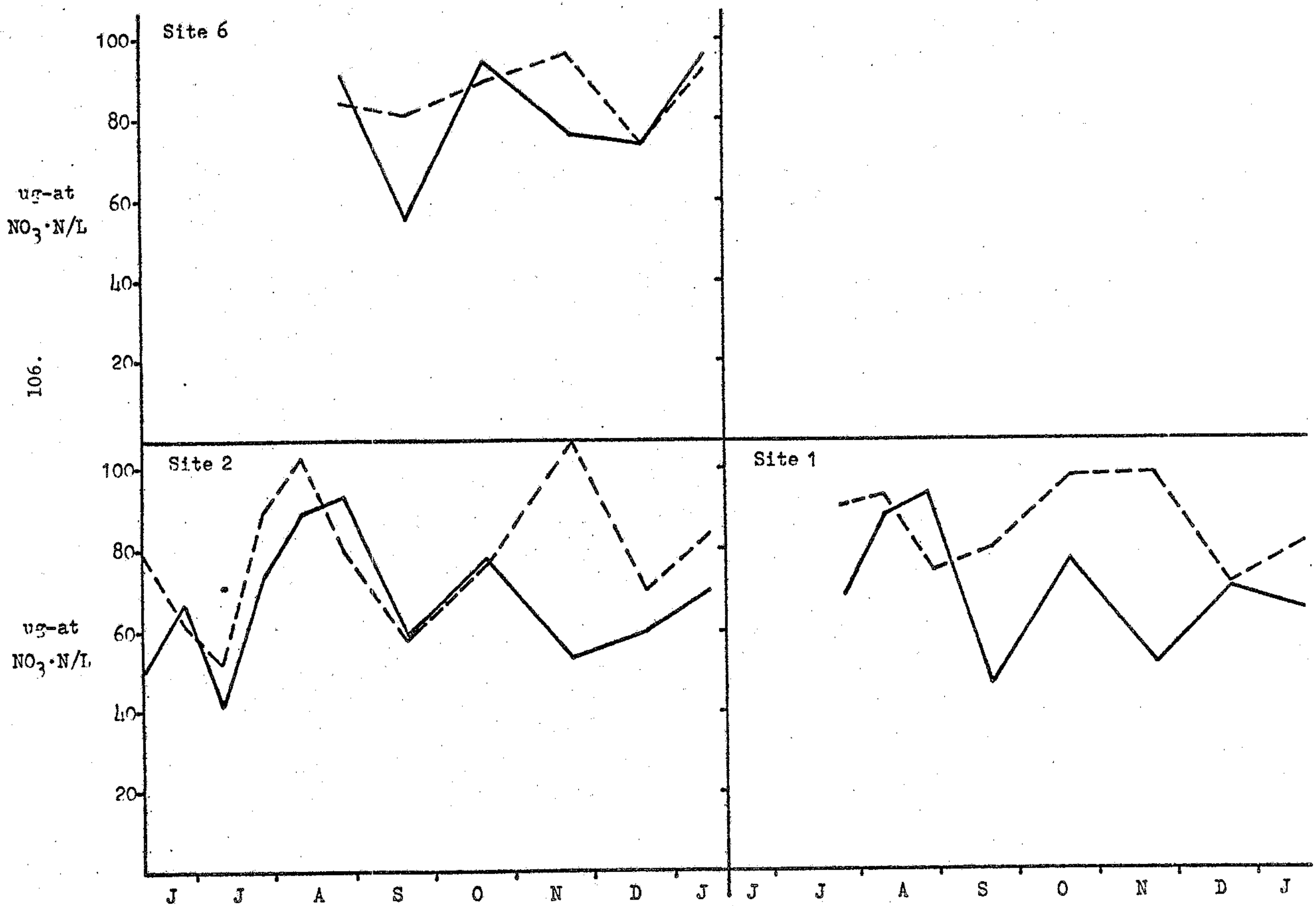


Figure 31. Changes in nitrate-nitrogen from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



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.

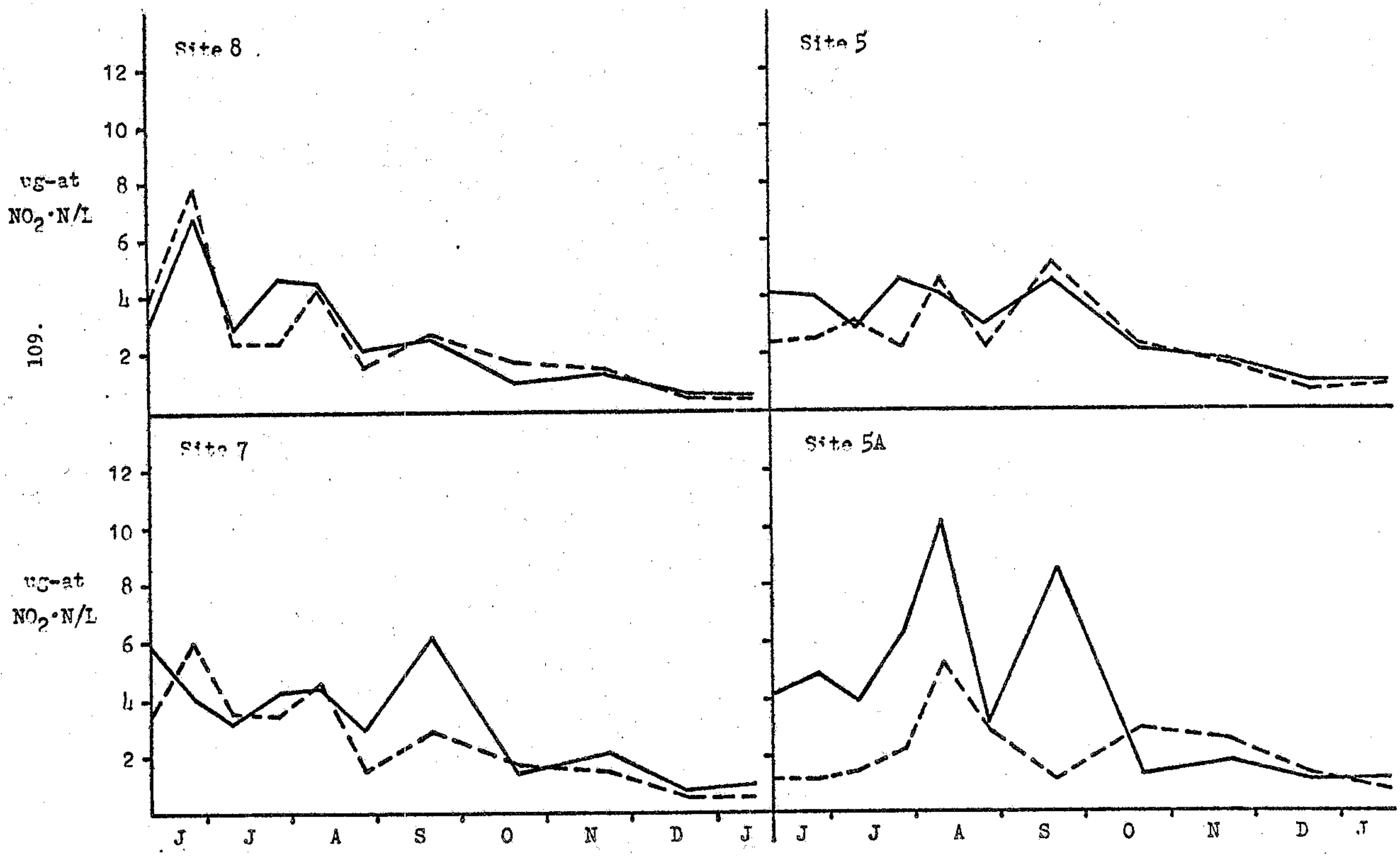


Figure 34. Changes in nitrite-nitrogen from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

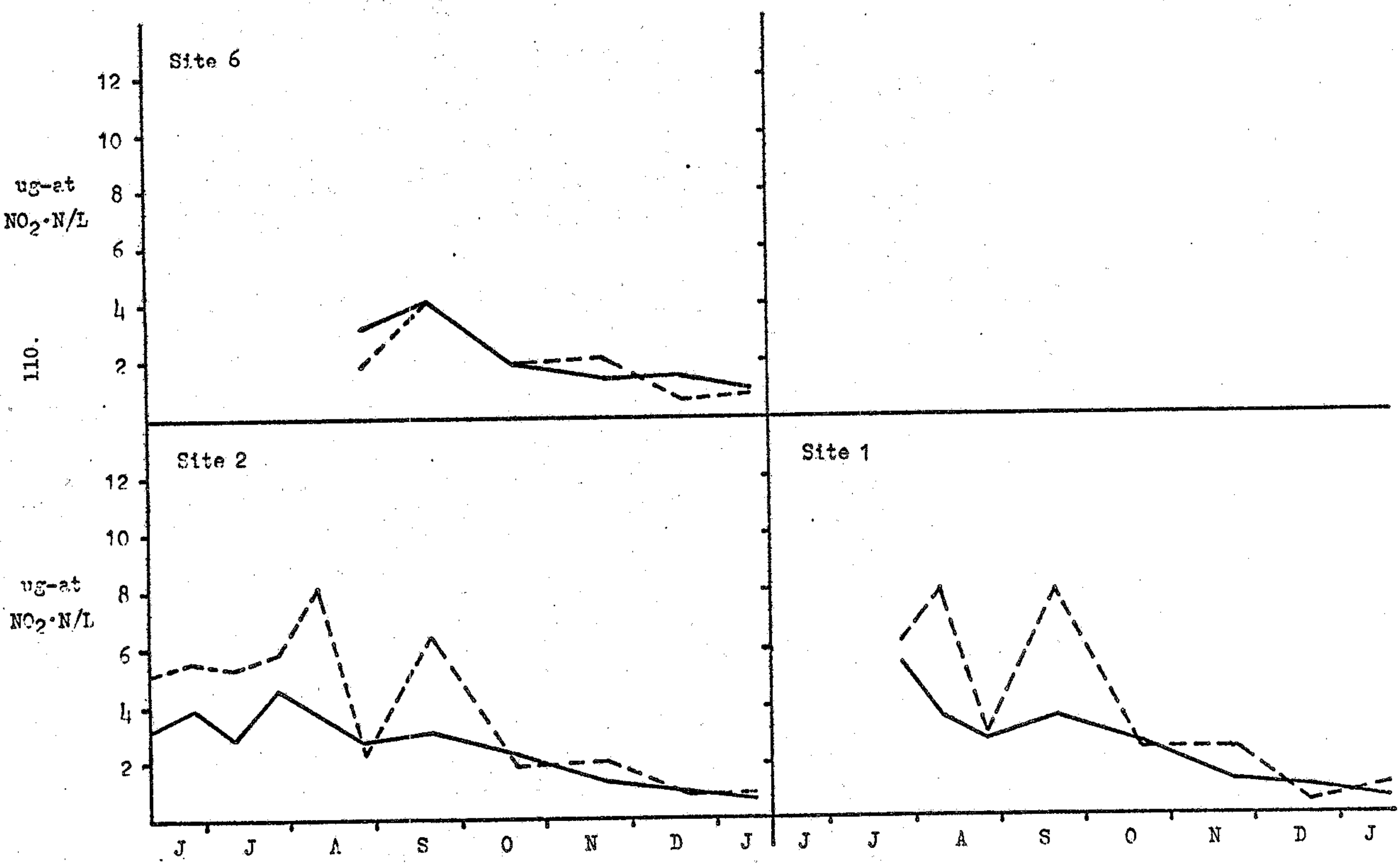


Figure 35. Changes in nitrite-nitrogen from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

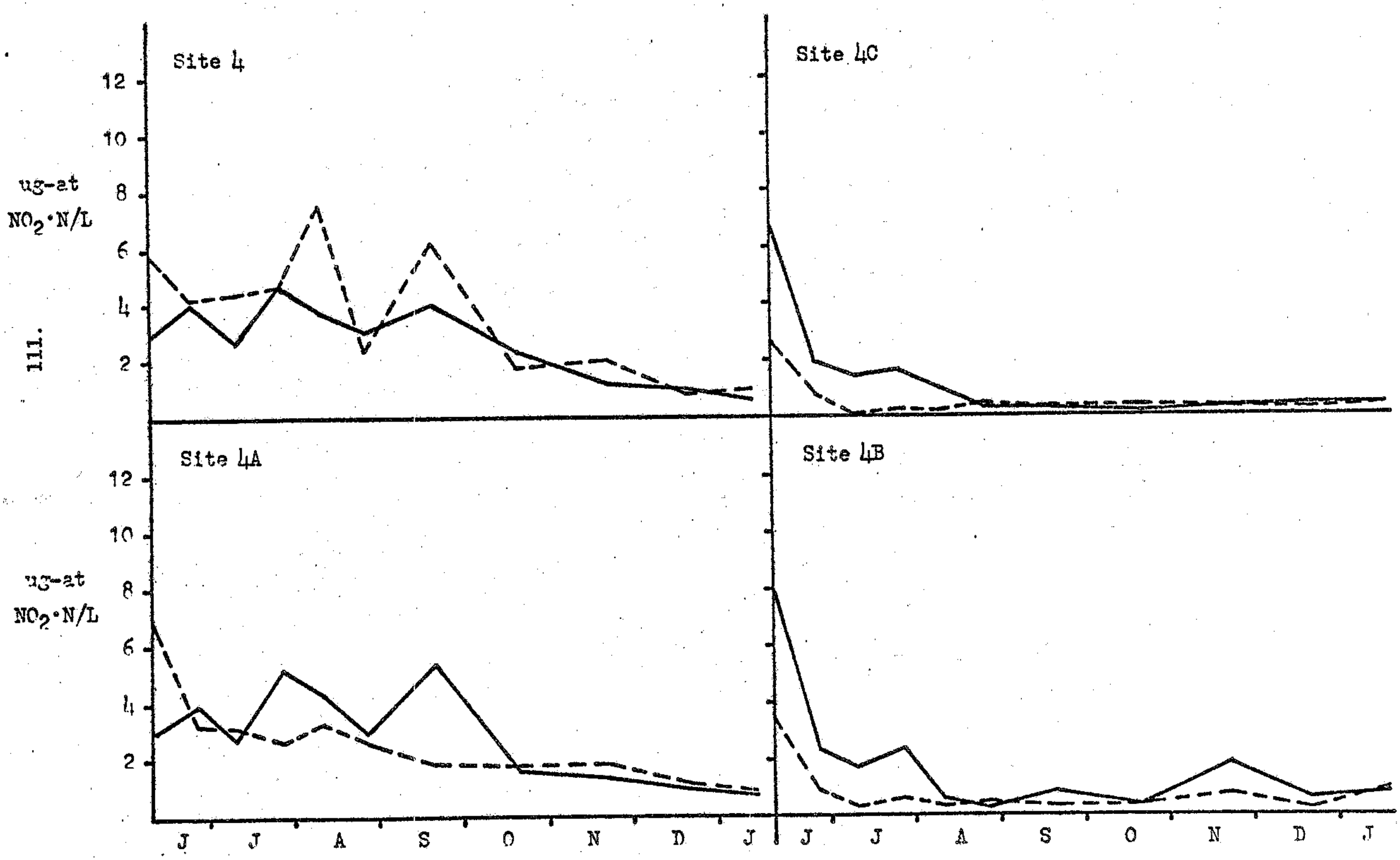


Figure 36. Changes in ammonia-nitrogen (plus some amino-acid nitrogen) from June 1974 through January 1975 at Sites 5, 5A, 7, and 8. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

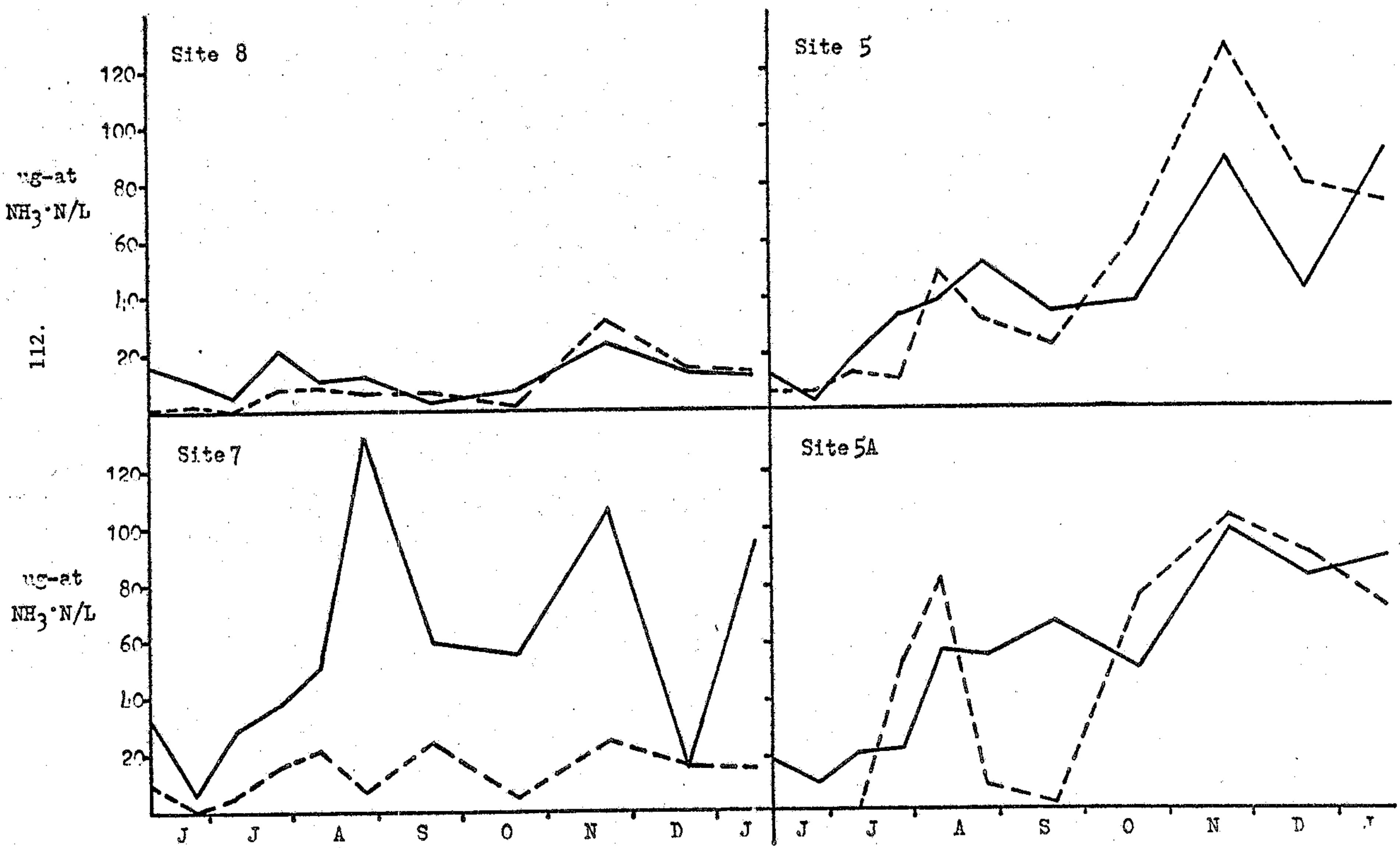


Figure 37. Changes in ammonia-nitrogen (plus some amino-acid nitrogen) from June 1974 through January 1975 at Sites 1, 2, and 6. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

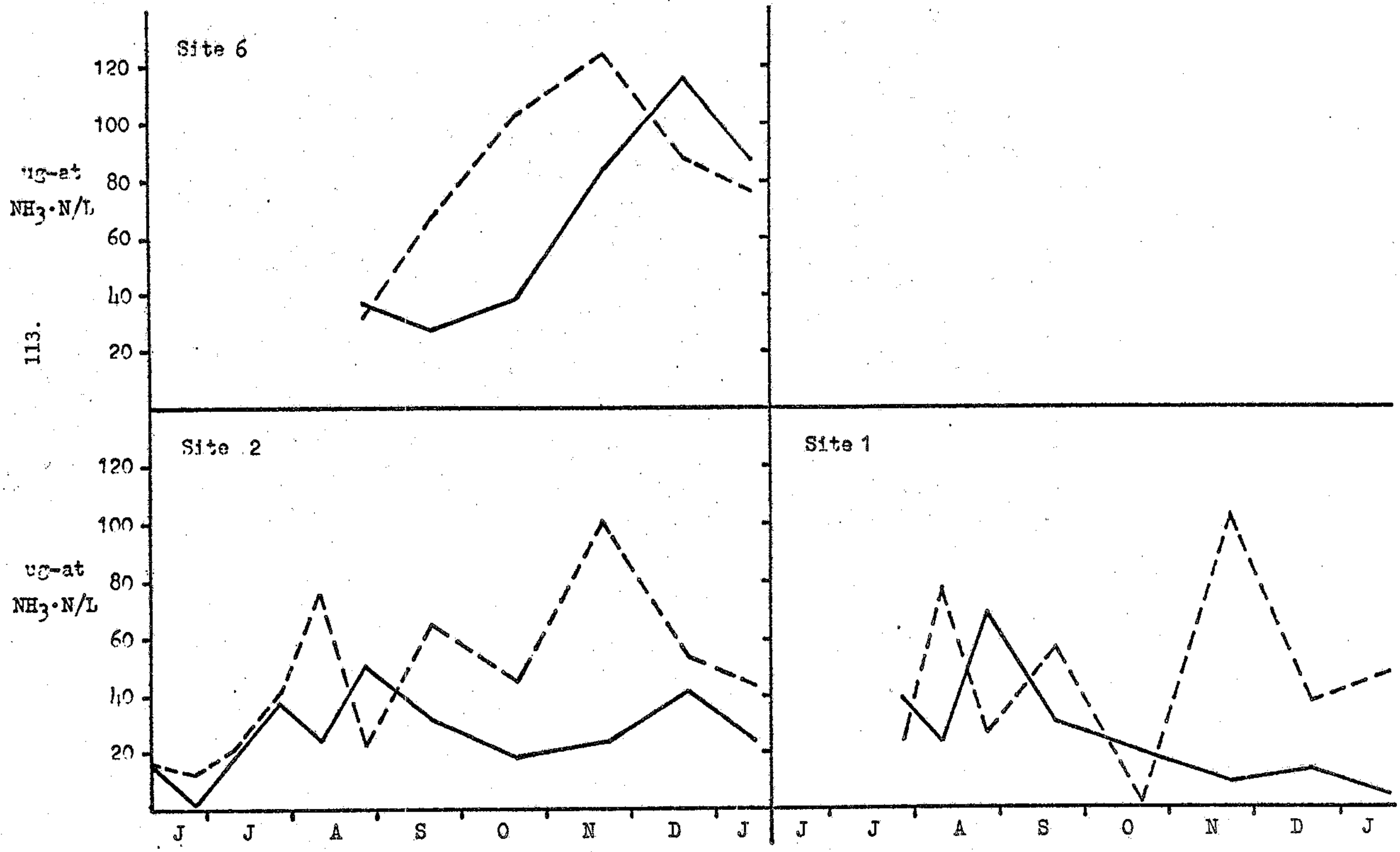
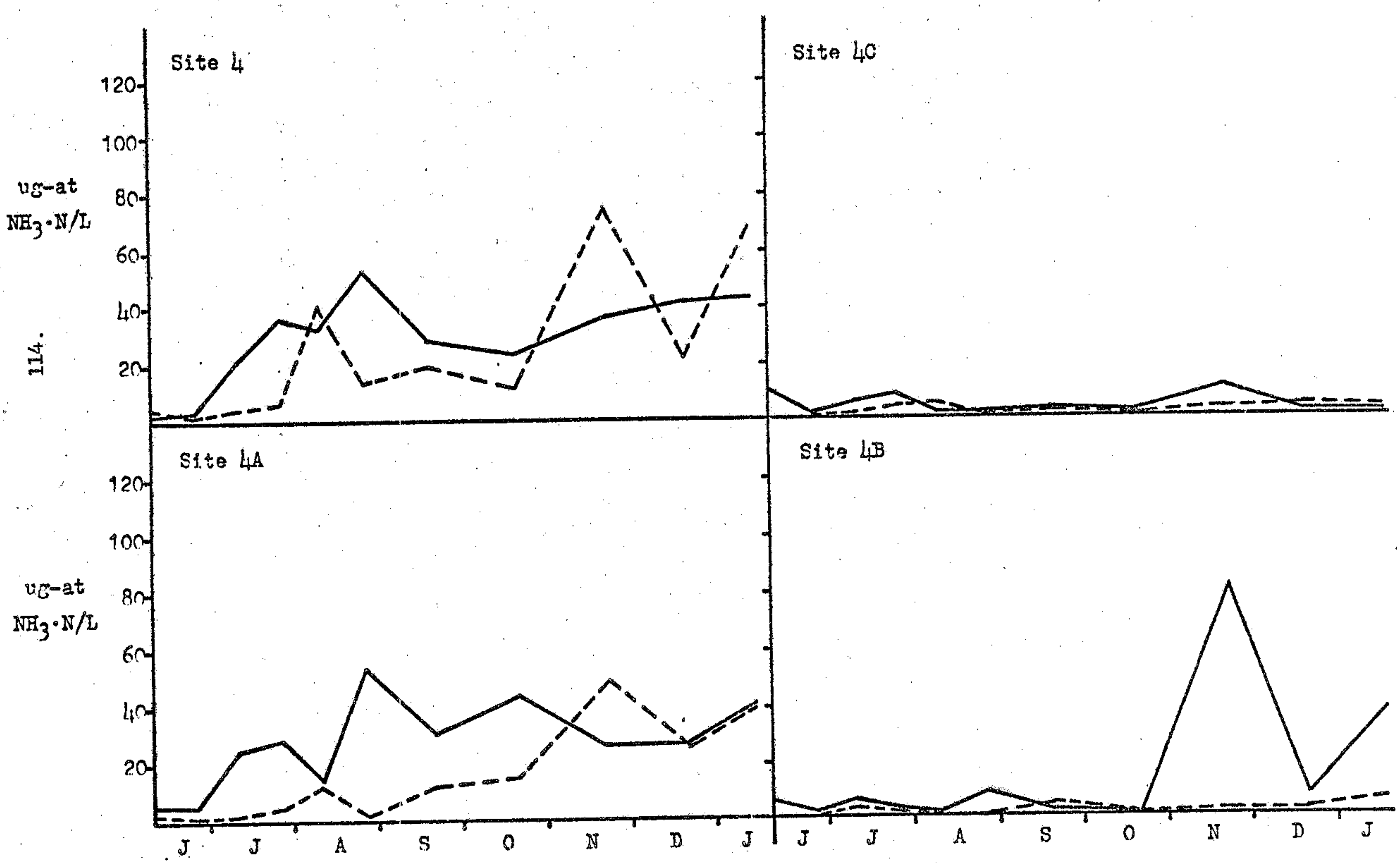


Figure 38. Changes in ammonia-nitrogen (plus some amino-acid nitrogen) from June 1974 through January 1975 at Sites 4, 4A, 4B, & 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.



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.

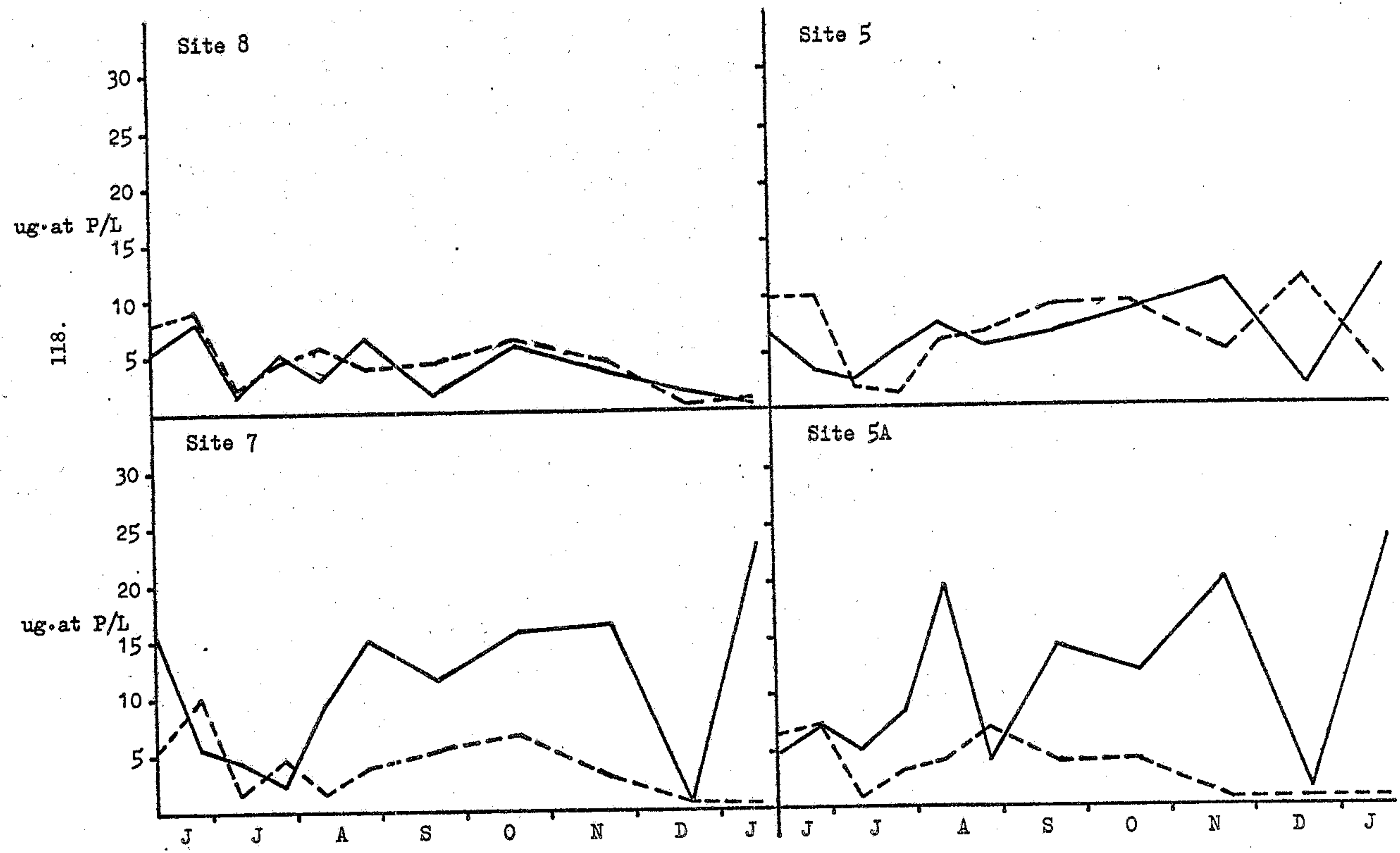


Figure 40. Changes in reactive phosphate from June 1974 through January 1975 at Sites 4, 4A, 4B, and 4C. Solid lines represent morning high tide values and dashed lines represent afternoon low tide values.

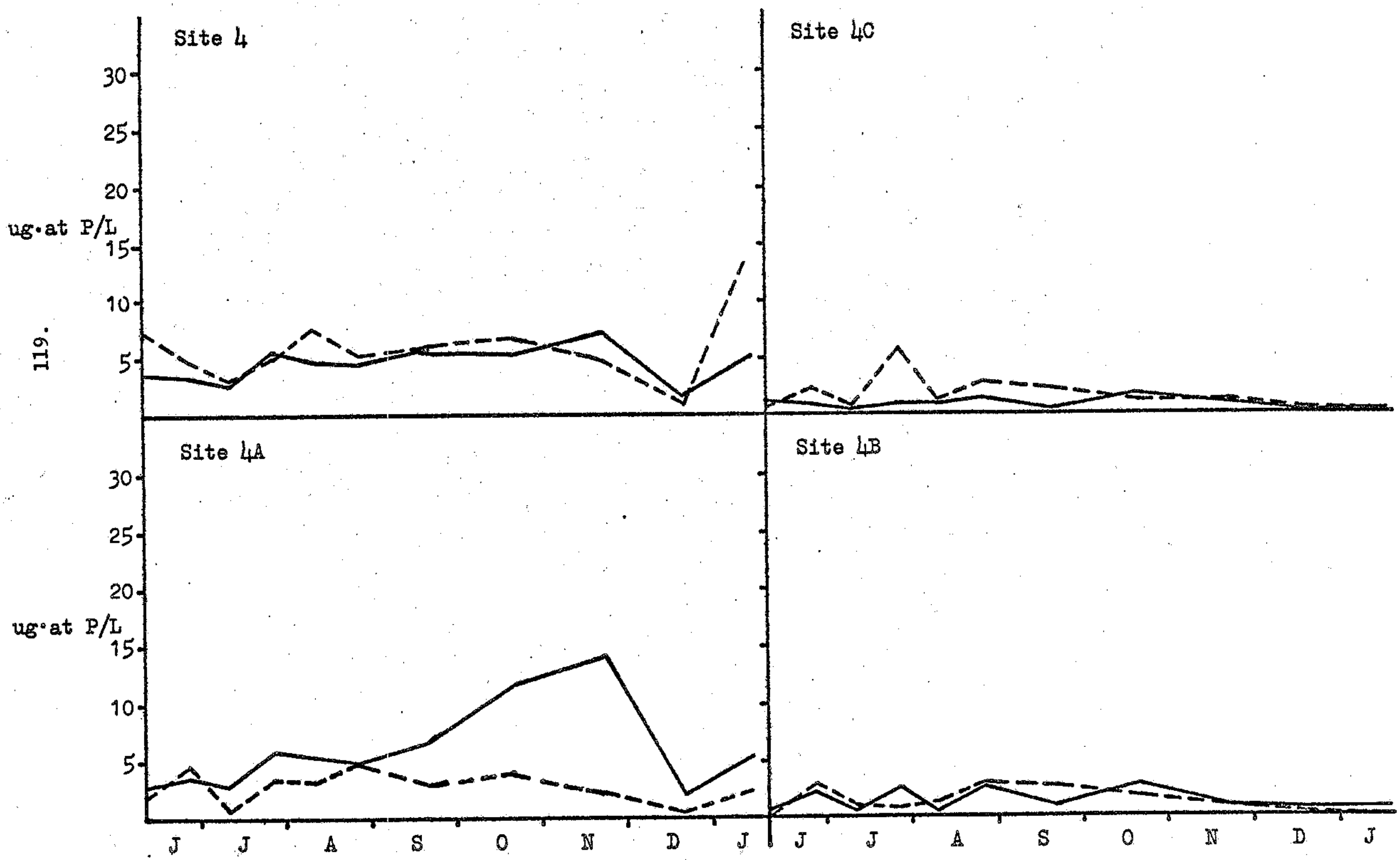
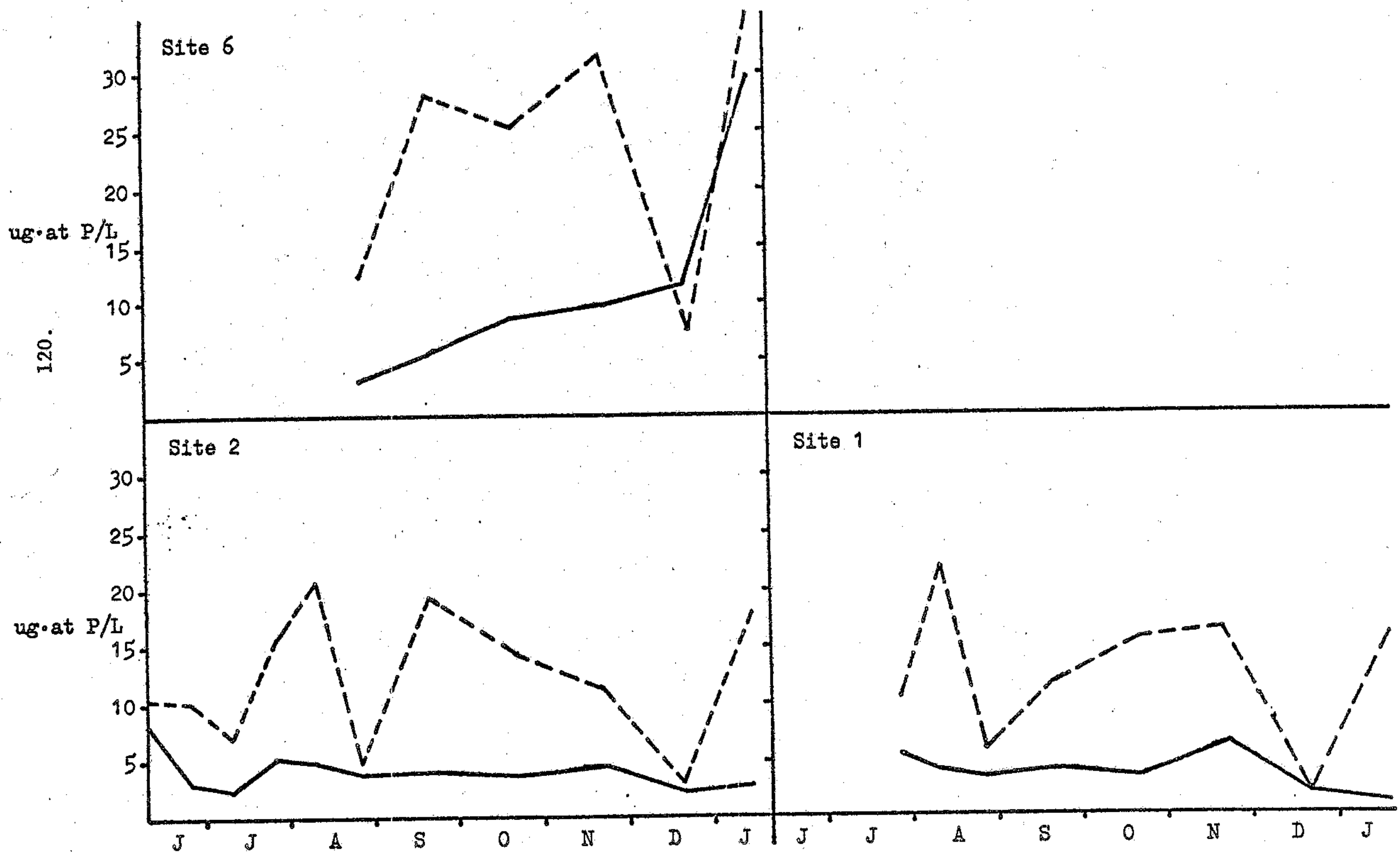


Figure 41. Changes in reactive phosphate from June 1974 through January 1975 at Sites 1, 2, and 6. solid lines represents morning high tide values and dashed lines represent afternoon low tide values.



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^{o}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

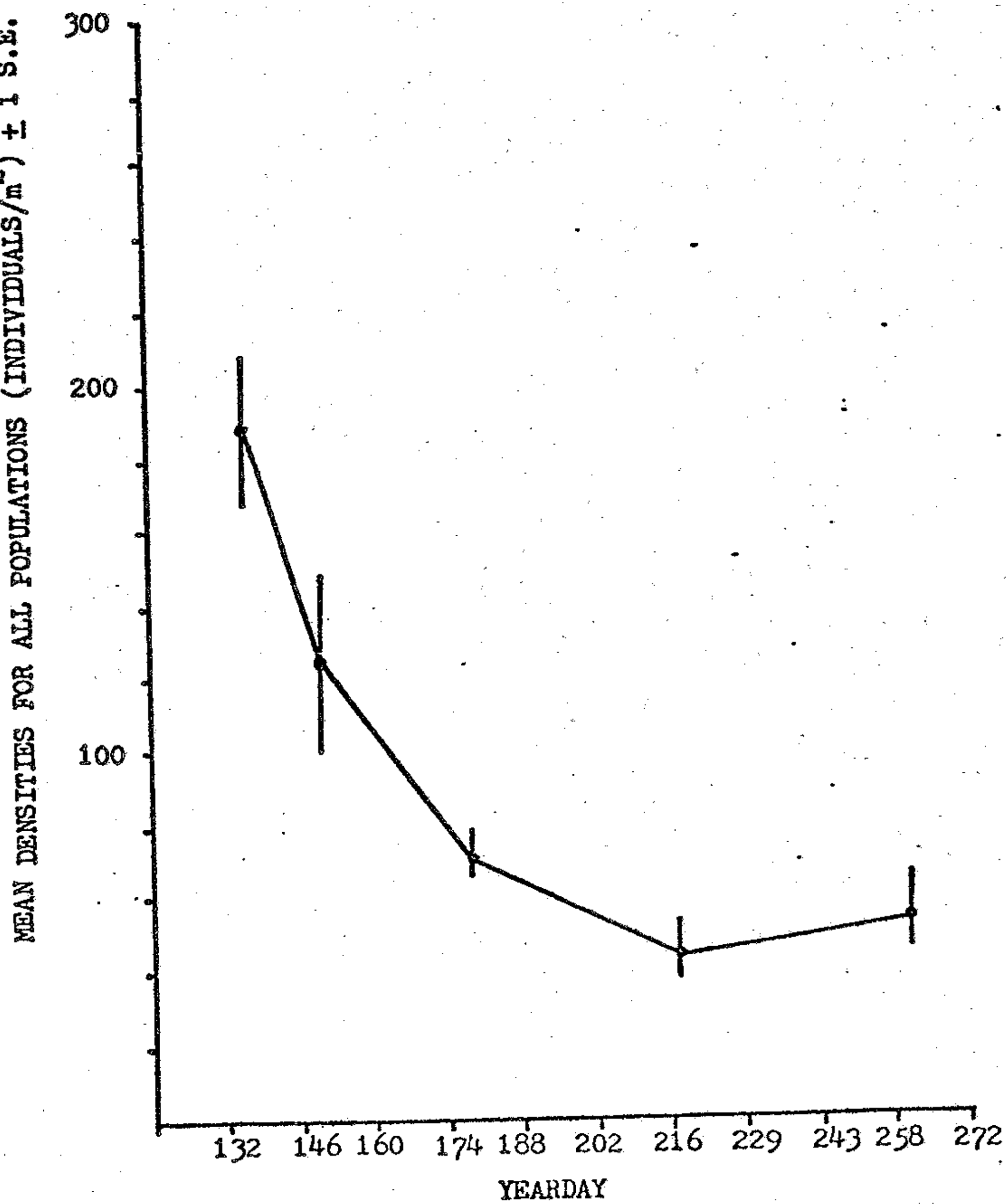
The vast majority of plants (98.7%) produced one inflorescence. The average number of seeds per inflorescence was 655 $\pm$ 193 (N=20) and the average density of seed bearing plants was $57 \times 10^4 \pm 28 \times 10^4$ per hectare. Estimated seed production was 373×10^6 seeds/hectare. Wild rice occupies 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