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NUTRIENT FLUX THROUGH
THE SALT MARSH ECOSYSTEM

A Dissertation
Presented to
The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Doctor of Philosophy

By
Donald M. Axelrad
1974

APPROVAL SHEET

This dissertation is submitted in partial fulfillment
of the requirements for the degree of
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TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS v

LIST OF TABLES. vi

LIST OF FIGURES vii

ABSTRACT. x

INTRODUCTION. 2

REVIEW OF LITERATURE. 6
  Phosphorus Cycling in Salt Marsh Systems 6
    Salt Marsh Phosphorus Flux. 6
    Salt Marsh Sediment-Phosphorus Interactions 7
    Phosphorus Cycling by Salt Marsh Biota. 8
  Nitrogen Cycling in Salt Marsh Systems 10
    Salt Marsh Nitrogen Flux. 10
    Salt Marsh Sediment-Nitrogen Interactions 10
    Nitrogen Cycling by Salt Marsh Biota. 11

MATERIALS AND METHODS 12
  Study Areas. 12
  Preliminary Field Measurements 12
  Field Measurements and Sampling Procedures 17
  Laboratory Measurements. 19
  Tidal Nutrient Transport Calculation 22
  Annual Nutrient Transport Calculation. 25
  Statistical Analysis 26

RESULTS 28
  Seasonal and Tidal Nutrient Concentration Trends 28
    Dissolved Inorganic Phosphorus. 28
    Dissolved Organic Phosphorus. 28
    Particulate Phosphorus. 29
    Nitrate 29
    Nitrite 30
    Ammonia 30
    Dissolved Organic Nitrogen. 31
    Particulate Nitrogen. 31

Page

Seasonal Nutrient Flux Trends. 31
  Dissolved Inorganic Phosphorus. 31
  Dissolved Organic Phosphorus. 32
  Particulate Phosphorus. 32
  Total Phosphorus. 32
  Nitrate 33
  Nitrite 33
  Ammonia 33
  Dissolved Organic Nitrogen. 34
  Particulate Nitrogen. 34
  Total Nitrogen. 34
  Diurnal versus Nocturnal Tidal Nutrient Transport . . . 34
Phytoplankton Productivity Correlations. 35

DISCUSSION. 87
Phosphorus Flux Through the Salt Marsh Ecosystem 87
Nitrogen Flux Through the Salt Marsh Ecosystem 92
Effects of the Salt Marsh Ecosystem on Estuarine Productivity 98

APPENDIX. 102

LITERATURE CITED. 128

VITA. 134

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LIST OF TABLES

Table | Page

1. Replicability of twenty duplicate samples 23

2. Correlation matrix of nutrient concentrations, salinity, water temperature, tide height, and water flow in Ware Creek over the year 36

3. Correlation matrix of nutrient concentrations, salinity, water temperature, tide height, and water flow in Carter Creek over the year 37

4. Ware Creek tidal phosphorus transport 77

5. Carter Creek tidal phosphorus transport 78

6. Ware Creek tidal nitrogen transport 79

7. Carter Creek tidal nitrogen transport 80

8. Ware Creek annual phosphorus budget 81

9. Carter Creek annual phosphorus budget 82

10. Ware Creek annual nitrogen budget 83

11. Carter Creek annual nitrogen budget 84

12. Ware Creek flood and ebb tide simple and partial correlation coefficients. 85

13. Carter Creek flood and ebb tide simple and partial correlation coefficients. 86

LIST OF FIGURES

Figure Page

1. The marine biogeochemical phosphorus cycle. 4

2. The marine biogeochemical nitrogen cycle. 5

3. The York River in relation to the Chesapeake Bay estuarine system. 13

4. Ware Creek and Carter Creek in relation to the York River 14

5. Ware Creek Marsh. 15

6. Carter Creek Marsh. 16

7. Annual variation in mean water temperature over a tidal cycle for Ware Creek and Carter Creek marshes 38

8. Annual variation in Ware Creek marsh high slack water and low slack water salinity. 39

9. Annual variation in Carter Creek marsh high slack water and low slack water salinity. 40

10. Annual variation in Ware Creek marsh high slack water and low slack water dissolved inorganic phosphorus concentration 41

11. Annual variation in Carter Creek marsh high slack water and low slack water dissolved inorganic phosphorus concentration 42

12. Annual variation in Ware Creek marsh high slack water and low slack water dissolved organic phosphorus concentration 43

13. Annual variation in Carter Creek marsh high slack water and low slack water dissolved organic phosphorus concentration 44

Figure Page

14. Annual variation in Ware Creek marsh high slack water and low slack water particulate phosphorus concentration 45

15. Annual variation in Carter Creek marsh high slack water and low slack water particulate phosphorus concentration 46

16. Annual variation in Ware Creek marsh high slack water and low slack water nitrate concentration 47

17. Annual variation in Carter Creek marsh high slack water and low slack water nitrate concentration 48

18. Annual variation in Ware Creek marsh high slack water and low slack water nitrite concentration 49

19. Annual variation in Carter Creek marsh high slack water and low slack water nitrite concentration 50

20. Annual variation in Ware Creek marsh high slack water and low slack water ammonia concentration 51

21. Annual variation in Carter Creek marsh high slack water and low slack water ammonia concentration 52

22. Annual variation in Ware Creek marsh high slack water and low slack water dissolved organic nitrogen concentration 53

23. Annual variation in Carter Creek marsh high slack water and low slack water dissolved organic nitrogen concentration 54

24. Annual variation in Ware Creek marsh high slack water and low slack water particulate nitrogen concentration. . 55

25. Annual variation in Carter Creek marsh high slack water and low slack water particulate nitrogen concentration. . 56

26. Annual variation in Ware Creek marsh high slack water and low slack water chlorophyll _a_ concentration 57

27. Annual variation in Carter Creek marsh high slack water and low slack water chlorophyll _a_ concentration 58

28. Annual variation in Ware Creek marsh high slack water and low slack water phytoplankton productivity. 59

Figure Page

29. Annual variation in Carter Creek marsh high slack water and low slack water phytoplankton productivity. 60

30. Variation in dissolved inorganic phosphorus concentration over Ware Creek marsh summer and winter tidal cycles. . . 61

31. Variation in dissolved inorganic phosphorus concentration over Carter Creek marsh summer and winter tidal cycles. . 62

32. Variation in dissolved organic phosphorus concentration over Ware Creek marsh summer and winter tidal cycles. . . 63

33. Variation in dissolved organic phosphorus concentration over Carter Creek marsh summer and winter tidal cycles. . 64

34. Variation in particulate phosphorus concentration over Ware Creek marsh summer and winter tidal cycles 65

35. Variation in particulate phosphorus concentration over Carter Creek marsh summer and winter tidal cycles 66

36. Variation in nitrate concentration over Ware Creek marsh summer and winter tidal cycles. 67

37. Variation in nitrate concentration over Carter Creek marsh summer and winter tidal cycles. 68

38. Variation in nitrite concentration over Ware Creek marsh summer and winter tidal cycles. 69

39. Variation in nitrite concentration over Carter Creek marsh summer and winter tidal cycles. 70

40. Variation in ammonia concentration over Ware Creek marsh summer and winter tidal cycles. 71

41. Variation in ammonia concentration over Carter Creek marsh summer and winter tidal cycles. 72

42. Variation in dissolved organic nitrogen concentration over Ware Creek marsh summer and winter tidal cycles. . . 73

43. Variation in dissolved organic nitrogen concentration over Carter Creek marsh summer and winter tidal cycles. . 74

44. Variation in particulate nitrogen concentration over Ware Creek marsh summer and winter tidal cycles 75

45. Variation in particulate nitrogen concentration over Carter Creek marsh summer and winter tidal cycles 76

ABSTRACT

Annual phosphorus and nitrogen budgets for two Virginia salt marshes were determined by measurement of flood tide and ebb tide water transports and nutrient concentrations over monthly tidal cycles.

The phosphorus and nitrogen budgets and seasonal concentration trends suggest annual salt marsh phosphorus and nitrogen cycles consisting of fixation of molecular nitrogen by marsh flora and tidal import of estuarine particulate phosphorus and particulate nitrogen to the marsh followed by biotic mineralization of a fraction of this particulate phosphorus and particulate nitrogen with subsequent export of dissolved inorganic phosphorus, dissolved organic phosphorus, ammonia, and dissolved organic nitrogen from the marsh to the estuary. However, estuarine ammonia is imported to the salt marsh in autumn, possibly as a result of marsh photoautotrophic and bacterial ammonia assimilation, or nitrification followed by denitrification. Nitrate and nitrite are imported to the marsh throughout the year, possibly as a result of denitrification, or nitrate and nitrite assimilation by marsh photoautotrophs and bacteria.

The salt marsh ecosystem serves to promote estuarine productivity by transforming estuarine particulate phosphorus and particulate nitrogen to dissolved nutrient forms suitable for utilization by estuarine photoautotrophs.

NUTRIENT FLUX THROUGH
THE SALT MARSH ECOSYSTEM

INTRODUCTION

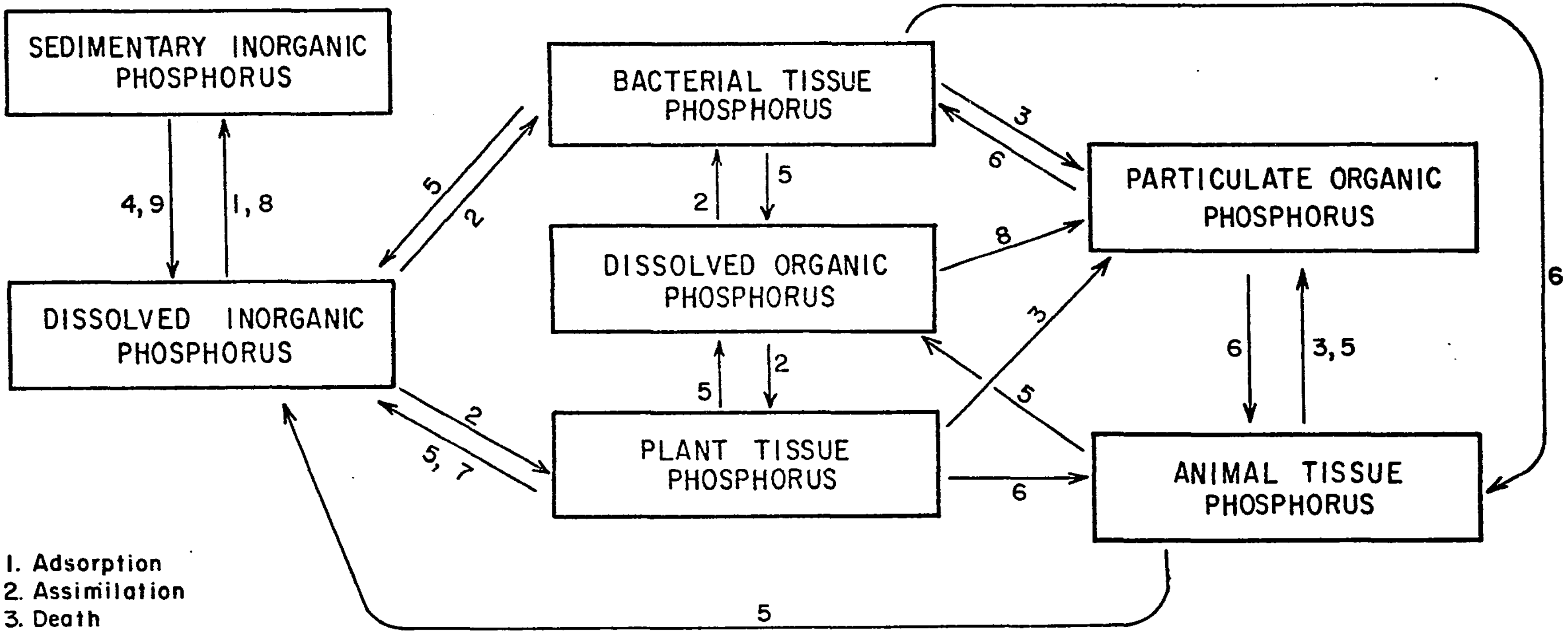
As a result of its high rate of primary production, abundance of organic substrate, and dynamic sediment-water-air interfaces, the salt marsh ecosystem provides a favorable environment for many reactions of the biogeochemical phosphorus and nitrogen cycles (Figures 1 and 2). Since low ambient phosphorus and nitrogen concentrations often limit estuarine photosynthetic productivity (Fournier, 1966; Thayer, 1969), salt marsh induced qualitative and quantitative alterations of these nutrients in estuarine waters moving tidally through the marsh system, can have far reaching influence on the estuarine community.

Though many of the nutrient cycling reactions indigenous to salt marshes are known, the resultant import or export of phosphorus and nitrogen to or from the marshes due to these processes remains to be elucidated. Therefore, this study was initiated to determine:

1) the seasonal variation in flux of several phosphorus and nitrogen species into and out of the salt marsh ecosystem,
2) the seasonal and tidal variation in the concentrations of these phosphorus and nitrogen compounds in marsh waters,
3) theoretical marsh nutrient cycling schemes explaining the observed nutrient flux and concentration data, and

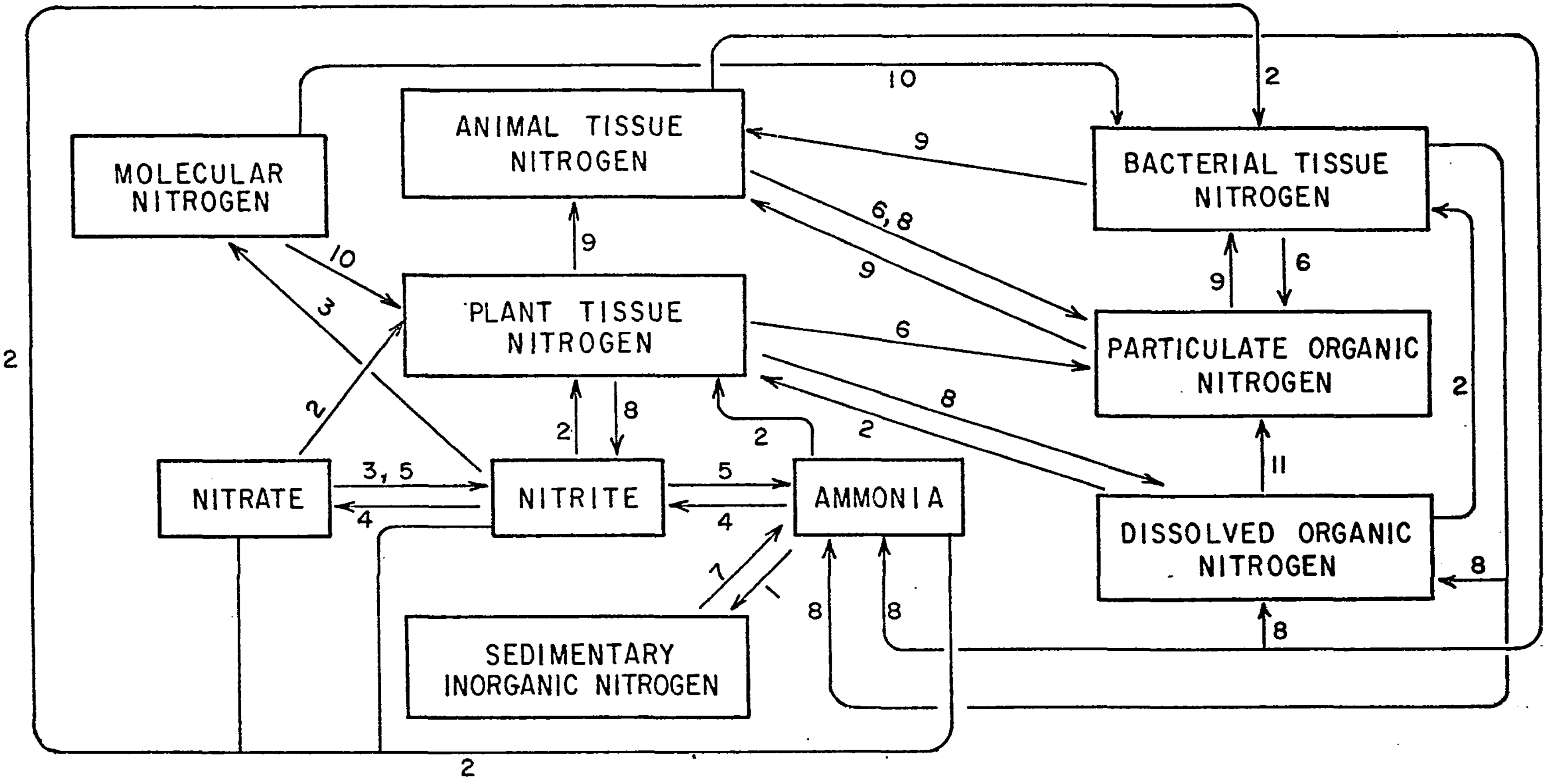
4) the effect of salt marsh induced phosphorus and nitrogen transformations on estuarine primary productivity.

Figure 1. The marine biogeochemical phosphorus cycle.
Modified from Riley and Chester, (1971).



1. Adsorption
2. Assimilation
3. Death
4. Desorption
5. Excretion
6. Grazing
7. Guttation
8. Precipitation
9. Solubilization

Figure 2. The marine biogeochemical nitrogen cycle.
Modified from Riley and Chester, (1971).



1. Adsorption
2. Assimilation
3. Bacterial Denitrification
4. Bacterial Nitrification
5. Bacterial Nitrogen Reduction
6. Death
7. Desorption
8. Excretion
9. Grazing
10. Nitrogen Fixation
11. Precipitation

REVIEW OF LITERATURE

Phosphorus Cycling in Salt Marsh Systems

Salt Marsh Phosphorus Flux

The seasonal phosphorus cycle of several Delaware salt marsh creeks was characterized by elevated summer dissolved inorganic, dissolved organic, and particulate phosphorus levels (Reimold, 1969; Daiber, Aurand, and Shlopak, 1969; Daiber, Gallagher, and Sullivan, 1970). Waters overlying the marshes in areas of tall *Spartina alterniflora* growth had higher dissolved phosphorus concentrations than did creek waters, but displayed seasonal concentration fluctuations similar to those of the creeks (Gallagher, 1971). Monthly measurements made over a year revealed greater dissolved phosphorus concentrations in marsh creeks at low slack than at high slack water, suggesting export of dissolved phosphorus from the marshes to the estuary (Reimold and Daiber, 1970).

Blum (1969) theorized that high marsh *Spartina patens* was adapted to rapid absorption of nutrients when flooded by spring high tides. It was further suggested that the mesh of dead leaves and stalks beneath live growth could function as a filter system and remove particulate nutrients brought to the high marsh by these tides. Measurements over a June tidal cycle revealed that the waters overlying the marsh during flood tide had significantly lower dissolved inorganic phosphorus concentrations and significantly higher total phosphorus concentrations than at ebb tide.

Flux measurements over several fall tidal cycles, utilizing phosphorus concentration and water discharge data, indicated that two North Carolina *Juncus* dominated marshes exerted little effect on the estuary with respect to particulate and dissolved inorganic phosphorus. Dissolved organic phosphorus was the predominant phosphorus species of these marshes and calculations revealed a small net export of this nutrient to the estuary (Byron, 1968).

Salt Marsh Sediment-Phosphorus Interactions

In two Louisiana *Spartina* marshes, yearly averages of sediment interstitial water dissolved inorganic phosphorus concentrations were many times greater than concentrations in corresponding water columns. Higher interstitial water phosphorus concentrations from August through November were attributed to increased detrital decomposition rate. Parallel seasonal concentration trends in the water column suggested diffusion of phosphorus from sediments to water (Ho and Lane, 1973). Highest dissolved inorganic phosphorus concentrations in Georgia marsh sediment interstitial waters were found under dense *Spartina* growth, again indicating detrital mineralization as a possible process supplying phosphorus to marsh sediments. Sediment cores taken in this marsh also revealed increasing interstitial water phosphorus concentrations with increasing depth (Maye, 1972).

Gooch (1968) postulated a seasonal cycle of precipitation and solubilization of inorganic phosphorus from salt marsh sediments. In this cycle, bacterial hydrogen sulfide production initiated inorganic phosphorus release from sediments. Thus it was believed that minimal hydrogen sulfide production in winter and maximal production in late spring caused dissolved inorganic phosphorus uptake in winter and release in spring.

Pomeroy, Smith, and Grant (1965) suggested that movement of dissolved inorganic phosphorus between undisturbed salt marsh - estuarine sediments and overlying water involved a two step ion exchange between clay and water, plus an exchange between interstitial microorganisms and water. In undisturbed sediments, abiotic exchange predominated, but in resuspended sediments, biologically mediated exchange was of the same magnitude as physical exchange. Sediment - water exchange processes buffered estuarine water to a dissolved inorganic phosphorus level of about one microgram atom per liter.

Phosphorus Cycling by Salt Marsh Biota

Turnover rate of dissolved inorganic phosphorus was found to be significantly greater in salt marsh waters than in other aquatic environments (Pomeroy, 1960). The high levels of dissolved inorganic phosphorus in Georgia salt marsh waters were attributed to this rapid turnover rate. A cycle of uptake of sedimentary phosphorus by *Spartina*, with subsequent bacterial utilization of *Spartina* detritus, followed by assimilation of detritus and associated bacteria by detritivores and excretion by detritivores, introduced dissolved phosphorus to marsh waters (Pomeroy, Johannes, Odum, and Roffman, 1969). Another explanation for the high concentrations of dissolved inorganic phosphorus in marsh waters has been suggested by Reimold (1972) who indicated that *Spartina alterniflora* pumped sedimentary phosphorus from rhizomes to leaves, where phosphorus was released to marsh waters upon *Spartina* inundation by high tides. Seasonal variation in dissolved inorganic phosphorus concentration of marsh waters was ascribed to changes in the rate of uptake and release of phosphorus from *Spartina*, resulting from seasonal changes in rate of *Spartina* production.

In a *Typha* dominated tidal marsh, periphyton communities were primarily responsible for removal of phosphorus from marsh waters. *Typha* competed with periphyton for the phosphorus of shallow marsh sediments, but the importance of the angiosperm in phosphorus cycling was mainly that it provided increased surface area for periphyton growth (Correll, Faust, and Severn, 1973).

A phosphorus budget of a salt marsh mussel population indicated that the population removed particulate phosphorus from marsh waters with a turnover time of 2.6 days (Kuenzler, 1961). Investigation of phosphorus cycling by marsh arthropod communities revealed that the communities mineralized large amounts of organic phosphorus through their detrital and periphyton grazing activities (Marples, 1966; Pomeroy et al., 1969).

The high carbon to phosphorus ratio of *Spartina alterniflora* detritus led Thayer (1969; 1974) to speculate that bacteria must assimilate phosphorus from marsh waters to completely utilize detrital carbon. Additions of dissolved inorganic phosphorus to estuarine water containing *Spartina* detritus increased detrital decomposition rate and thus supported this contention (Ustach, 1969).

Nitrogen Cycling in Salt Marsh Systems

Salt Marsh Nitrogen Flux

In a North Carolina *Juncus roemerianus* dominated salt marsh, Byron (1968) found that forty-one percent of the nitrogen entering the system over several fall tidal cycles was not returned to the estuary. Flux calculations utilizing water discharge and nitrogen concentration data indicated that particulate nitrogen of estuarine origin was lost to the marsh. Low levels of nitrite and nitrate in marsh creek ebb tide waters suggested that this organic nitrogen was not mineralized in the marsh and subsequently returned to the estuary.

Nitrate concentrations of waters overlying two Delaware *Spartina alterniflora* dominated salt marshes were generally lower than concentrations within marsh creeks (Daiber, et al., 1970; Gallagher, 1971). Monthly sampling of the marsh creeks revealed the presence of maximal nitrate levels in winter and minimal nitrate levels in summer (Daiber et al., 1969; Aurand and Daiber, 1973). The occurrence of winter nitrate concentration peaks at high slack water and summer nitrate concentration peaks at low slack water led Aurand (1968) to speculate that the Delaware marsh systems imported nitrate in winter but exported small amounts of nitrate in summer.

Salt Marsh Sediment-Nitrogen Interactions

Sampling over a year in two Louisiana *Spartina* marshes indicated that sediment interstitial water ammonia concentrations were many times greater than levels in the corresponding water columns. Highest interstitial water ammonia concentrations were found from

August through November and were attributed to increased detrital decomposition rates. Parallel concentration trends in the water column suggested diffusion of ammonia from sediments to water (Ho and Lane, 1973).

Maye (1972) found highest interstitial water ammonia concentrations in sediments beneath thick *Spartina* growth again indicating mineralization of *Spartina* detritus as a possible mechanism supplying ammonia to marsh sediments. Sediment cores taken in this Georgia marsh also revealed increased ammonia concentration with depth.

Nitrogen Cycling by Salt Marsh Biota

Evidence of algal nitrogen fixation was found in two Florida salt marshes. Epiphytic blue-green algae on dead *Spartina* and *Juncus* stems exhibited greater nitrogen fixation rates than did algae of surface sediments; the water column seldom displayed any activity (Green and Edmisten, 1972). More than sixty percent of the bacteria in Delaware salt marsh sediments were able to utilize molecular nitrogen as their sole nitrogen source. Large numbers of ammonifying, nitrifying, and dentrifying bacteria were also isolated from these sediments (Daiber and Gooch, 1968).

Thayer (1969; 1974) theorized that bacteria using characteristically nitrogen poor *Spartina* detritus as an energy source must obtain their nitrogen requirements from marsh waters. Ustach (1969) supported this theory by demonstrating increased heterotrophic utilization of *Spartina* detritus upon addition of nitrate to a detritus-estuarine water system.

MATERIALS AND METHODS

Study Areas

Two salt marshes in the York River, Virginia, watershed were selected as study sites for this investigation (Figures 3 and 4). These marshes were chosen because: 1) they were undisturbed, 2) they were of different salinity regimes and hence had distinct floral compositions, and 3) they were surrounded on three sides by higher ground which effectively minimized any unmeasured transport of water to or from the marshes.

Ware Creek Marsh (Fig. 5), 14 hectares in extent, had a yearly mean high tide salinity of approximately 7 o/oo (Fig. 8), and was dominated by *Spartina cynosuroides*, with *S. alterniflora*, and *Juncus spp.* as subdominants. Carter Creek Marsh (Fig. 6), 10 hectares in size, had a yearly mean high tide salinity of about 12 o/oo (Fig. 9), and was dominated by *S. alterniflora* with *S. patens* and *Distichlis spicata* as subdominants (Mendelssohn, 1973).

Preliminary Field Measurements

A sampling platform was constructed in the creek draining each marsh, located such that all tidal waters entering and leaving the marsh flowed past the sampling station. Creek cross sectional profiles at the sampling sites were measured before and during the

Figure 3. The York River in relation to the Chesapeake Bay estuarine system.

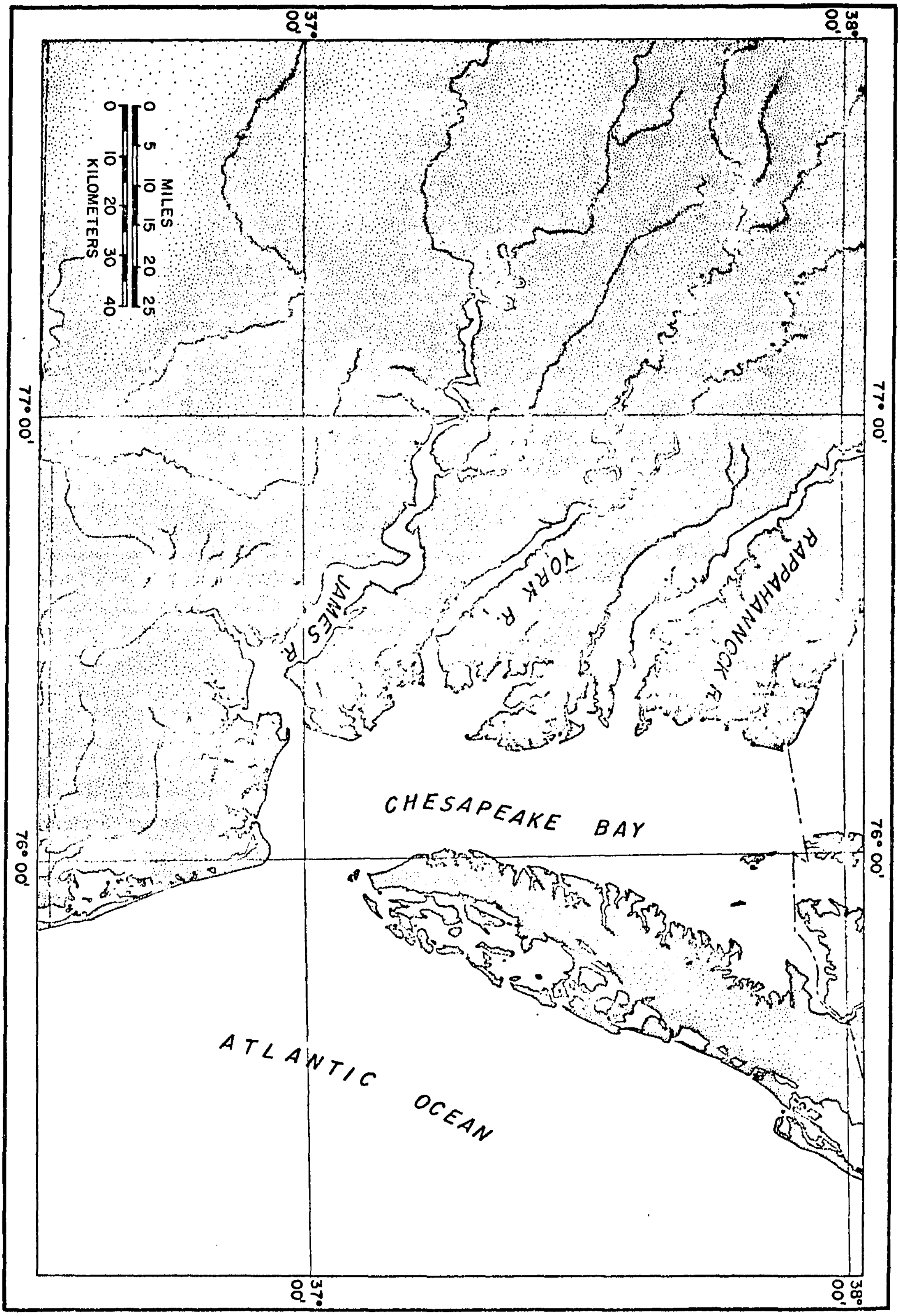

37° 00'
38° 00'
77° 00'
76° 00'
MILES
0 5 10 15 20 25
KILOMETERS
0 10 20 30 40
JAMES R.
YORK R.
RAPPAHANNOCK R.
CHESAPEAKE BAY
ATLANTIC OCEAN

Figure 4. Ware Creek and Carter Creek in relation to the York River.

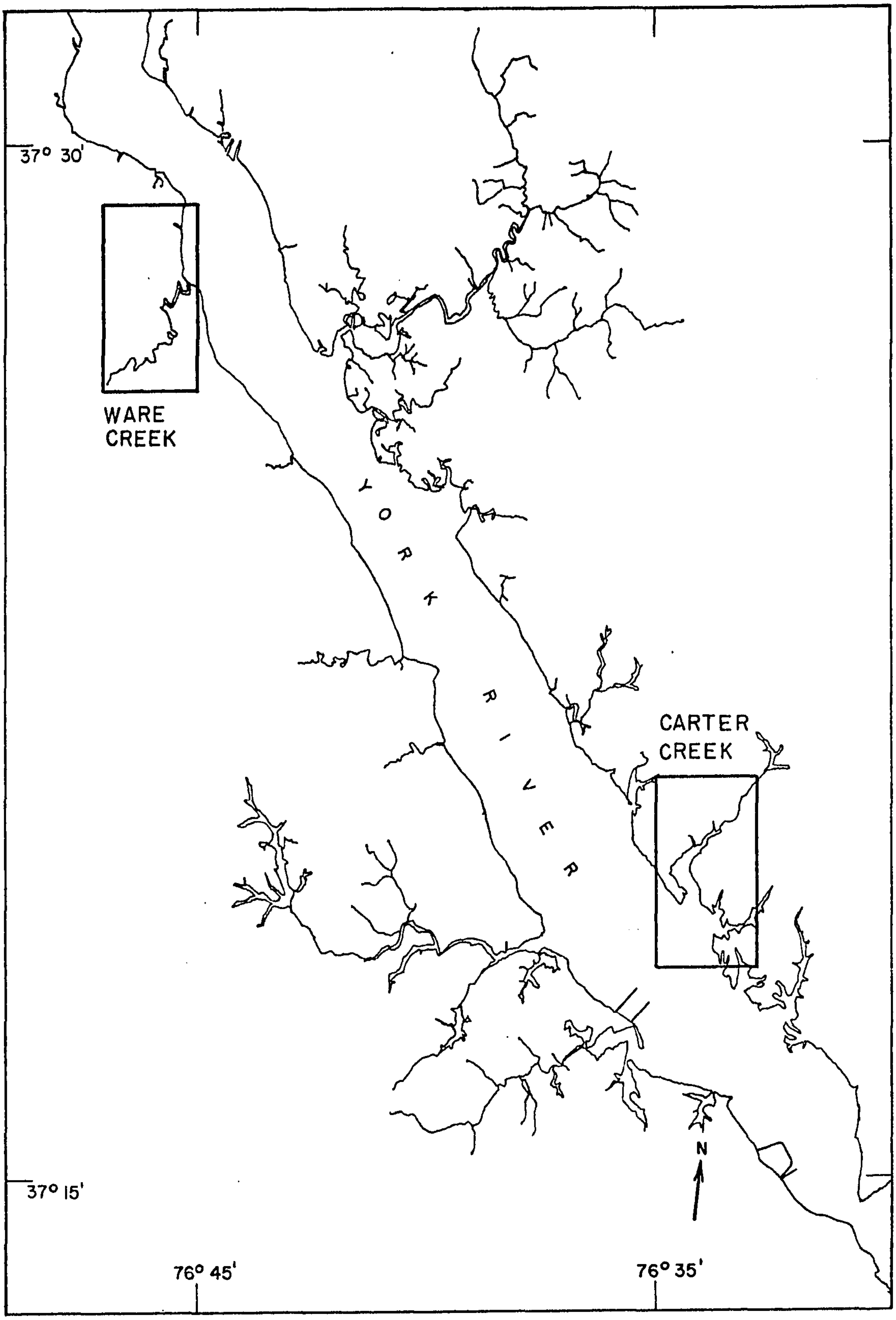

37° 30'
37° 15'
76° 45'
76° 35'
WARE CREEK
CARTER CREEK
YORK RIVER
N

Figure 5. Ware Creek Marsh.

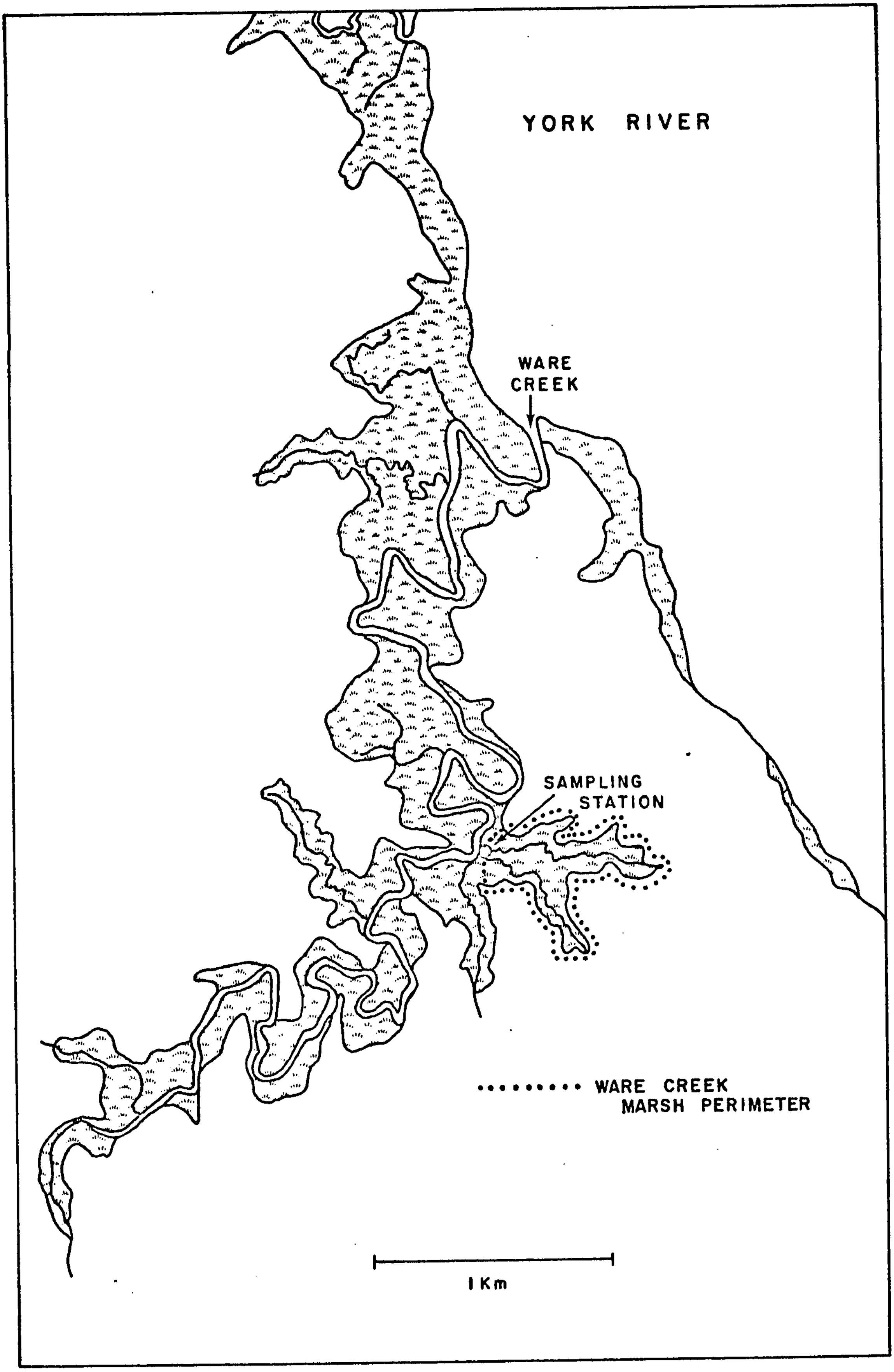
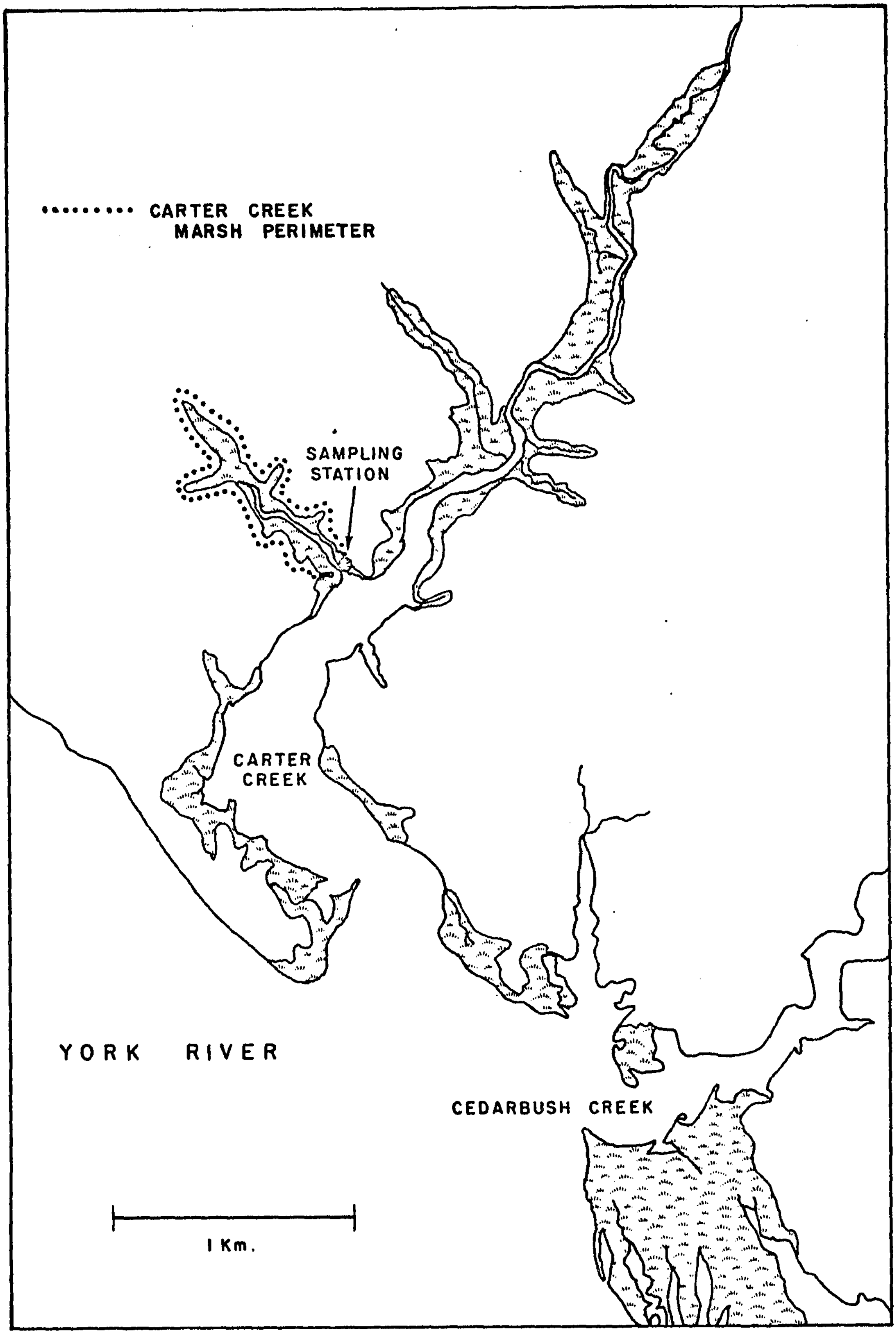

YORK RIVER
WARE CREEK
SAMPLING STATION
•••••••• WARE CREEK MARSH PERIMETER
1 Km

Figure 6. Carter Creek Marsh.


••••••••• CARTER CREEK MARSH PERIMETER
SAMPLING STATION
CARTER CREEK
YORK RIVER
CEDARBUSH CREEK
1 Km.

sampling period by determining creek depth below a horizontal line positioned across the creek width. No significant change in creek cross sectional profile was detected over the study period.

Nutrient concentration variation within the measured marsh creek cross section, and optimal sampling frequency for tidal nutrient transport calculation, were determined by collecting water samples semi-hourly over a tidal cycle from depths of 20 cm, mid-depth, and 20 cm above creek bottom. Statistical analysis of these data indicated that at any given time the water column was homogeneous with respect to nutrient concentrations and that hourly sampling was sufficient for accurate nutrient transport determination. Therefore, over subsequently monitored tidal cycles, water samples were taken hourly from a depth of approximately 20 cm.

Field Measurements and Sampling Procedures

Ware Creek and Carter Creek marshes were sampled for tidal nutrient transport determination over day time tidal cycles on several occasions during 1971 and approximately monthly from January, 1972 to January, 1973. Two consecutive Ware Creek tidal cycles were sampled in June, 1972 to compare day and night time tidal nutrient transport. In so far as possible, sampling dates were selected to correspond to periods of near mean tidal range within each month as predicted by the U. S. Department of Commerce National Ocean Survey tide tables.

During monthly samplings, water samples for nutrient and chlorophyll _a_ analysis were taken from the marsh creeks hourly, from low slack to high slack to second low slack water. Nutrient samples were also taken at twenty minute intervals over each tidal cycle for "combined sample" determination of nutrient flux direction (Appendix Table B1). Water samples were collected in clean, one liter, polyethylene bottles and stored in the dark at 0°C after preservation with 40 mg of $HgCl_2$.

Air and water temperatures were measured hourly to the nearest 0.5°C with a mercury thermometer. Samples for dissolved oxygen determination were taken hourly while salinity samples were collected every twenty minutes over a tidal cycle.

Marsh creek current velocity was determined (coincidental with the nutrient sampling) at twenty minute intervals over the entire tidal cycle using a ducted impeller type current speed indicator (Byrne and Boon, 1973; Boon, 1974). The current meter was positioned approximately at the center of the creek section during current velocity determination. Simultaneous with current speed measurement, a reading of tide height was taken from a meter stick fixed at a known position within the measured creek cross section.

Water for phytoplankton productivity determination was taken every two hours over a tidal cycle beginning at first low slack water. Three 125 ml glass bottles (two light bottles and one dark bottle) were filled to 100 ml from a well mixed liter sample. One milliliter of a stock solution containing one microcurie per milliliter of carbon-14 (^{14}C) as $NaH^{14}CO_3$, buffered to pH 9.5 with approximately 10 mg/liter Na_2CO_3, was pipetted into each of the bottles. The light bottles were placed into the light compartment of an incubator illuminated by Westinghouse twenty watt "cool white", "warm white", and "plant gro" fluorescent lamps. The dark bottle was placed into the dark compartment of the incubator. Both compartments were maintained at ambient temperature by water pumped from the marsh creek. After three hours, the productivity samples were fixed with 1 ml of 10% neutral formaldehyde solution and stored in the dark at 0°C (Strickland and Parsons, 1968).

Laboratory Measurements

The morning following sampling, 500 ml of each of the nutrient samples were filtered first through a Gelman type A glass fiber filter and then through a Millipore type HA 0.45 micron membrane filter. The 500 ml filtered and unfiltered fractions were stored in a refrigerator at 4°C until analyzed. Glass fiber filters through which a known volume of sample had been filtered were wetted with $MgCO_3$ slurry, then placed in a desiccator and refrigerated for later chlorophyll analysis. Light and dark bottle primary productivity samples were each filtered through a Millipore type HA 0.45 micron membrane filter, the filters rinsed with 50 ml distilled water and stored in scintillation vials at room temperature.

Dissolved inorganic phosphorus concentration was determined on duplicate filtered samples using a Technicon Autoanalyzer II system employing the single reagent method (U. S. Environmental Protection Agency, 1971; Technicon, 1971). Total dissolved phosphorus concentration of filtered samples and total phosphorus concentration of unfiltered samples was determined, following persulfate digestion, by single reagent analysis of duplicate 50 ml sample aliquots (U. S. Environmental Protection Agency, 1971). A Klett-Summerson photoelectric colorimeter calibrated with the standards of the autoanalyzer phosphorus method was used in the analysis. Particulate phosphorus concentrations were obtained by subtracting total dissolved phosphorus from total phosphorus concentrations. Dissolved organic phosphorus concentration was obtained by taking the difference between total dissolved phosphorus and dissolved inorganic phosphorus concentrations.

Nitrate and nitrite concentrations were determined on duplicate filtered samples using the Technicon Autoanalyzer II system. Nitrite was measured directly by colorimetry while nitrate was determined by cadmium-copper reduction of nitrate followed by colorimetric measurement of nitrite produced. Nitrate and nitrite standards were included in sample runs (U. S. Environmental Protection Agency, 1971; Technicon, 1971). Fifty milliliter unfiltered water samples for total Kjeldahl nitrogen analysis, and filtered samples for dissolved Kjeldahl nitrogen analysis, were digested with a sulfuric acid-mercuric sulfate mixture. Fifty milliliter filtered water samples for ammonia determination and the digested Kjeldahl samples were then analyzed using the distillation-titration technique (U. S. Environmental Protection Agency, 1971). Ammonia standards were analyzed along with samples and several samples from each run were measured in duplicate. Standard titrant used was 0.001 N HCl. Particulate nitrogen concentrations were obtained by subtracting dissolved Kjeldahl nitrogen from total Kjeldahl nitrogen concentrations. Dissolved organic nitrogen concentration was obtained by taking the difference between dissolved Kjeldahl nitrogen and ammonia concentrations.

Salinity was determined using a Beckman Model RS-7B portable induction salinometer. Dissolved oxygen concentration was measured using a modified Winkler titration (Strickland and Parsons, 1968).

Chlorophyll a concentration uncorrected for phaeophytin was analyzed using the fluorimetric method (Strickland and Parsons, 1968). Glass fiber filters with their chlorophyll load were mixed with 90% aqueous acetone in a tissue grinder and pulverized. The product was centrifuged, the extract brought to volume, and read on a Turner Model 111 fluorimeter calibrated for chlorophyll a determination against a Cary 15 scanning spectrophotometer.

Phytoplankton productivity was measured by liquid scintillation counter determination of phytoplankton ^{14}C uptake. Ten milliliters of scintillation cocktail consisting of 100 grams napthalene and 5 grams PPO (2,5 diphenyloxazole) per liter of dioxane was added to each Millipore filter with its phytoplankton load in the scintillation vial. Activity of the cells was measured on a Beckman LS-150 Liquid Scintillation System. Counting efficiency was determined by spiking samples with known activity ^{14}C hexadecane. Productivity was calculated from light and dark bottle phytoplankton ^{14}C uptake, counting efficiency, and the dissolved inorganic carbon concentration of the samples as determined by Moore (1974), by use of the equation:

phytoplankton productivity (mg carbon/liter-hour)

$$= \frac{\left[\frac{L_1+L_2}{2} - D\right] (C)\ 1.05}{RTE}$$

where L_1 = phytoplankton ^{14}C uptake (counts per minute) of light bottle #1

L_2 = phytoplankton ^{14}C uptake (counts per minute) of light bottle #2

D = phytoplankton ^{14}C uptake (counts per minute) of dark bottle

C = dissolved inorganic carbon concentration (mg/l)

1.05 = isotope correction factor

R = activity (disintegrations per minute) of ^{14}C added to light and dark bottles

T = light and dark bottle incubation time (hours)

E = counting efficiency

Relative error of the analytical procedures is listed in Table 1.

Tidal Nutrient Transport Calculation

For purposes of water transport determination, the creek cross sectional profiles at the sampling stations were drawn to one tenth scale and the cross sectional area of water was planimetrically determined at 10 cm intervals from lowest to highest observed tide height. The data obtained were used to calculate a regression equation relating water cross sectional area to tide height. All tide height observations were converted to water cross sectional area values in this manner. Water cross sectional area values were multiplied by corresponding current velocity data to produce instantaneous water transport values. Water transport values were then matched with existing nutrient concentration and salinity data and additional nutrient concentration data were generated by interpolation, such that all water transport values had corresponding nutrient concentration values. With this data, the

Table 1

Replicability of Twenty Duplicate Samples

	Range of Sample Concentrations	Range of Absolute Differences	Mean Absolute Difference	Range of Relative Differences	Mean Relative Difference
Dissolved Inorganic Phosphorus	0.3-5 µg at/l	0-0.4 µg at/l	0.01 µg at/l	0-7%	1.2%
Total Dissolved Phosphorus	0.5-6 µg at/l	0-0.10 µg at/l	0.03 µg at/l	0-8%	2.1%
Total Phosphorus	2-18 µg at/l	0-0.26 µg at/l	0.06 µg at/l	0-5%	1.2%
Nitrate	0.3-25 µg at/l	0-0.10 µg at/l	0.03 µg at/l	0-8%	1.9%
Nitrite	0.2-1.8 µg at/l	0-0.02 µg at/l	0.01 µg at/l	0-7%	2.8%
Ammonia	1-20 µg at/l	0-2 µg at/l	1.2 µg at/l	0-13%	8.1%
Dissolved Kjeldahl Nitrogen	10-80 µg at/l	0-7 µg at/l	2.8 µg at/l	0-12%	7.8%
Total Kjeldahl Nitrogen	20-220 µg at/l	0-17 µg at/l	4.7 µg at/l	0-14%	8.8%
Chlorophyll *a*	2-200 µg/l	0-10 µg/l	0.6 µg/l	0-14%	5.7%
Primary Productivity	200-2900 cpm	4-410 cpm	92 cpm	1-19%	5.8%

tidal fluxes of water, salinity, and nutrients were determined for each sampled tidal cycle using a spline fit program (Boon, 1974) and an IBM 1130 computer which:

1. multiplied nutrient and salinity concentrations by instantaneous water transport producing instantaneous nutrient and salinity transport;
2. plotted graphs of instantaneous nutrient, salinity, and water transport versus time and integrated the area under the flood tide and ebb tide halves of the curve;
3. subtracted flood tide nutrient, salinity, and water transport from ebb tide transport yielding net flux for the complete tidal cycle.

Comparison of salinity and water transport data indicated absence of non-tidal water input to the marshes. Consequently, any inequality between measured flood and ebb tidal prisms over a tidal cycle was attributed to error in water transport measurement. This error can be ascribed to differences between flood and ebb tide creek cross sectional current velocity distribution, caused by the curvature of the marsh channels (R. J. Byrne, personal communication). As a result, the current meter, which was held at a fixed point on the creek cross section, measured different relative velocities over each half tidal cycle and thus produced constantly biased current velocity and water transport data. To correct for this sampling error, measured flood and ebb water transports over a tidal cycle were multiplied by constants which equated them to the mean of the measured flood and ebb tidal prisms over the tidal cycle. Tidal nutrient transport data were also corrected in this manner.

Annual Nutrient Transport Calculation

For calculation of annual nutrient flux between the marshes and the estuary, the sampling year was divided into eleven, approximately month long periods, each containing a sampled tidal cycle near its mid-point. Salt marsh nutrient transport over each "month" was computed using two equations based on contrasting assumptions. The assumption of the first calculation was that every tidal cycle within a given month imported or exported a quantity of nutrients equal to the net quantity transported over the tidal cycle sampled within that month. Thus net transport over each month was calculated by use of the equation:

$$T_m = N\ T_{tc}$$

where T_m = net nutrient transport over the month

N = number of tidal cycles in the month

T_{tc} = net nutrient transport over the tidal cycle sampled during the month

The assumption of the second calculation was that net nutrient transport over a tidal cycle was directly proportional to marsh tidal prism. Thus, net transport over each month was calculated by use of the equation:

$$T_m = N\ T_{tc}\ \bar{P}/P_{tc}$$

where $\bar{P}$ = mean salt marsh tidal prism for the month

P_{tc} = tidal prism of the tidal cycle sampled during the month

Data for computation of mean monthly salt marsh tidal prism was supplied by a continuously recording York River tide gauge. Regression equations relating marsh tidal prism to York River high water tide height were calculated from tidal prism and corresponding tide gauge data. Then, mean monthly York River high water tide heights calculated from tide gauge data were substituted into the regression equations and mean monthly salt marsh tidal prisms were computed.

Since it was not clear which assumption had greater validity, net monthly tidal nutrient transport was estimated by taking the mean of the transports calculated from the two equations. Annual net tidal nutrient transport between the salt marshes and the estuary was then determined by summing the monthly transports for each marsh over the year.

Statistical Analysis

Relationships between nutrient concentrations and physical parameters were determined by correlation analysis (Snedecor and Cochran, 1967) using a program devised for the IBM 360-50 computer (Dixon, 1968).

Multiple regression analysis (Snedecor and Cochran, 1967) with phytoplankton productivity to chlorophyll _a_ ratio (assimilation number) as the dependent variable, and water temperature, dissolved inorganic phosphorus, nitrate, and ammonia concentrations as independent variables was also performed using the IBM 360-50 computer (Dixon, 1968). Assuming that marsh flood and ebb tide waters had similar phytoplankton assemblages, but that flood tide waters contained nutrients unaffected by the marshes while ebb tide waters contained nutrients that had interacted with the salt marsh ecosystem, separate regression equations for each half tidal cycle could then reveal the effect of marsh induced nutrient transformations on estuarine phytoplankton productivity.

RESULTS

Seasonal and Tidal Nutrient Concentration Trends

Dissolved Inorganic Phosphorus

The seasonal range in dissolved inorganic phosphorus (DIP) concentration of marsh waters was 0.25-2.95 μg at/l in Ware Creek and 0.22-5.06 μg at/l in Carter Creek (Appendix). Highest DIP concentrations and greatest concentration ranges were found over summer tidal cycles (Figures 10, 11, 30, and 31). Over tidal cycles throughout the year, DIP concentrations usually peaked at low slack water and decreased with increasing tide height to concentration minima at high slack water, as indicated by the significant negative correlations between DIP concentration and tide height listed in Tables 2 and 3. Exceptions to this DIP concentration pattern were the Ware Creek tidal cycles of late September and October which displayed greater DIP concentrations at high slack than at low slack water (Appendix Tables A9 and A10).

Dissolved Organic Phosphorus

Seasonal and tidal dissolved organic phosphorus (DOP) concentration trends generally followed those of dissolved inorganic phosphorus. Maximal DOP concentrations were detected in summer while minimal levels were found in winter and spring as shown in Figures 12 and 13 and by the significant positive correlations between DOP concentrations and water temperature in Tables 2 and 3. Annually, concentrations ranged from 0.19-1.40 μg at/l in Ware Creek and from 0.17-1.19 μg at/l in Carter Creek (Appendix). Over tidal cycles throughout the year, peak DOP levels often occurred at low slack water and concentrations generally decreased towards high slack water (Figures 32 and 33).

Particulate Phosphorus

Particulate phosphorus (PP) concentrations within the marsh creeks were maximal in summer and minimal in fall and winter (Figures 14 and 15, Tables 2 and 3). Annual concentration ranges were 0.61-8.79 μg at/l and 0.18-19.52 μg at/l in Ware Creek and Carter Creek respectively (Appendix). Peak PP levels over tidal cycles usually occurred just before low slack water in Carter Creek but were often found at times of maximal water flow in Ware Creek as shown by Figures 34 and 35 and by the significant positive correlations between Ware Creek PP concentrations and water flow in Table 2 and by the significant negative correlations between Carter Creek PP concentrations and tide height in Table 3. The highest sustained PP concentrations were measured in Carter Creek during a rain storm over the latter part of the July tidal cycle (Appendix Table A18).

Nitrate

Nitrate (NO_3^-) concentrations ranged seasonally from 0.26-24.39 μg at/l in Ware Creek and from 0.07-26.86 μg at/l in Carter Creek (Appendix). Highest concentrations were measured in winter while lowest levels were found in summer (Figures 16, 17, 36 and 37, Tables 2 and 3). Low slack water NO_3^- concentrations were greater than high slack water concentrations from May through August in Ware Creek and from June through October in Carter Creek (Figures 16 and 17). At other times, high slack water NO_3^- concentrations were greater than low slack water values.

Nitrite

Carter Creek nitrite (NO_2^-) concentrations varied seasonally from 0.07-0.77 µg at/l. Nitrite concentrations in Ware Creek ranged annually from 0.07-1.83 µg at/l, however, with the exclusion of the September sampling, concentrations ranged only from 0.09-0.71 µg at/l (Appendix). While seasonal and tidal NO_2^- concentration ranges were relatively small, low slack water NO_2^- concentrations were generally greater than or equal to high slack water concentrations (Figures 18, 19, 38, and 39). Exceptions were the Ware Creek tidal cycles of late September and October while clearly displayed increasing NO_2^- concentrations toward high slack water (Appendix Tables A9 and A10).

Ammonia

Annual ammonia (NH_4^+) concentration ranges were 1.0-22.2 µg at/l and 1.0-26.0 µg at/l in Ware Creek and Carter Creek respectively (Appendix). While there were no readily apparent seasonal concentration trends (Figures 20 and 21, Tables 2 and 3), over tidal cycles throughout the year, NH_4^+ concentrations generally increased with decreasing tide height (Figures 40 and 41, Tables 2 and 3).

Dissolved Organic Nitrogen

Dissolved organic nitrogen (DON) concentrations were generally highest in summer (Figures 22 and 23). Annual concentration ranges were 3.0-65.2 µg at/l in Ware Creek and 7.6-82.2 µg at/l in Carter Creek (Appendix). Over the year, peak DON concentrations were often found at low slack water and concentrations generally decreased with increasing tide height (Figures 42 and 43).

Particulate Nitrogen

Particulate nitrogen (PN) concentrations of the marsh creeks followed a seasonal cycle similar to that of particulate phosphorus (Tables 2 and 3). Highest PN concentrations were measured in summer while lowest concentrations were found in winter (Figures 24 and 25, Tables 2 and 3). Seasonally, PN concentrations ranged from 5.0-74.6 µg at/l in Ware Creek and from 3.4-174.6 µg at/l in Carter Creek (Appendix). Peak PN levels over tidal cycles usually occurred just before low slack water in Carter Creek but were often found at times of maximal water flow in Ware Creek (Figures 44 and 45, Tables 2 and 3). Highest sustained PN concentrations were measured during a rain storm over the July sampling of Carter Creek (Appendix).

Seasonal Nutrient Flux Trends

Dissolved Inorganic Phosphorus

As indicated by the annual budgets, significant quantities of dissolved inorganic phosphorus (DIP) were exported from Ware Creek and Carter Creek marshes (Tables 8 and 9). Ware Creek exhibited net output of DIP over winter, spring, and summer tidal cycles, but for three consecutive fall samplings, calculations indicated a net input of DIP to the marsh (Table 4). Carter Creek exported DIP year round, with greatest net output during summer (Table 5).

Dissolved Organic Phosphorus

Dissolved organic phosphorus (DOP) was exported from Ware Creek and Carter Creek during all seasons (Tables 4 and 5). Though calculations indicated import of DOP to the marshes over several samplings, the net inputs were generally small and no seasonal pattern of import was discernible. Annually, significant amounts of DOP were exported from both marshes with greater export from Ware Creek than from Carter Creek (Tables 8 and 9).

Particulate Phosphorus

On an annual basis, calculations indicated a net input of particulate phosphorus (PP) to the marshes (Tables 8 and 9). Ware Creek exported PP during spring and summer while Carter Creek exported PP over two consecutive fall samplings (Tables 4 and 5). Large quantities of PP were also exported from Carter Creek over the storm tidal cycle of July (Table 5).

Total Phosphorus

Considering all three phosphorus species, on an annual basis phosphorus was imported to Ware Creek and Carter Creek marshes (Tables 8 and 9). The yearly net input of particulate phosphorus to the marshes was greater than the net output of dissolved inorganic and dissolved organic phosphorus from the marshes.

Nitrate

Significant quantities of nitrate (NO_3^-) were imported to Ware Creek over every sampled tidal cycle, with greatest net input in fall and winter months (Table 6). Carter Creek exhibited net input of NO_3^- during all seasons, though calculations indicated net output of NO_3^- over several tidal cycles (Table 7). On an annual basis, there was NO_3^- import to both marshes with considerably greater NO_3^- import to Ware Creek than to Carter Creek (Tables 10 and 11).

Nitrite

While there was nitrite (NO_2^-) export from the marshes over several tidal cycles, NO_2^- was imported to the marshes during all seasons (Tables 6 and 7). Annually, significantly greater quantities of NO_2^- were imported to Ware Creek than to Carter Creek (Tables 10 and 11).

Ammonia

Ammonia (NH_4^+) was exported from Ware Creek and Carter Creek with the exception of three consecutive fall and fall-winter tidal cycles when there was a net input of NH_4^+ to the marshes (Tables 6 and 7). While a large net input of NH_4^+ was indicated for the Carter Creek storm tidal cycle of July, this input was discounted due to the anomalous transport of NH_4^+ relative to that of other nutrient species over this tidal cycle. Consequently, NH_4^+ transport over the "month" associated with the July sampling was calculated from the mean of the NH_4^+ transports of the preceding month and the following month. On an annual basis, Carter Creek displayed a small net input of NH_4^+ while Ware Creek exported significant quantities of NH_4^+ (Tables 10 and 11).

Dissolved Organic Nitrogen

Dissolved organic nitrogen (DON) was exported from the marshes during all seasons (Tables 6 and 7). Annually, there was significant net output of DON from both marshes with greater export from Carter Creek than from Ware Creek (Tables 10 and 11).

Particulate Nitrogen

Particulate nitrogen (PN) was exported from Ware Creek with the exception of a period from July through October when net input was indicated (Table 6). The annual budget revealed a slight export of PN from Ware Creek (Table 10).

Carter Creek displayed net input of PN during all seasons, however, a large quantity of PN was exported over the storm tidal cycle of July (Table 7). On an annual basis, there was significant net input of PN to Carter Creek (Table 11).

Total Nitrogen

Considering all nitrogen species, the marshes displayed significant annual export of nitrogen (Tables 10 and 11). The annual import of nitrate and nitrite to Ware Creek was exceeded by the annual export of ammonia, dissolved organic nitrogen, and particulate nitrogen from the marsh. For Carter Creek, the annual export of dissolved organic nitrogen exceeded the annual import of the other nitrogen species.

Diurnal versus Nocturnal Tidal Nutrient Transport

The consecutively sampled day-night Ware Creek tidal cycles of June, 1972, generally displayed similar net nutrient transport trends (Tables 4 and 6). Dissolved inorganic phosphorus was exported over both tidal cycles with greater export over the day time tidal cycle. However, while dissolved organic phosphorus was exported from the marsh over the diurnal tidal cycle, a small quantity was imported to the marsh over the nocturnal tidal cycle. Particulate phosphorus was exported from the marsh over both tidal cycles with significantly greater night time export. Nitrate was imported to the marsh while nitrite was exported from the marsh over the two tidal cycles. There was greater nitrate import to the marsh over the diurnal tidal cycle and greater nitrite export from the marsh over the nocturnal tidal cycle. Approximately equal amounts of ammonia were exported over the two tidal cycles, however, more dissolved organic nitrogen was imported to the marsh over the day time compared to the night time tidal cycle. A greater amount of particulate nitrogen was exported from the marsh over the diurnal than over the nocturnal tidal cycle.

Phytoplankton Productivity Correlations

Over the year, in Ware Creek and Carter Creek marsh waters, the ratio of phytoplankton productivity to chlorophyll a concentration (assimilation number) was best correlated with water temperature for both flood and ebb tides. Partial correlations, with temperature held constant, calculated between phytoplankton assimilation number and dissolved inorganic phosphorus, nitrate, and ammonia, revealed no significant correlations over either flood or ebb tides (Tables 12 and 13).

Table 2

CORRELATION MATRIX OF NUTRIENT CONCENTRATIONS, SALINITY, WATER TEMPERATURE, TIDE HEIGHT, AND WATER FLOW IN WARE CREEK OVER THE YEAR

	DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN	Sal.	Temp.	Tide Ht.	Flow
DIP	1.000	0.598	0.275	-0.051	0.183	0.352	0.326	0.149	-0.419	0.228	-0.510	-0.334
DOP		1.000	0.259	-0.238	-0.068	0.127	0.408	0.006	-0.304	0.422	-0.411	-0.166
PP			1.000	-0.210	0.230	0.050	0.538	0.740	-0.019	0.439	-0.163	0.285
NO_3^-				1.000	0.212	0.093	-0.200	-0.152	-0.082	-0.594	-0.046	-0.201
NO_2^-					1.000	-0.162	0.320	0.238	0.403	0.073	0.173	0.057
NH_4^+						1.000	-0.215	0.030	-0.276	-0.079	-0.296	-0.128
DON							1.000	0.375	0.145	0.565	0.000	0.077
PN								1.000	0.105	0.266	0.005	0.336
Sal.									1.000	0.221	0.680	0.364
Temp.										1.000	0.120	0.259
Tide Ht.											1.000	0.555
Flow												1.000

Correlations are significant ($\alpha = 0.01$) for $-0.210 > r > 0.210$

Table 3

CORRELATION MATRIX OF NUTRIENT CONCENTRATIONS, SALINITY, WATER TEMPERATURE, TIDE HEIGHT, AND WATER FLOW IN CARTER CREEK OVER THE YEAR

	DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN	Sal.	Temp	Tide Ht.	Flow
DIP	1.000	0.272	0.422	0.209	0.422	0.482	0.327	0.437	-0.597	-0.038	-0.667	-0.391
DOP		1.000	-0.027	-0.459	-0.040	-0.188	0.462	0.038	0.026	0.344	-0.075	-0.086
PP			1.000	0.044	0.450	0.376	0.338	0.935	-0.381	0.262	-0.538	-0.201
NO_3^-				1.000	0.136	0.471	-0.316	0.015	-0.529	-0.769	-0.318	-0.270
NO_2^-					1.000	0.391	0.271	0.427	-0.420	0.164	-0.357	-0.244
NH_4^+						1.000	0.135	0.358	-0.521	-0.168	-0.380	-0.141
DON							1.000	0.274	-0.059	0.067	-0.137	-0.034
PN								1.000	-0.380	0.258	-0.459	-0.151
Sal.									1.000	0.398	0.705	0.448
Temp.										1.000	0.210	0.257
Tide Ht.											1.000	0.616
Flow												1.000

Correlations are significant ($\alpha = 0.01$) for $-0.210>r>0.210$

Figure 7. Annual variation in mean water temperature over a tidal cycle for Ware Creek and Carter Creek marshes.

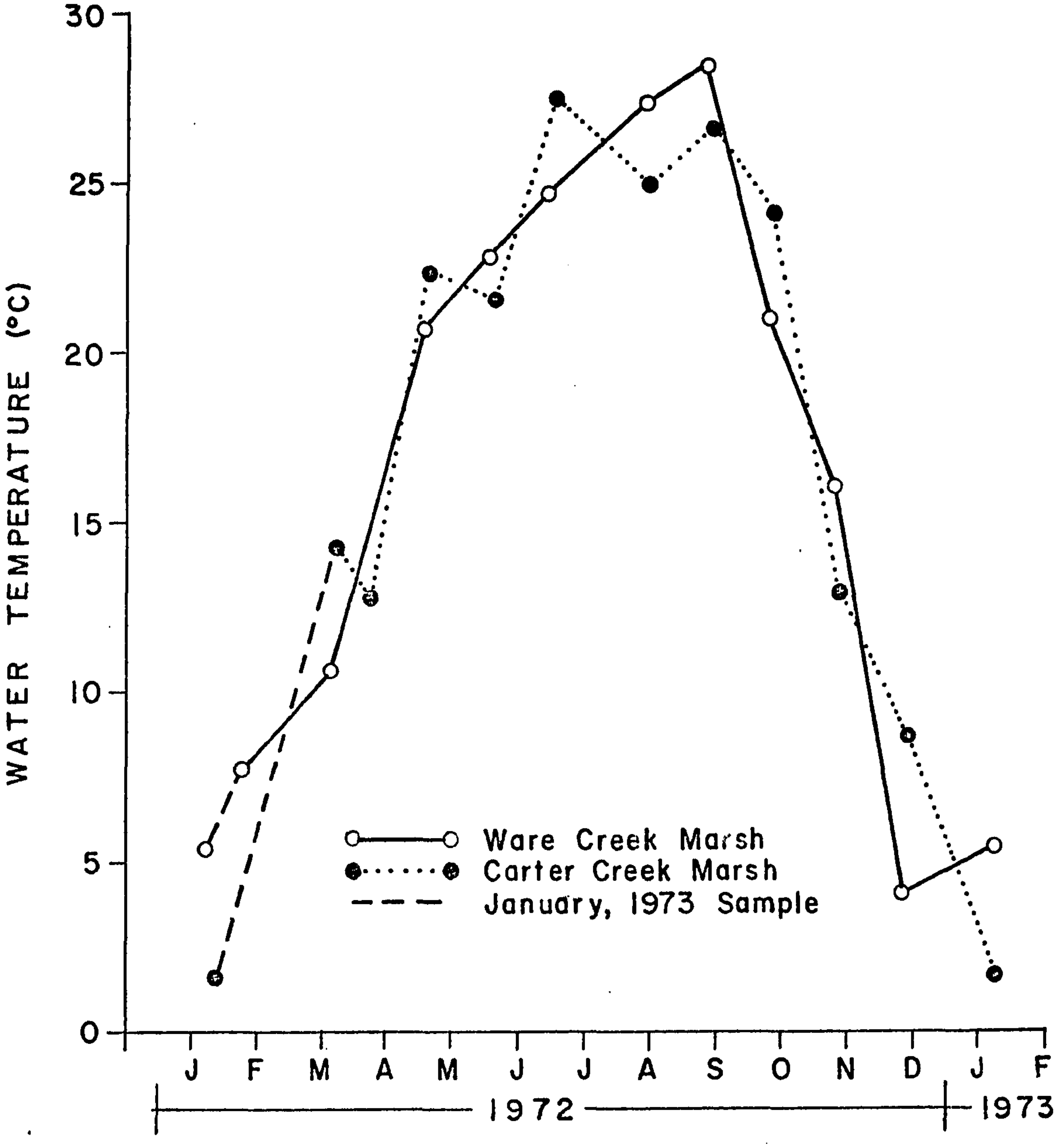
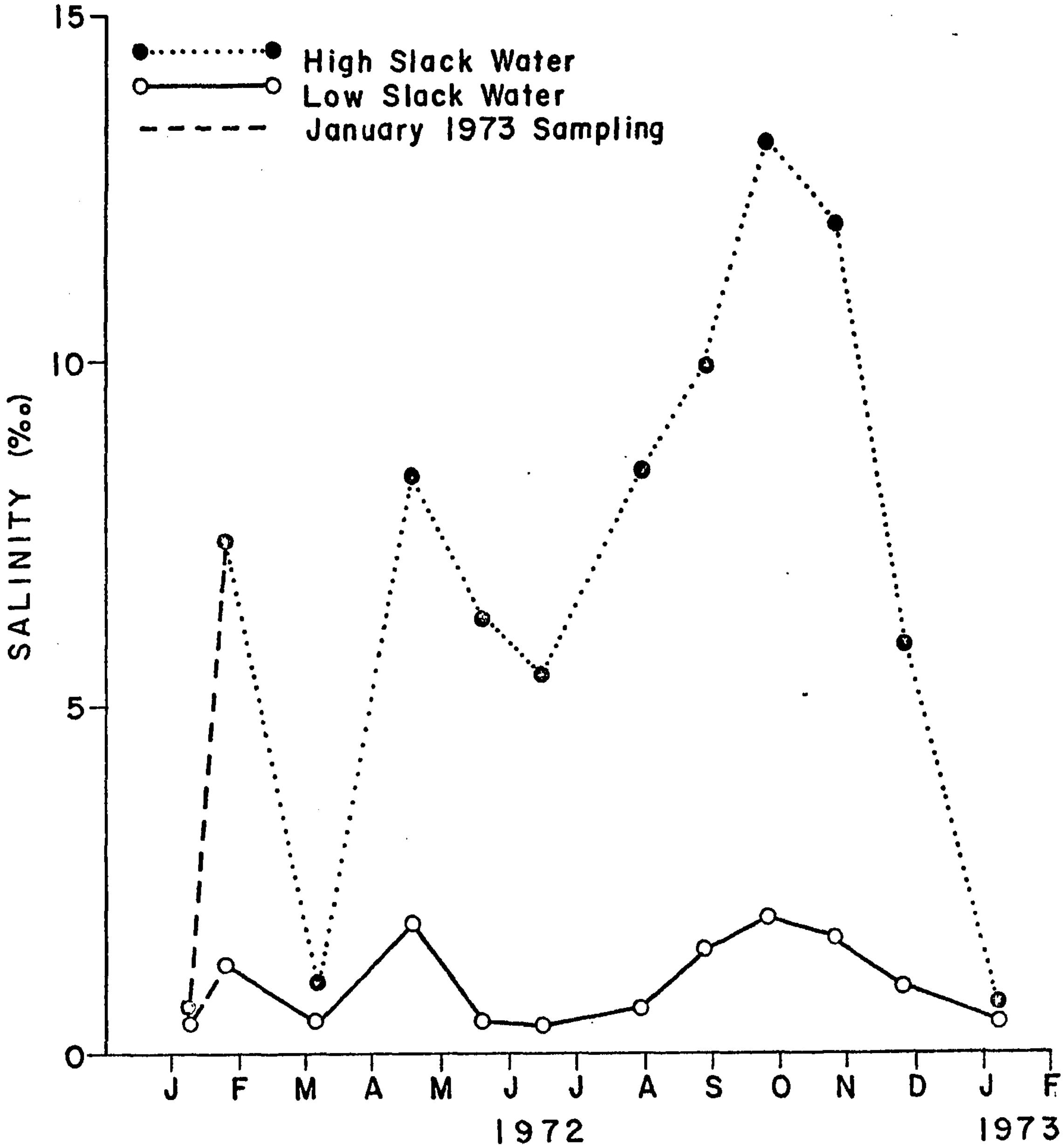

WATER TEMPERATURE (°C)
30
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973
Ware Creek Marsh
Carter Creek Marsh
January, 1973 Sample

Figure 8. Annual variation in Ware Creek marsh high slack water and low slack water salinity. Low slack water salinities are means of the two low slack waters sampled during each tidal cycle.



High Slack Water
Low Slack Water
January 1973 Sampling
SALINITY (‰)
0
5
10
15
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 9. Annual variation in Carter Creek marsh high slack water and low slack water salinity. Low slack water salinities are means of the two low slack waters sampled during each tidal cycle.

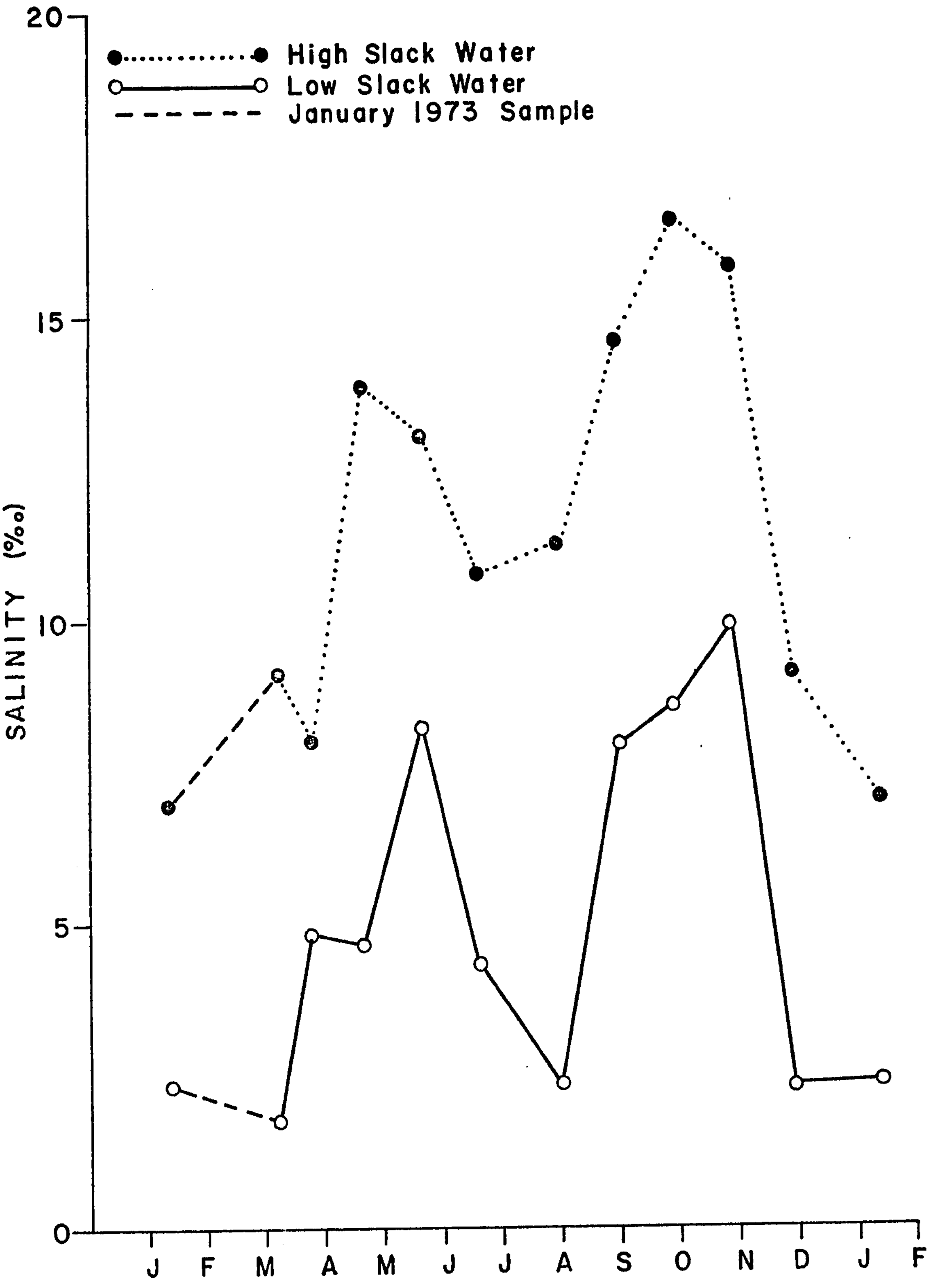

20
15
10
5
0
SALINITY (‰)
●·········● High Slack Water
○———○ Low Slack Water
- - - - - - January 1973 Sample
J
F
M
A
M
J
J
A
S
O
N
D
J
F

Figure 10. Annual variation in Ware Creek marsh high slack water and low slack water dissolved inorganic phosphorus concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

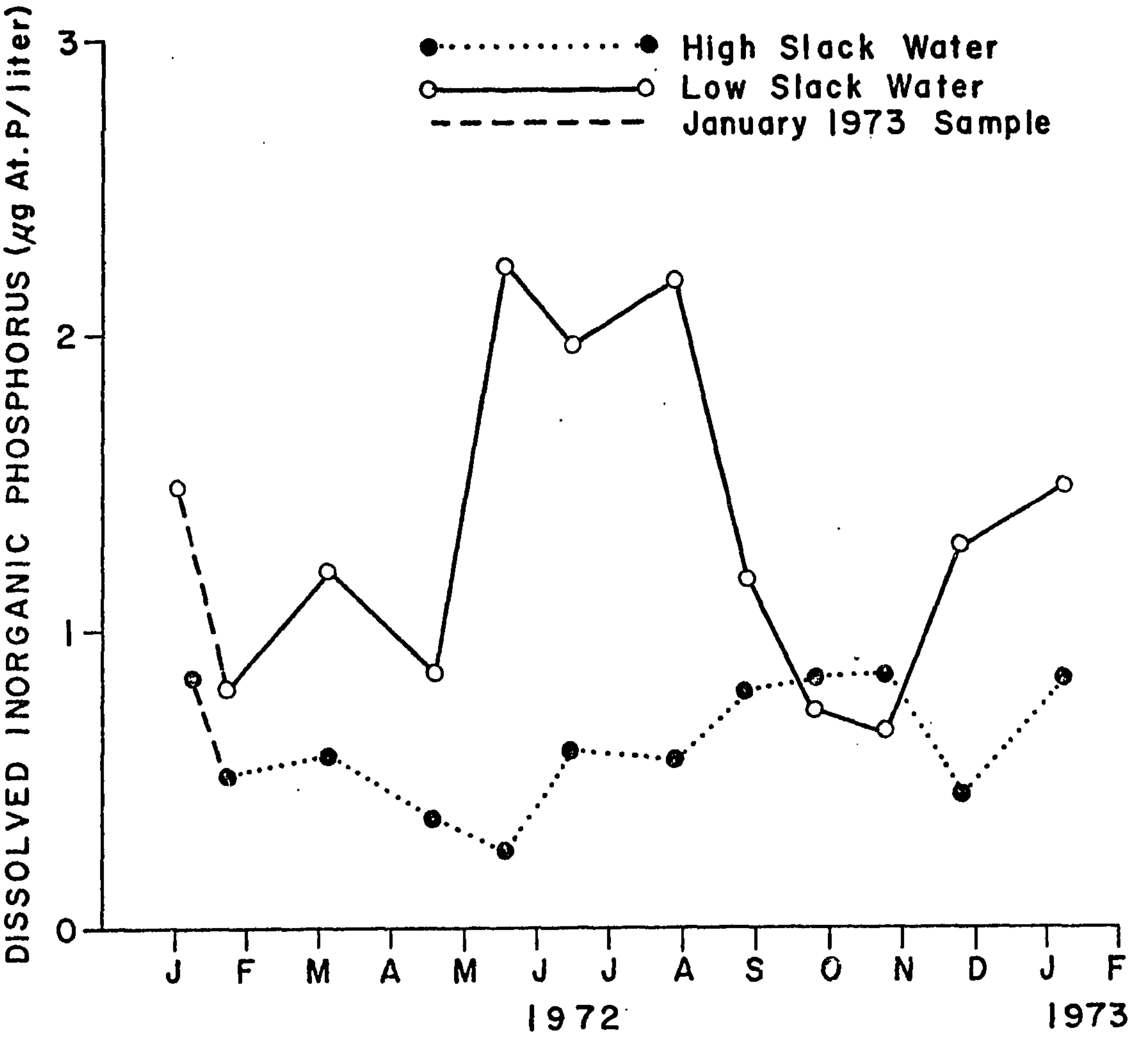

DISSOLVED INORGANIC PHOSPHORUS (μg At. P/liter)
3
2
1
0
High Slack Water
Low Slack Water
January 1973 Sample
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 11. Annual variation in Carter Creek marsh high slack water and low slack water dissolved inorganic phosphorus concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

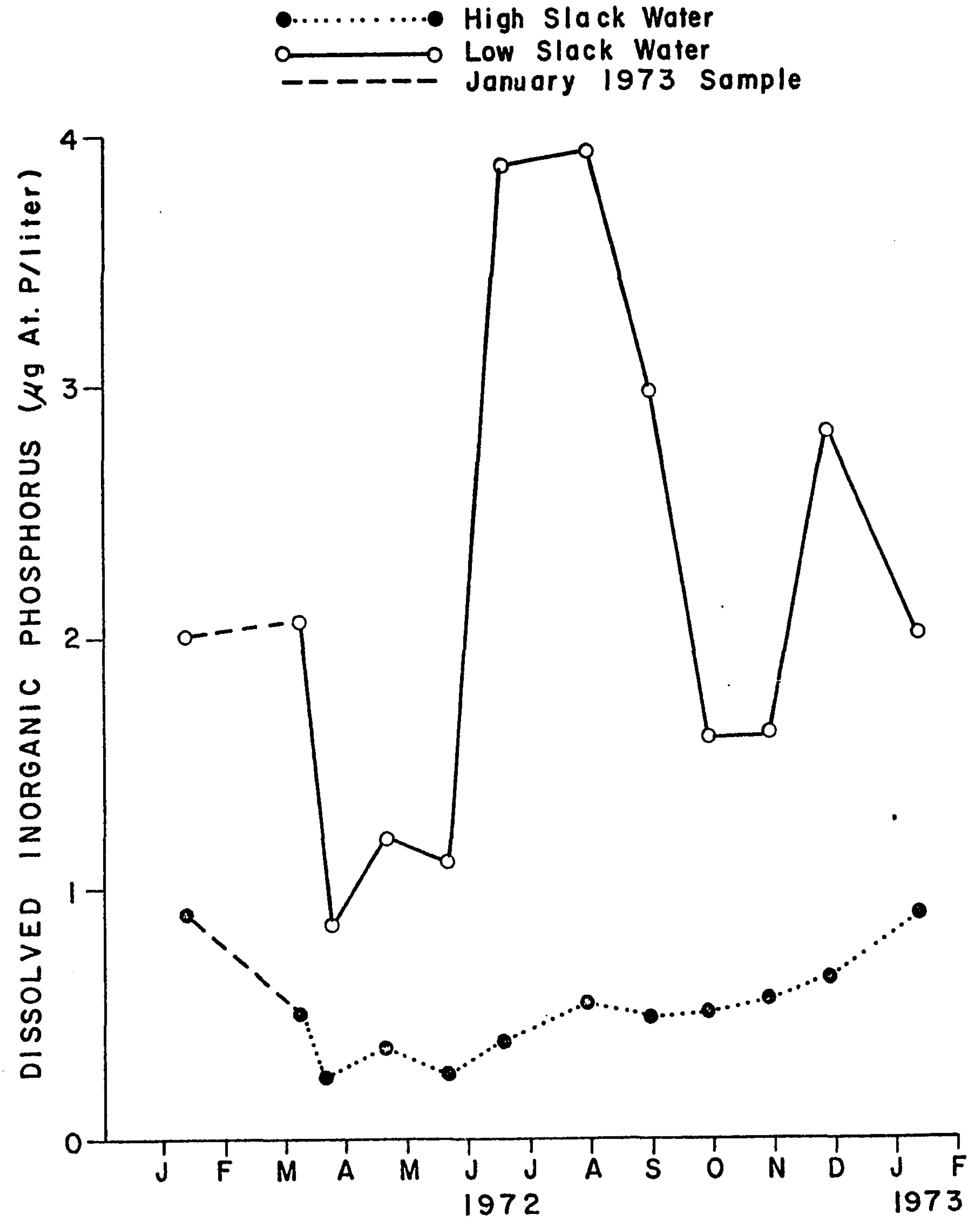

●·········● High Slack Water
○———○ Low Slack Water
– – – – – January 1973 Sample
DISSOLVED INORGANIC PHOSPHORUS (µg At. P/liter)
4
3
2
1
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 12. Annual variation in Ware Creek marsh high slack water and low slack water dissolved organic phosphorus concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

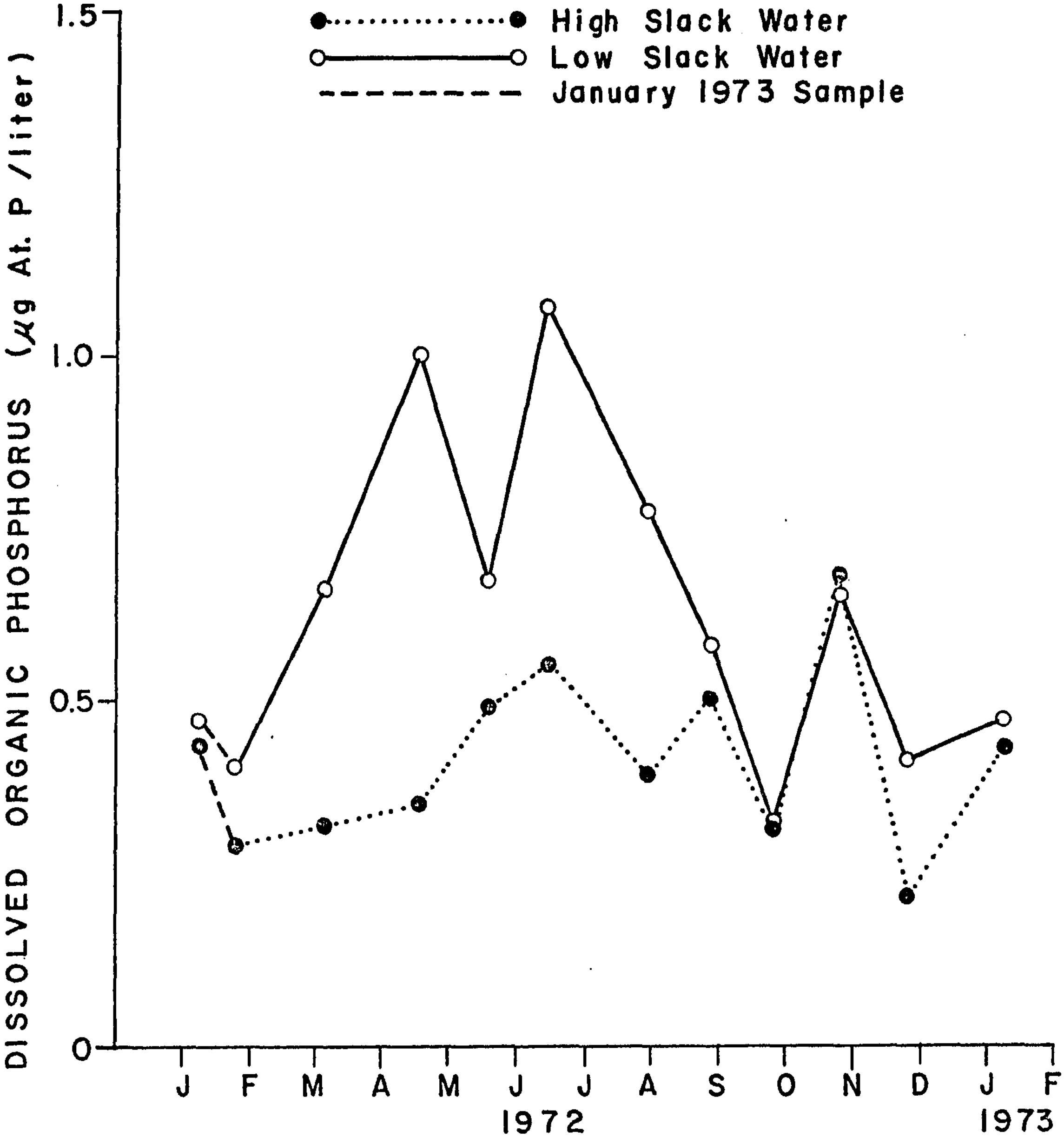

High Slack Water
Low Slack Water
January 1973 Sample
DISSOLVED ORGANIC PHOSPHORUS (µg At. P /liter)
1.5
1.0
0.5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 13. Annual variation in Carter Creek marsh high slack water and low slack water dissolved organic phosphorus concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

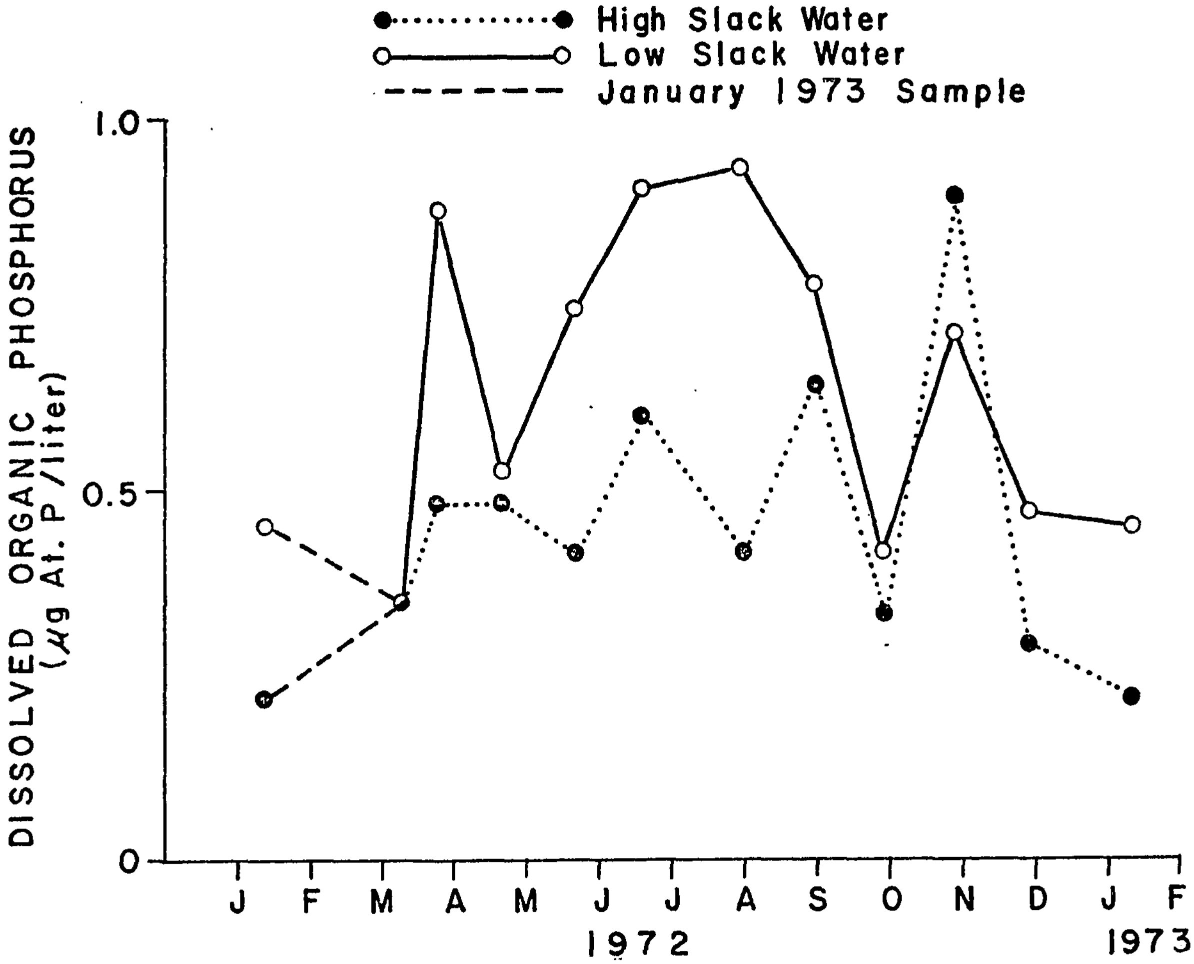

High Slack Water
Low Slack Water
January 1973 Sample
DISSOLVED ORGANIC PHOSPHORUS
(µg At. P /liter)
1.0
0.5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 14. Annual variation in Ware Creek marsh high slack water and low slack water particulate phosphorus concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

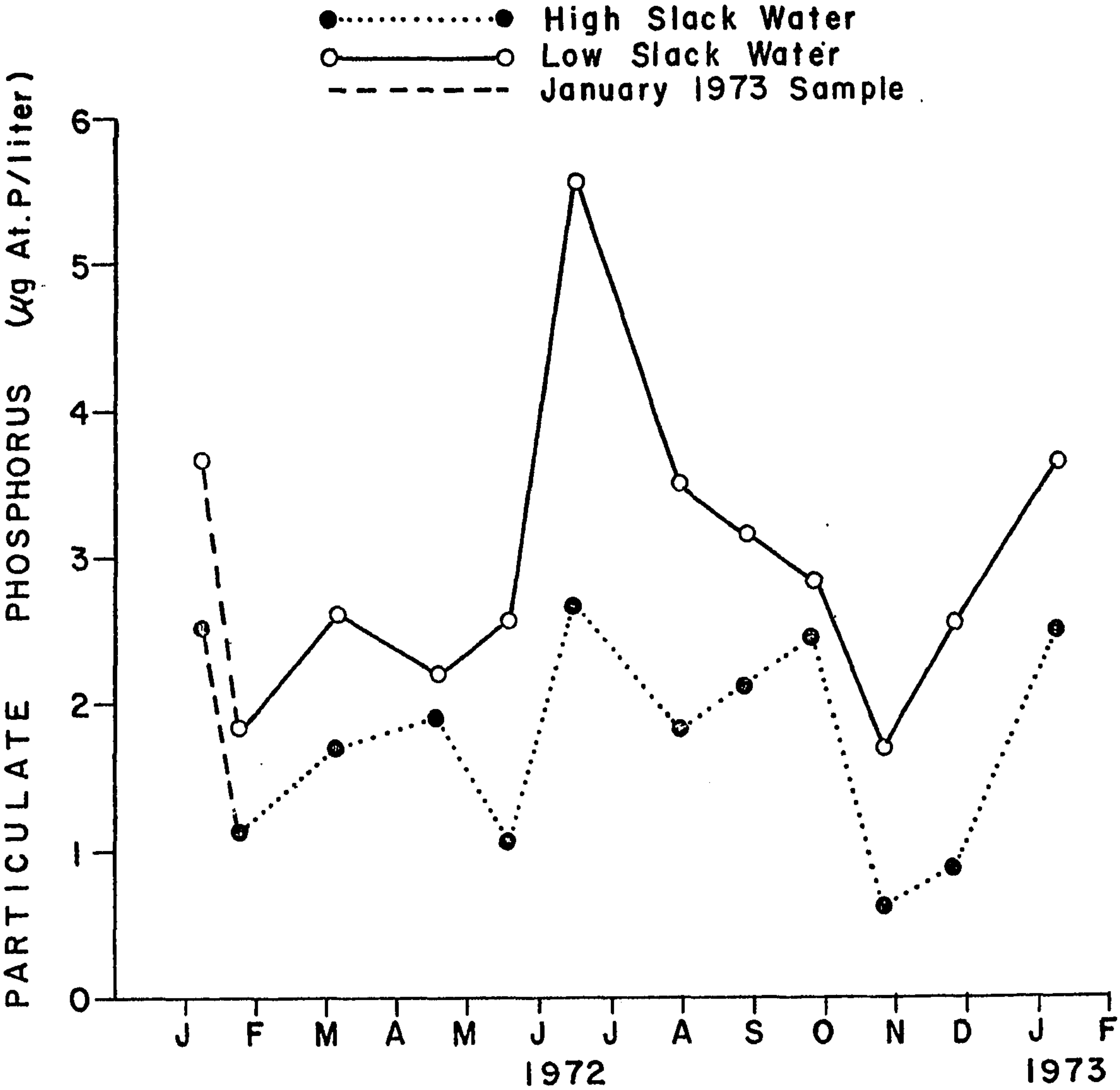

High Slack Water
Low Slack Water
January 1973 Sample
PARTICULATE PHOSPHORUS (µg At. P/liter)
0
1
2
3
4
5
6
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 15. Annual variation in Carter Creek marsh high slack water and low slack water particulate phosphorus concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

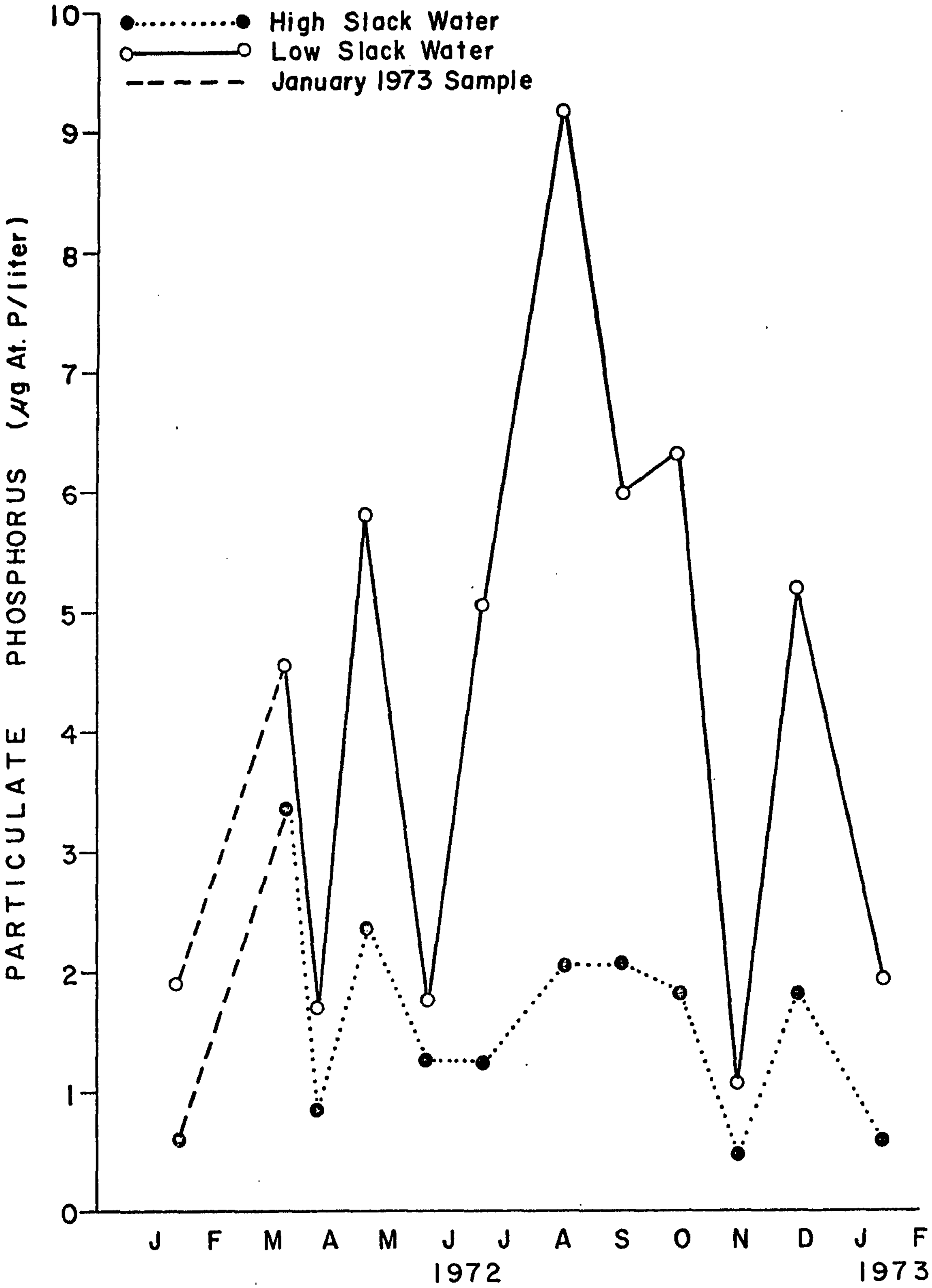

●·········● High Slack Water
○———○ Low Slack Water
– – – – January 1973 Sample
PARTICULATE PHOSPHORUS (µg At. P/liter)
10
9
8
7
6
5
4
3
2
1
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 16. Annual variation in Ware Creek marsh high slack water and low slack water nitrate concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

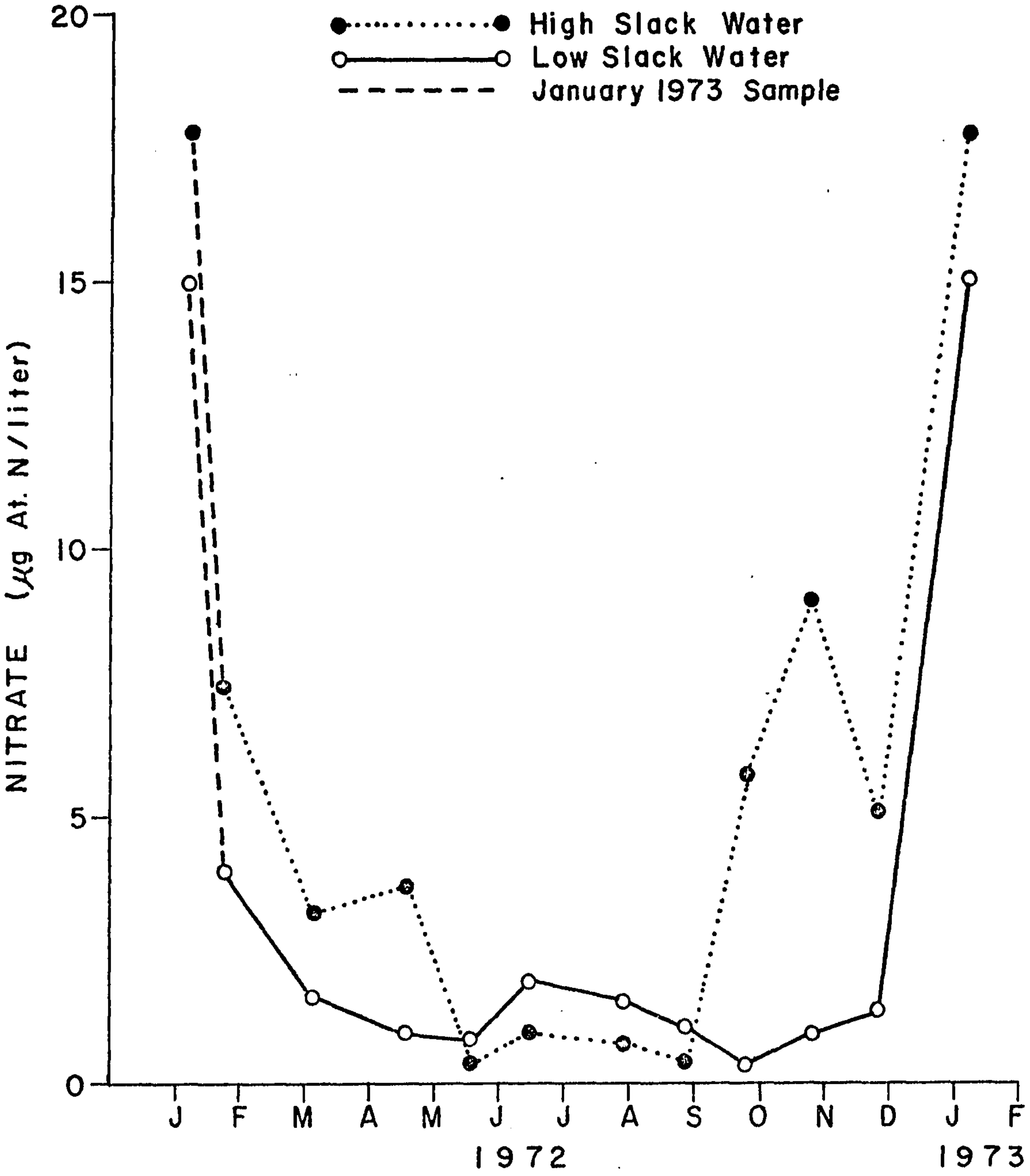

High Slack Water
Low Slack Water
January 1973 Sample
NITRATE (µg At. N/liter)
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 17. Annual variation in Carter Creek marsh high slack water and low slack water nitrate concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

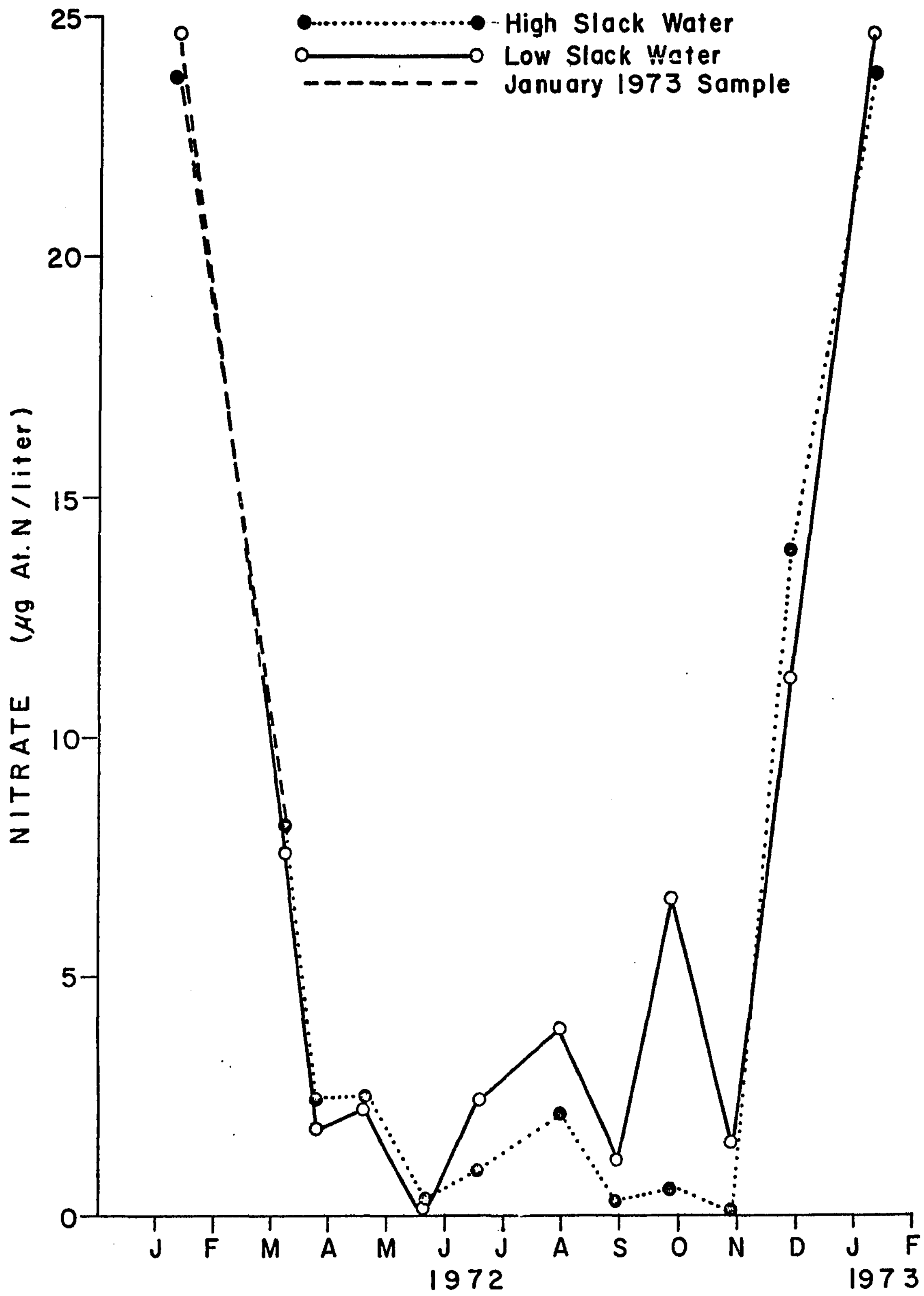

High Slack Water
Low Slack Water
January 1973 Sample
NITRATE (μg At. N / liter)
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 18. Annual variation in Ware Creek marsh high slack water and low slack water nitrite concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

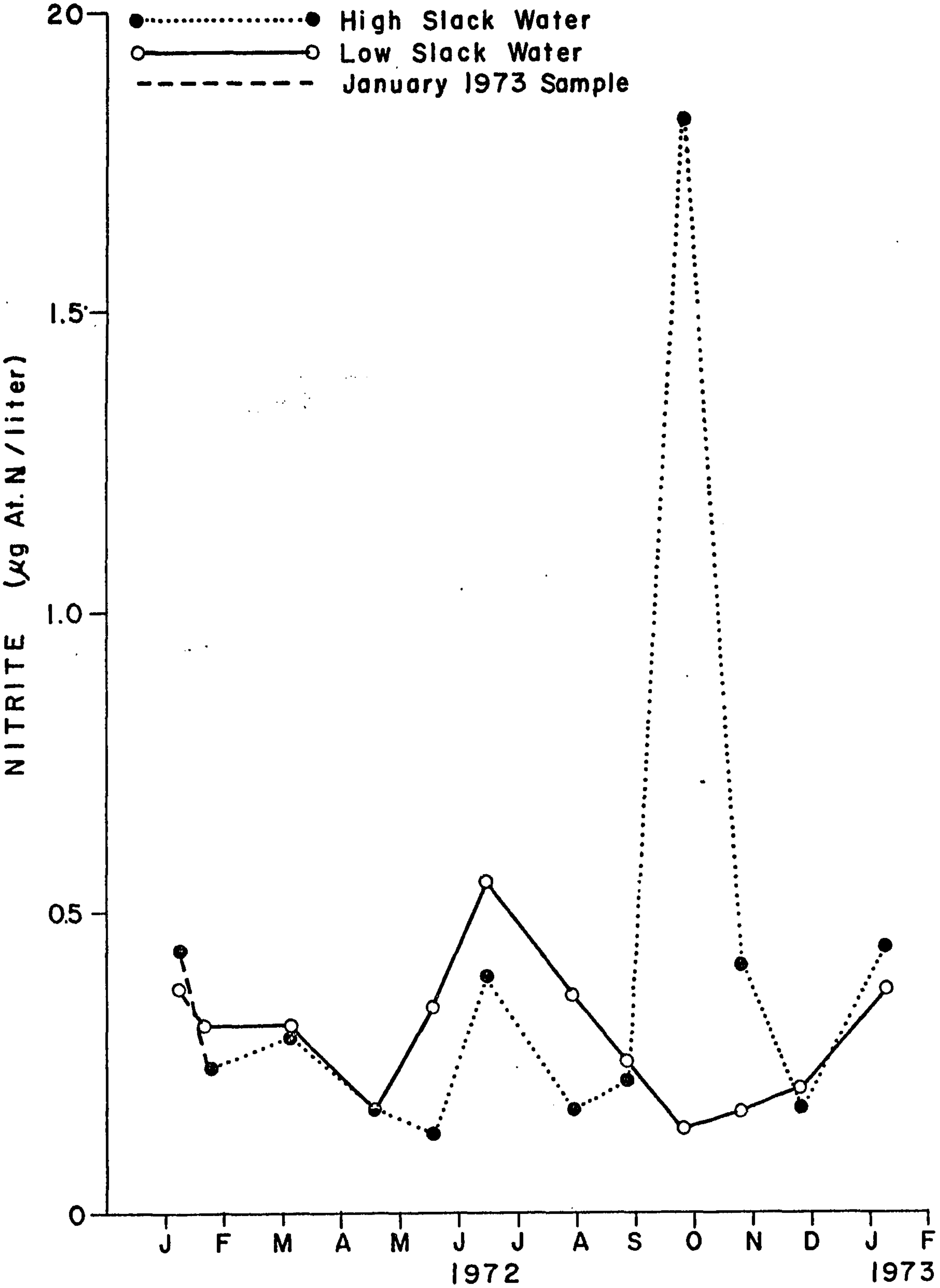

High Slack Water
Low Slack Water
January 1973 Sample
NITRITE (µg At. N/liter)
2.0
1.5
1.0
0.5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 19. Annual variation in Carter Creek marsh high slack water and low slack water nitrite concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

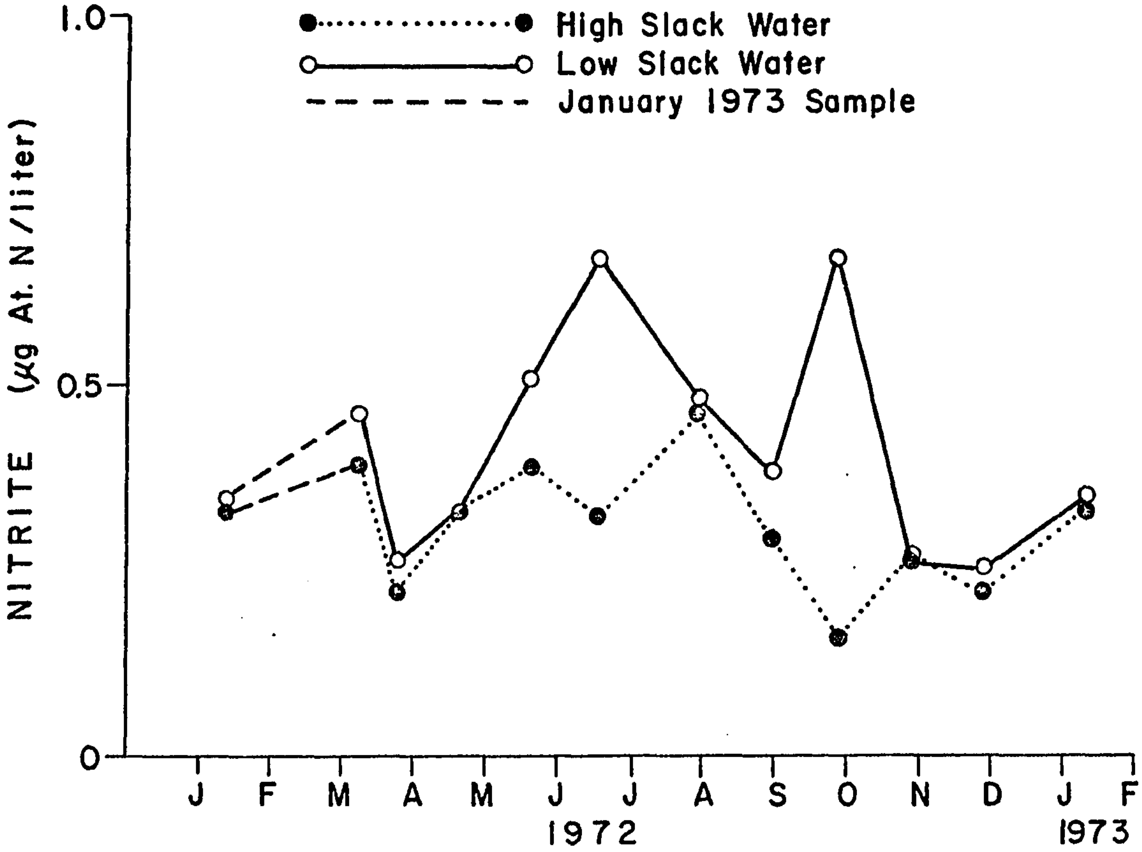

1.0
0.5
0
NITRITE (µg At. N/liter)
High Slack Water
Low Slack Water
January 1973 Sample
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 20. Annual variation in Ware Creek marsh high slack water and low slack water ammonia concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

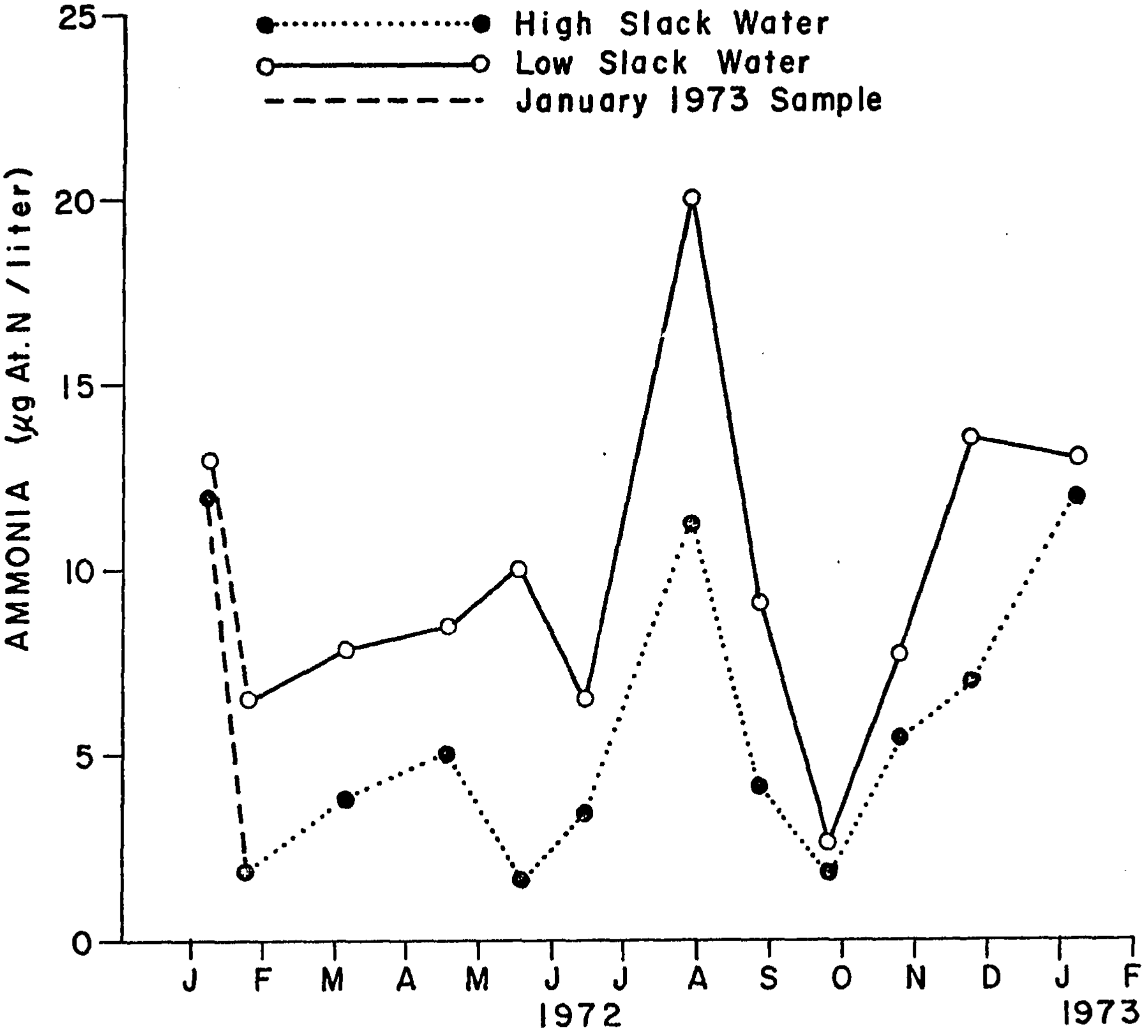

High Slack Water
Low Slack Water
January 1973 Sample
AMMONIA (µg At. N / liter)
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 21. Annual variation in Carter Creek marsh high slack water and low slack water ammonia concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

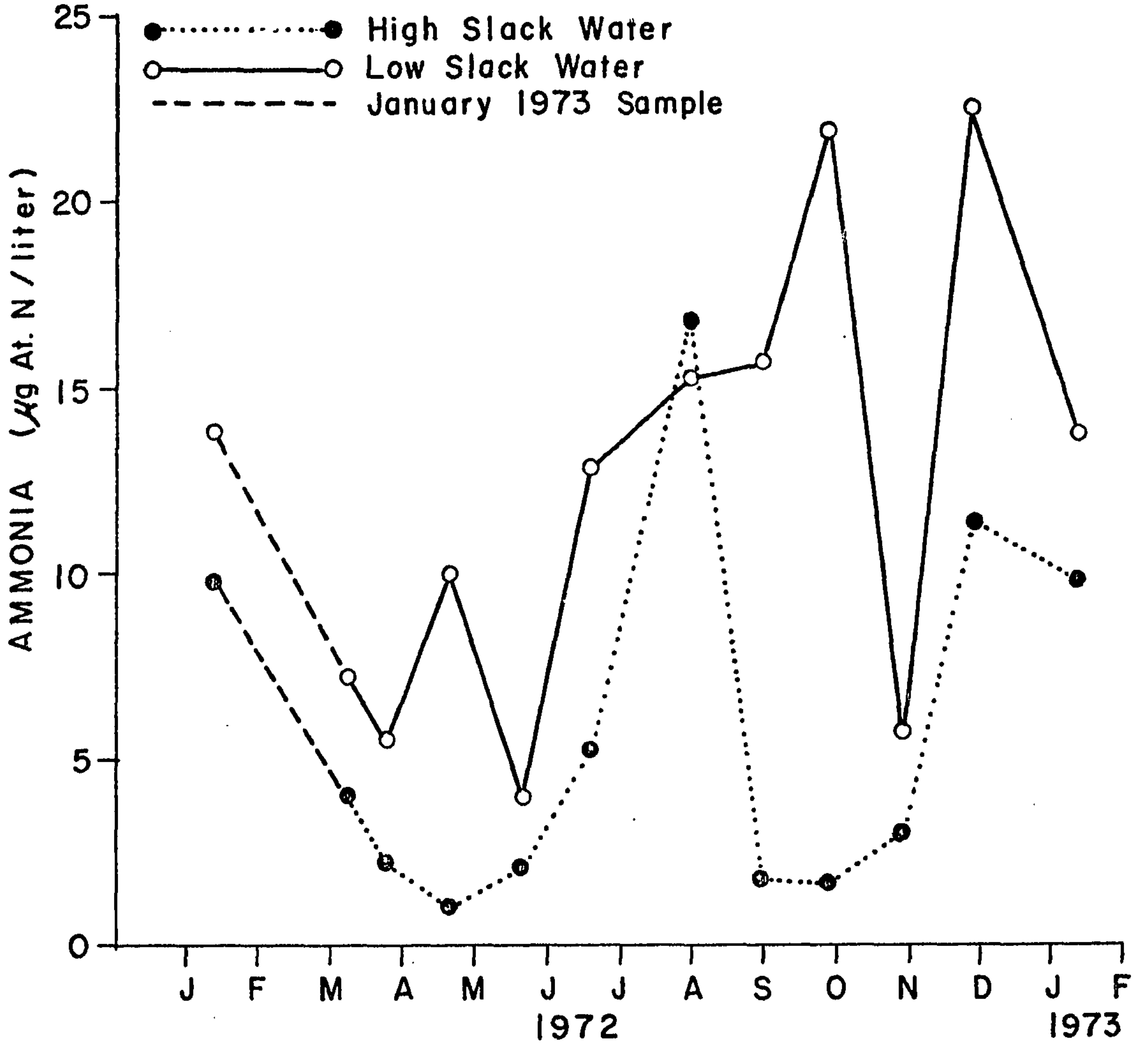

High Slack Water
Low Slack Water
January 1973 Sample
AMMONIA (µg At. N / liter)
0
5
10
15
20
25
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 22. Annual variation in Ware Creek marsh high slack water and low slack water dissolved organic nitrogen concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

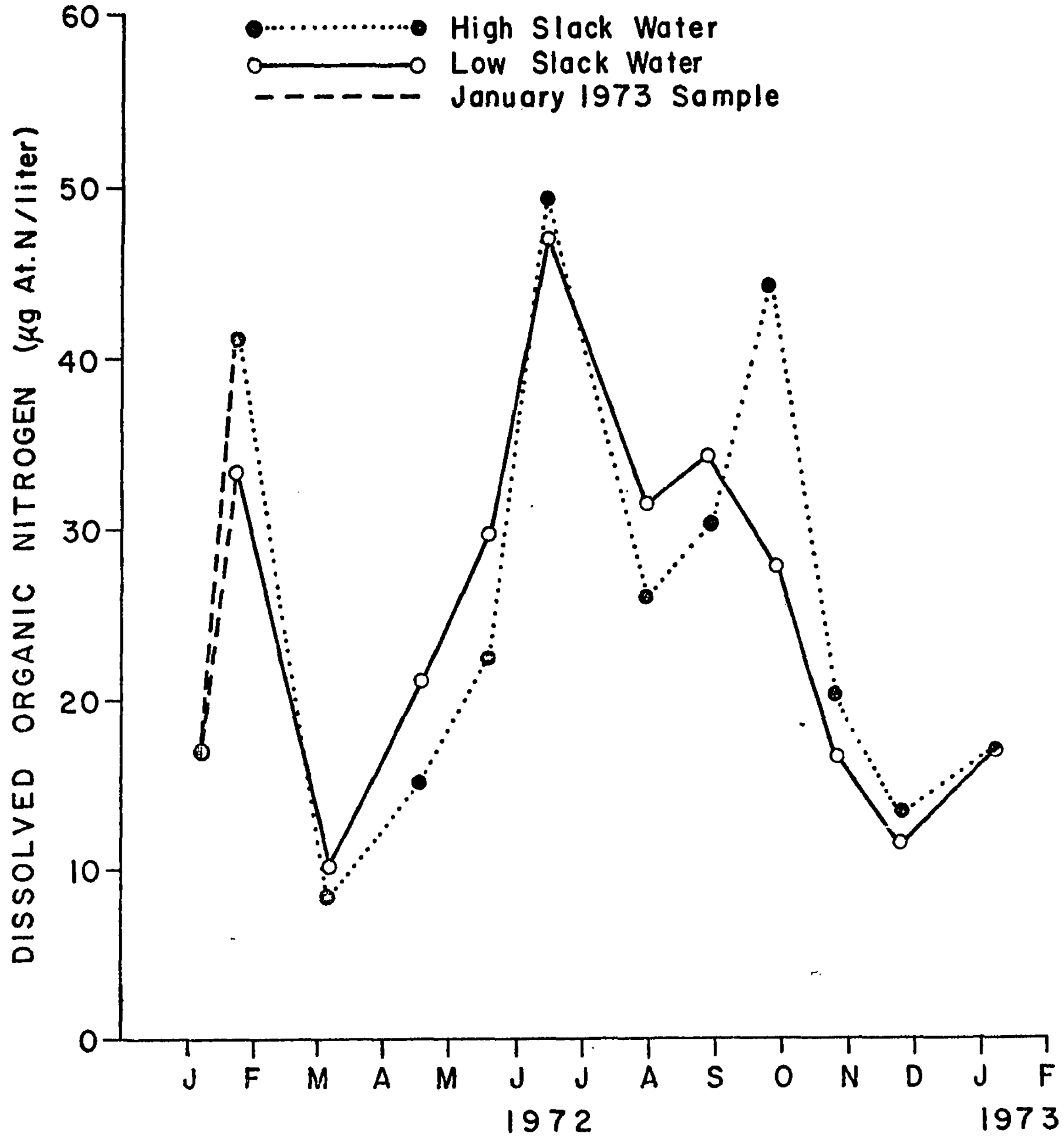
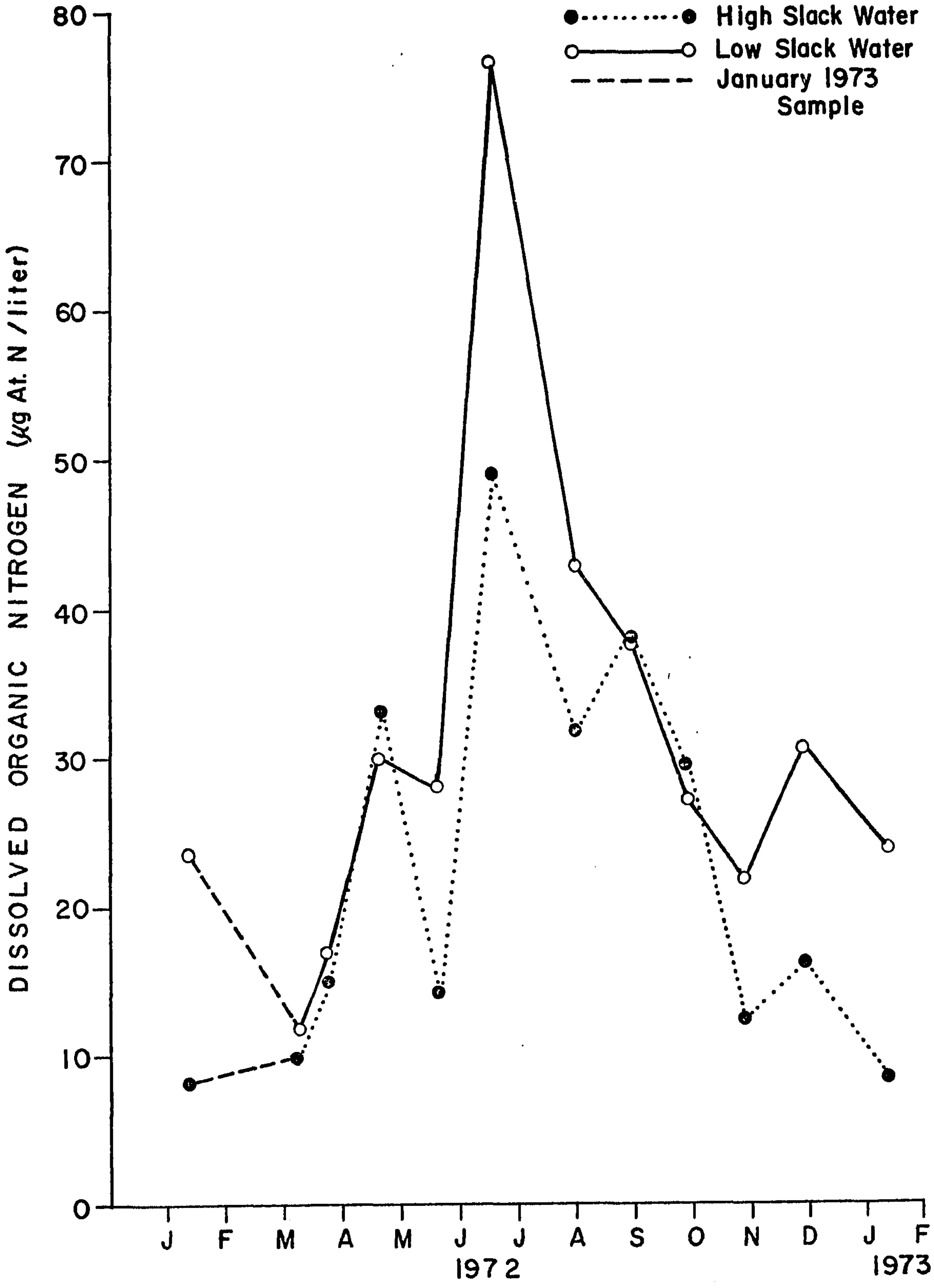
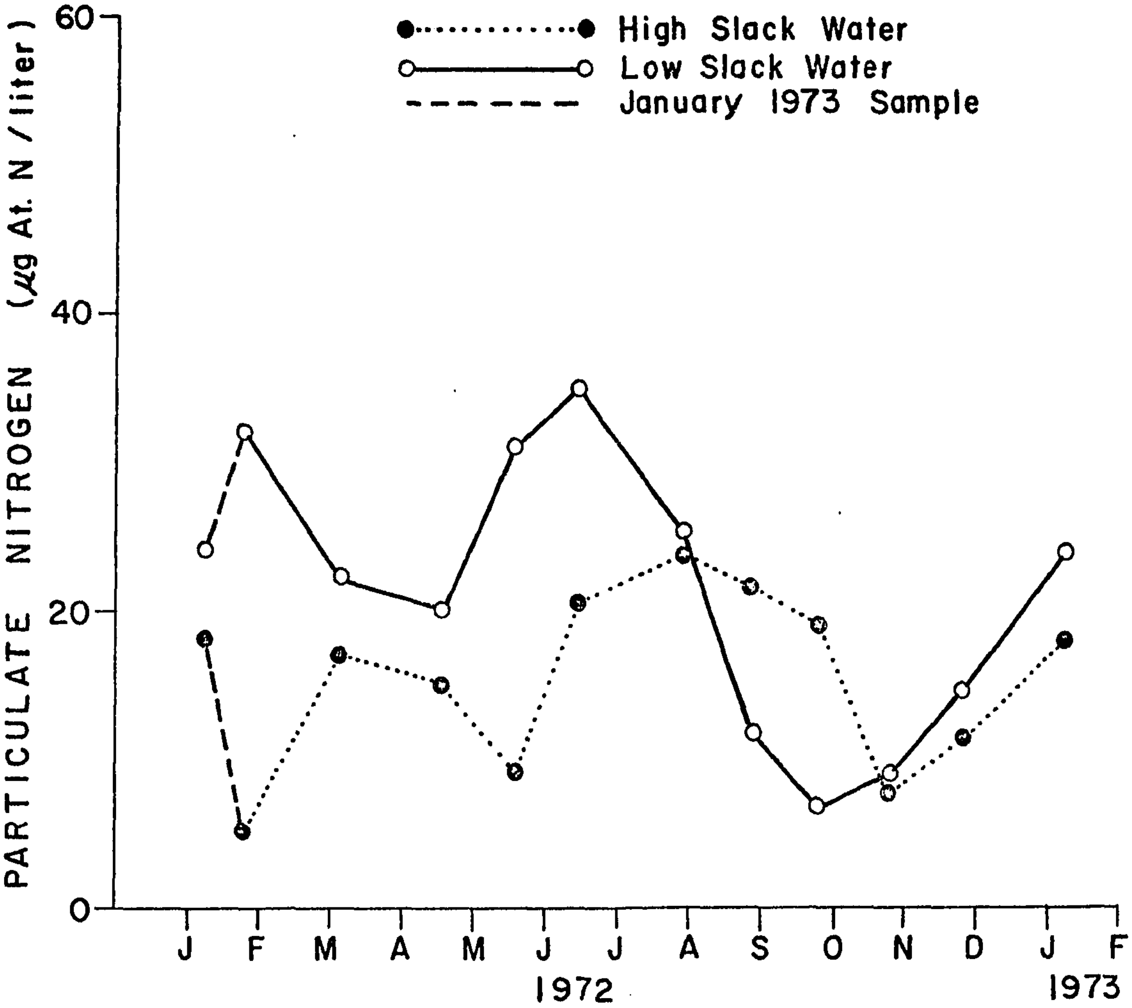

60
50
40
30
20
10
0
DISSOLVED ORGANIC NITROGEN (µg At. N/liter)
High Slack Water
Low Slack Water
January 1973 Sample
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 23. Annual variation in Carter Creek marsh high slack water and low slack water dissolved organic nitrogen concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.



High Slack Water
Low Slack Water
January 1973 Sample
DISSOLVED ORGANIC NITROGEN (µg At. N /liter)
0
10
20
30
40
50
60
70
80
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 24. Annual variation in Ware Creek marsh high slack water and low slack water particulate nitrogen concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.



60
40
20
0
PARTICULATE NITROGEN (μg At. N / liter)
High Slack Water
Low Slack Water
January 1973 Sample
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 25. Annual variation in Carter Creek marsh high slack water and low slack water particulate nitrogen concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

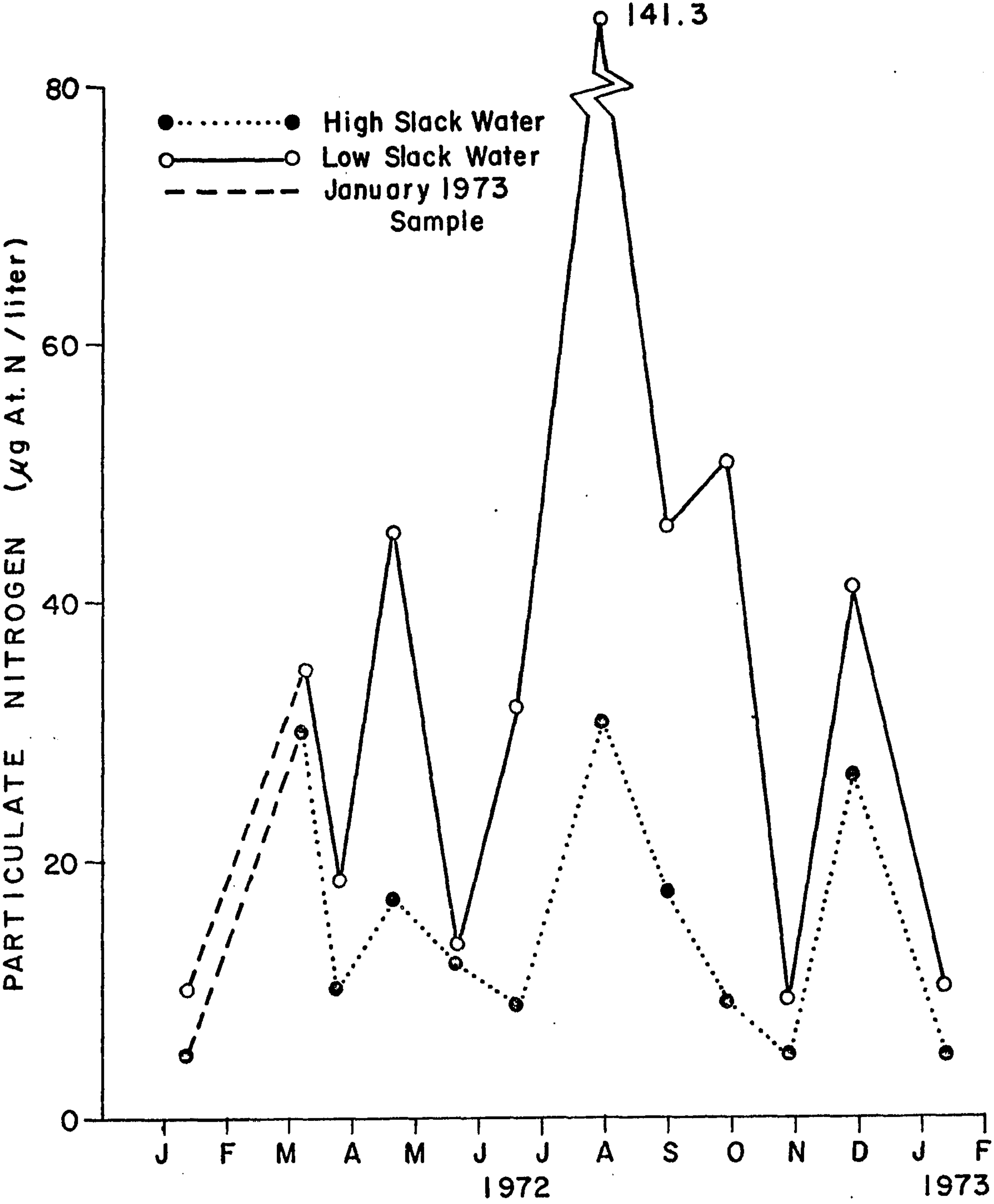
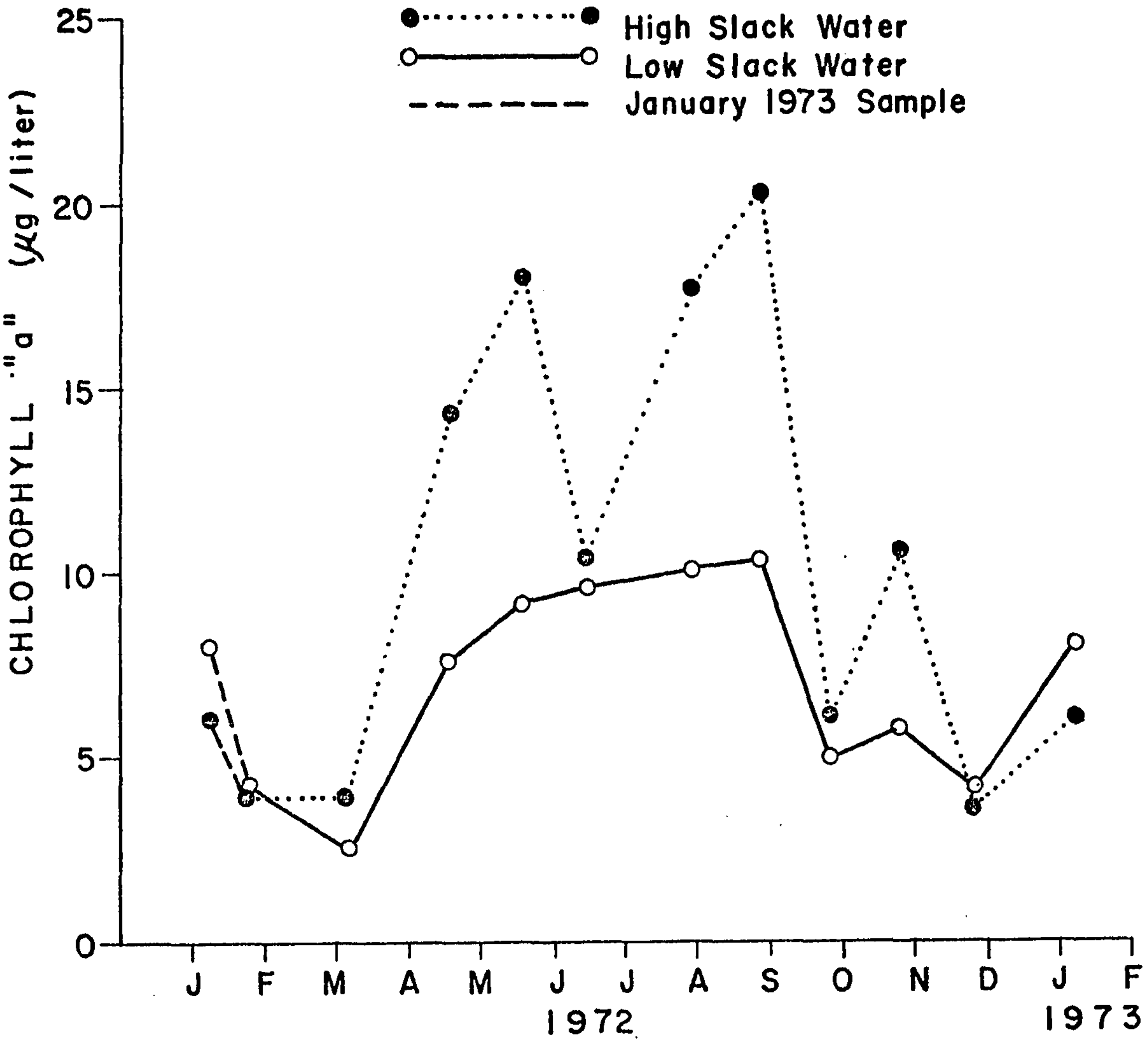

141.3
80
60
40
20
0
PARTICULATE NITROGEN (μg At. N / liter)
●·········● High Slack Water
○———○ Low Slack Water
– – – – – January 1973 Sample
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 26. Annual variation in Ware Creek marsh high slack water and low slack water chlorophyll "a" concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.



●·········● High Slack Water
○——○ Low Slack Water
– – – – – January 1973 Sample
CHLOROPHYLL "a" (µg / liter)
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 27. Annual variation in Carter Creek marsh high slack water and low slack water chlorophyll "a" concentration. Low slack water concentrations are means of the two low slack waters sampled during each tidal cycle.

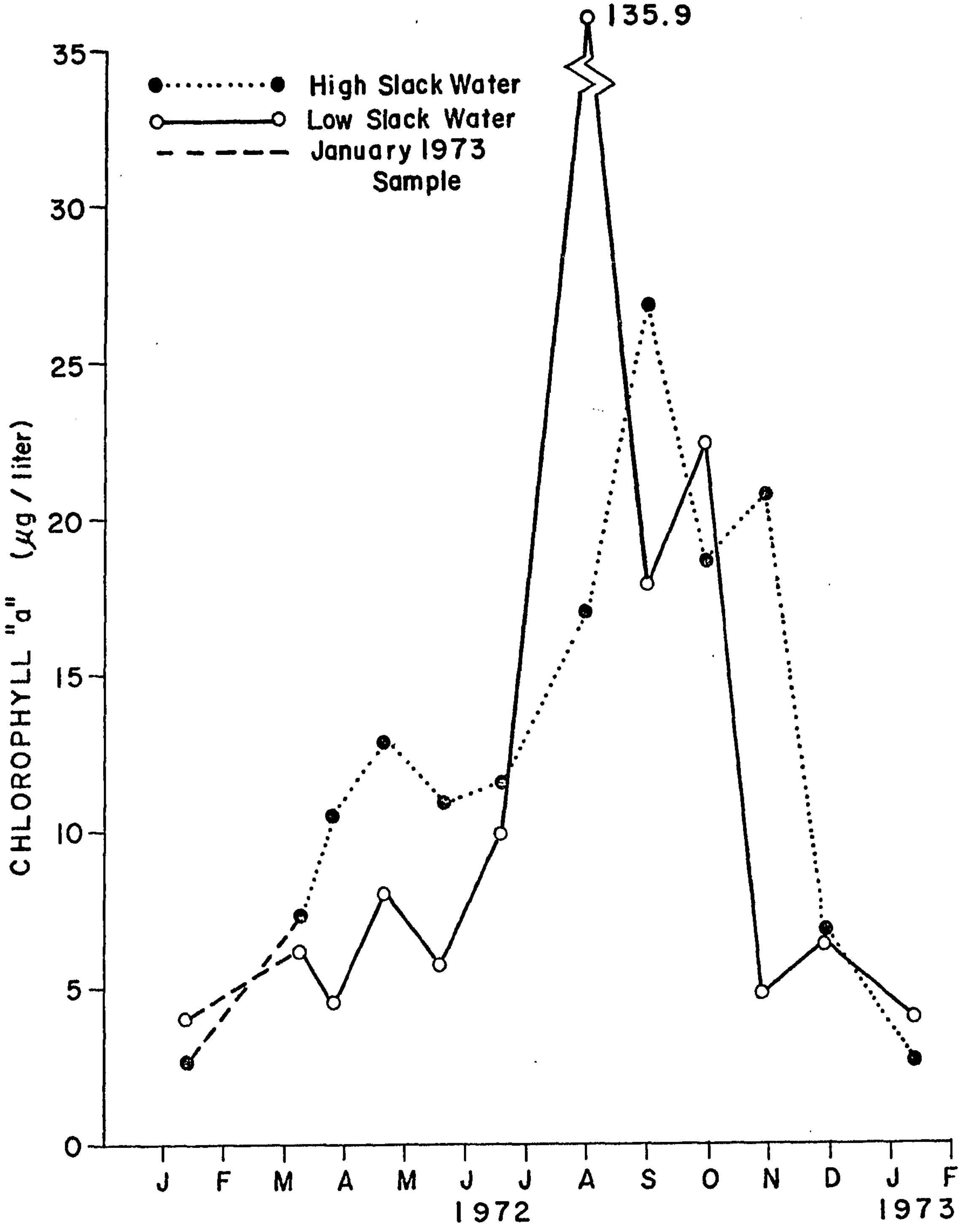

135.9
High Slack Water
Low Slack Water
January 1973 Sample
CHLOROPHYLL "a" (μg / liter)
35
30
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 28. Annual variation in Ware Creek marsh high slack water and low slack water phytoplankton productivity.

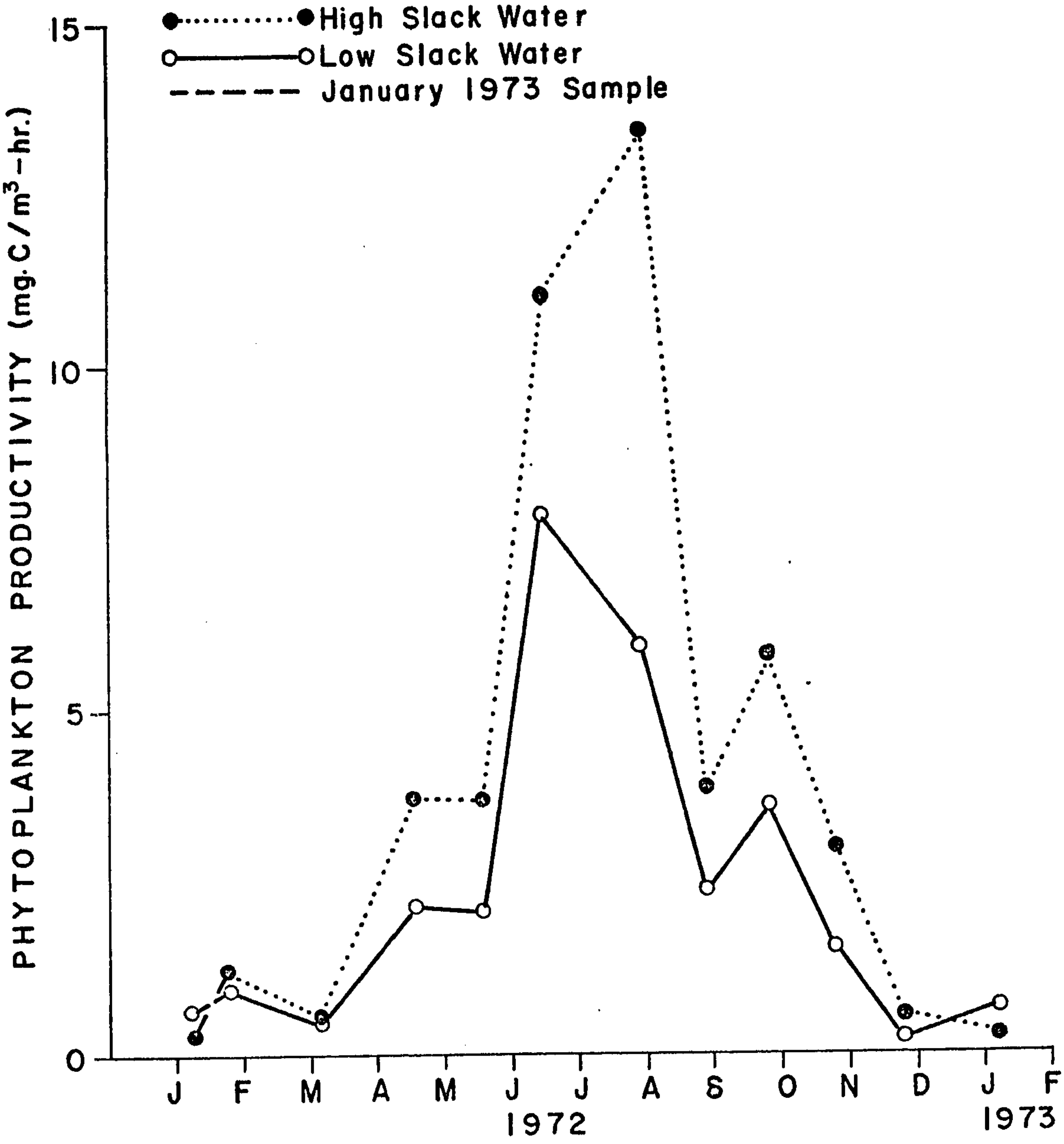

High Slack Water
Low Slack Water
January 1973 Sample
PHYTOPLANKTON PRODUCTIVITY (mg.C/m³-hr.)
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 29. Annual variation in Carter Creek marsh high slack water and low slack water phytoplankton productivity.

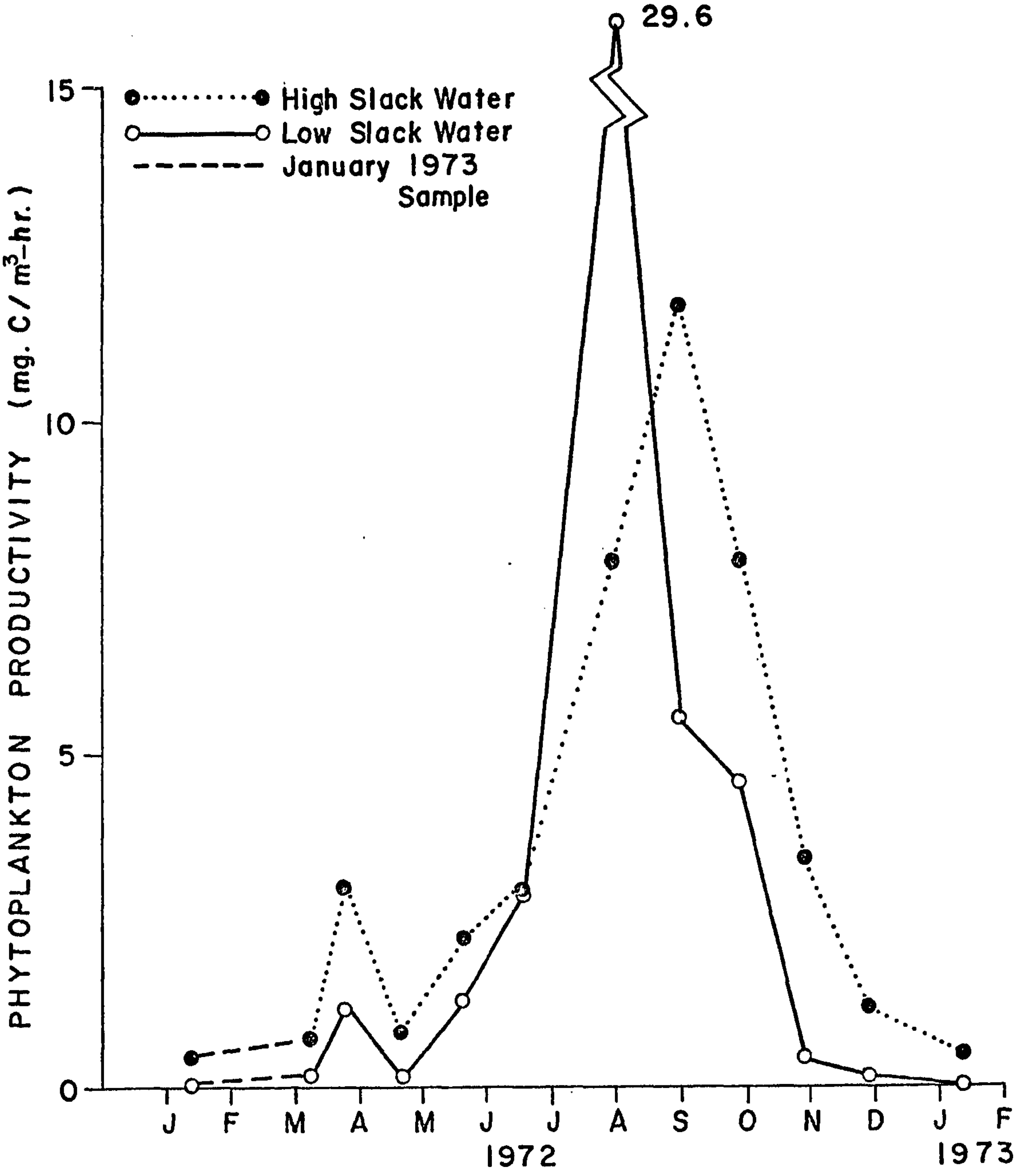

29.6
15
10
5
0
High Slack Water
Low Slack Water
January 1973 Sample
PHYTOPLANKTON PRODUCTIVITY (mg. C/m³-hr.)
J
F
M
A
M
J
J
A
S
O
N
D
J
F
1972
1973

Figure 30. Variation in dissolved inorganic phosphorus concentration over Ware Creek marsh summer and winter tidal cycles.

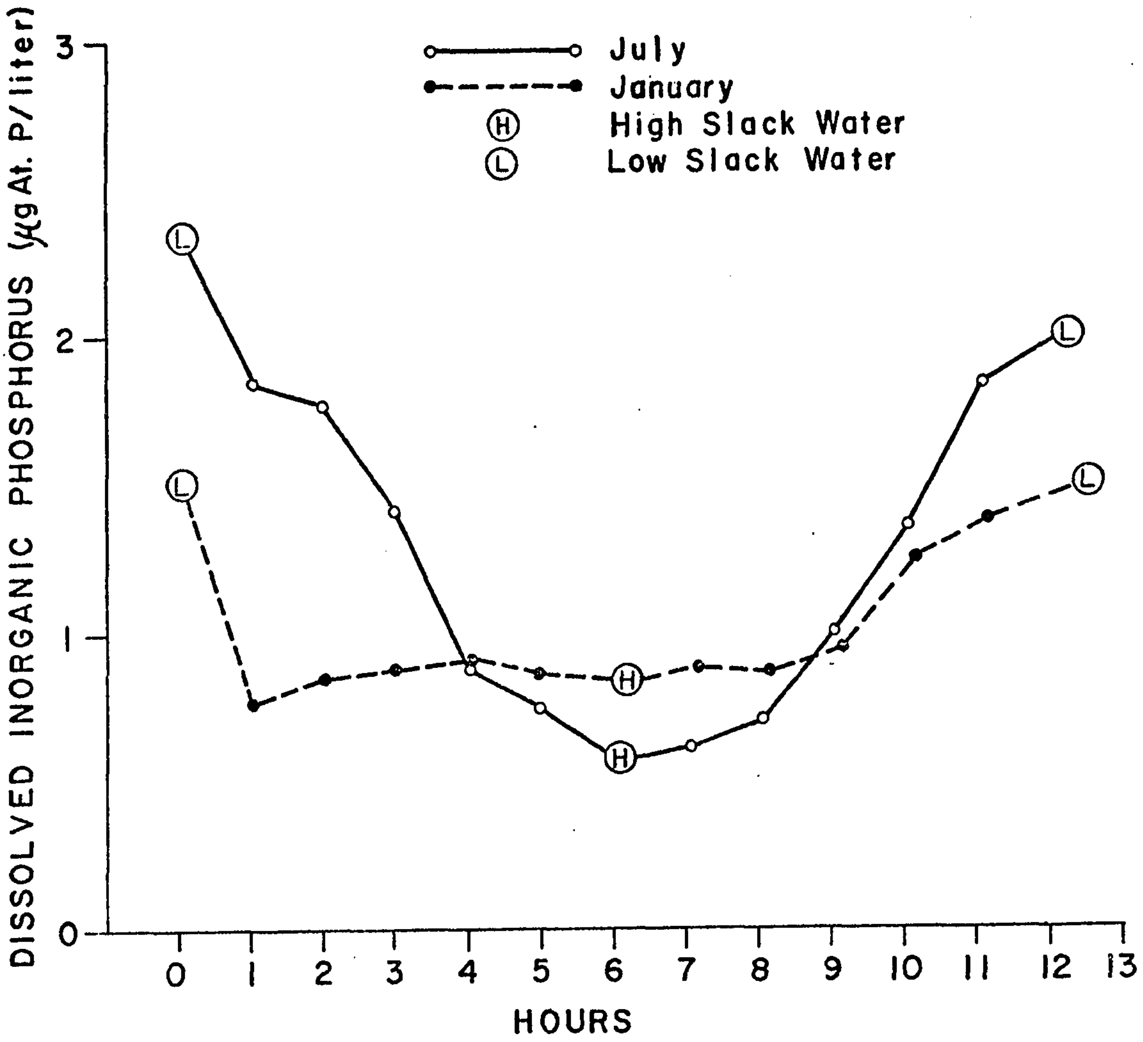

July
January
Ⓗ High Slack Water
Ⓛ Low Slack Water
DISSOLVED INORGANIC PHOSPHORUS (μg At. P/liter)
0
1
2
3
HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Ⓛ
Ⓗ

Figure 31. Variation in dissolved inorganic phosphorus concentration over Carter Creek marsh summer and winter tidal cycles.

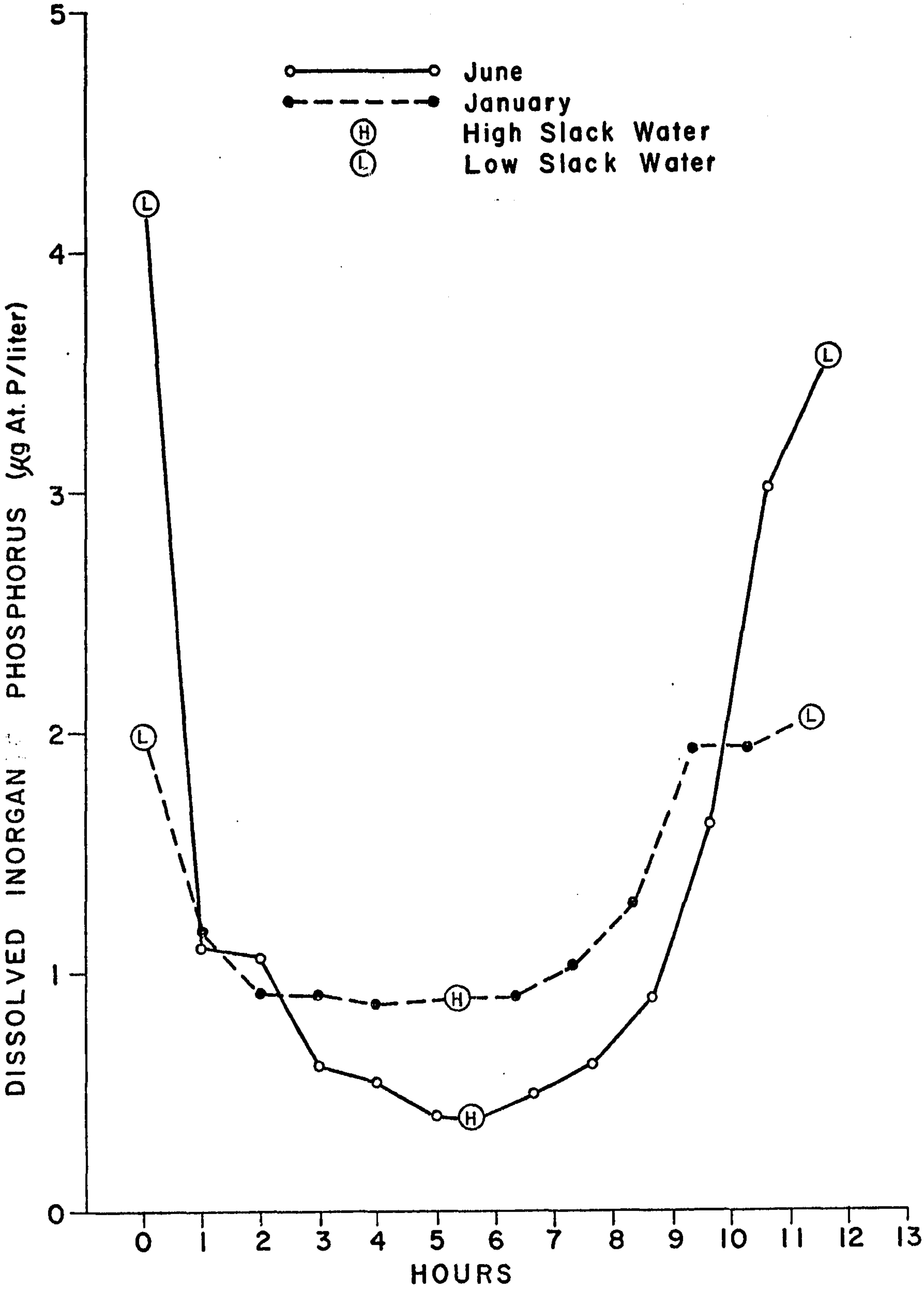

June
January
Ⓗ High Slack Water
Ⓛ Low Slack Water
DISSOLVED INORGANIC PHOSPHORUS (µg At. P/liter)
0
1
2
3
4
5
HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
L
H
L
L
H
L

Figure 32. Variation in dissolved organic phosphorus concentration over Ware Creek marsh summer and winter tidal cycles.

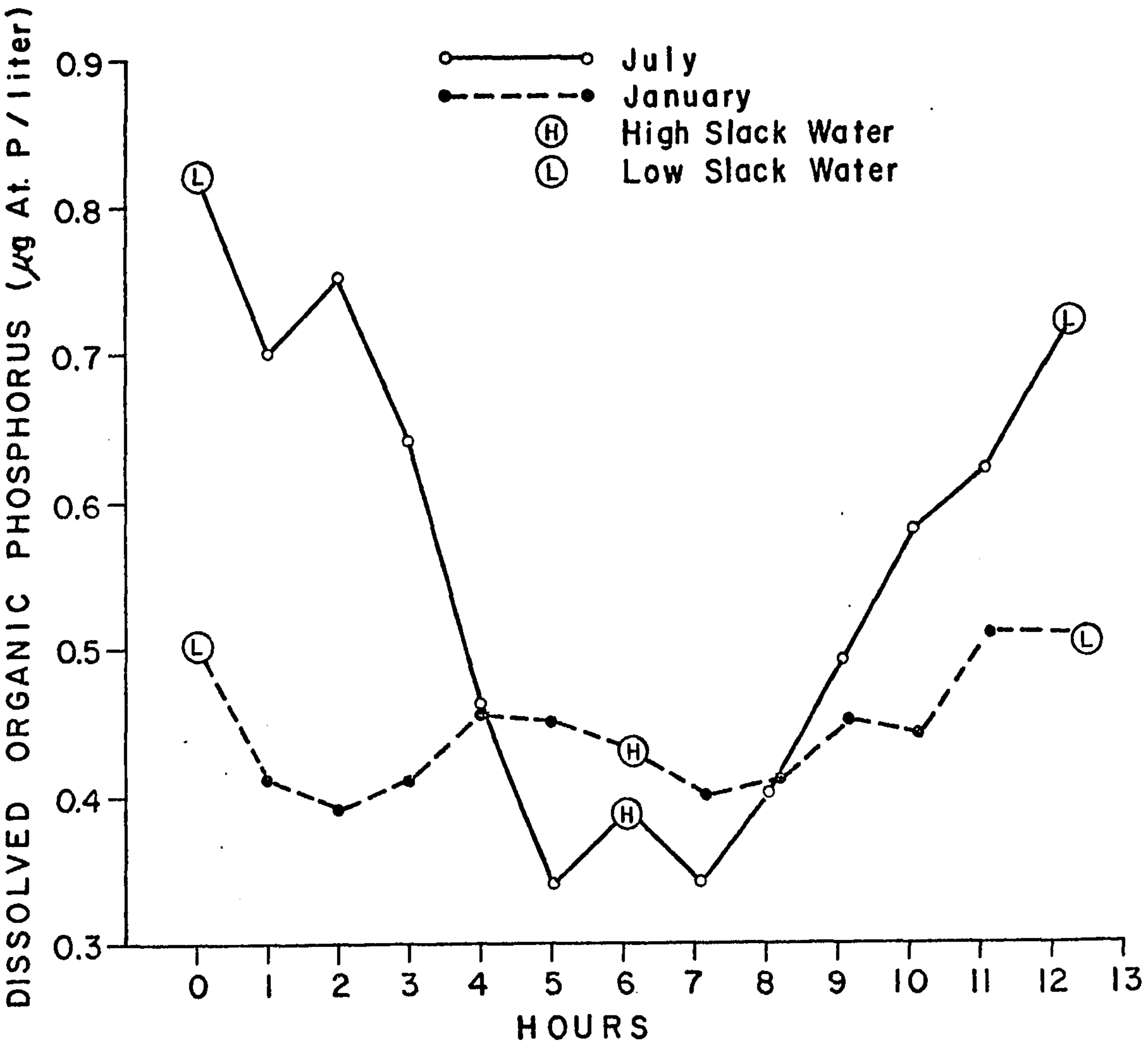

DISSOLVED ORGANIC PHOSPHORUS (µg At. P / liter)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
July
January
H High Slack Water
L Low Slack Water
L
H
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS

Figure 33. Variation in dissolved organic phosphorus concentration over Carter Creek marsh summer and winter tidal cycles.

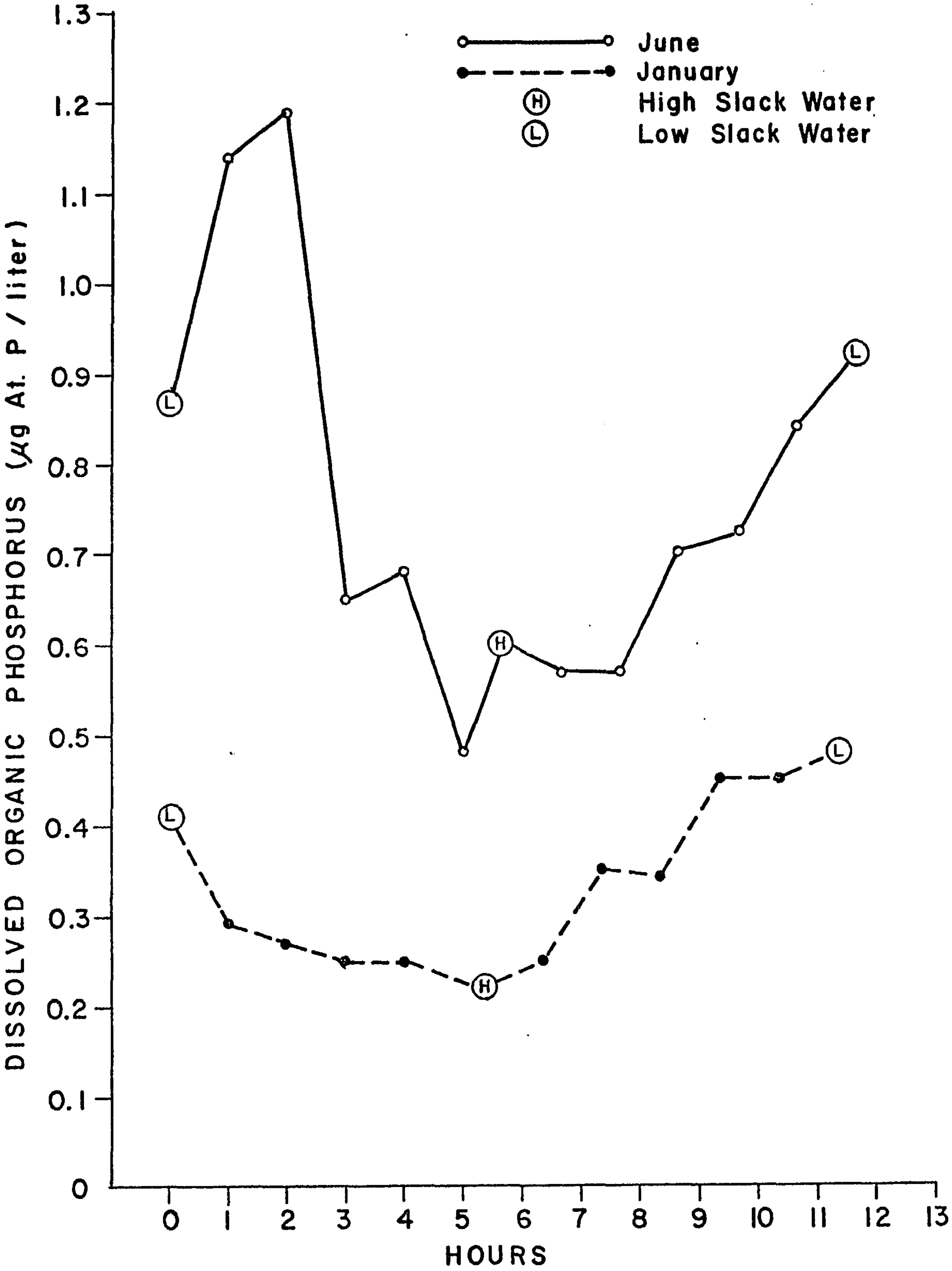

June
January
Ⓗ High Slack Water
Ⓛ Low Slack Water
DISSOLVED ORGANIC PHOSPHORUS (μg At. P / liter)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
Ⓛ
Ⓗ
Ⓛ
Ⓛ
Ⓗ
Ⓛ

Figure 34. Variation in particulate phosphorus concentration over Ware Creek marsh summer and winter tidal cycles.

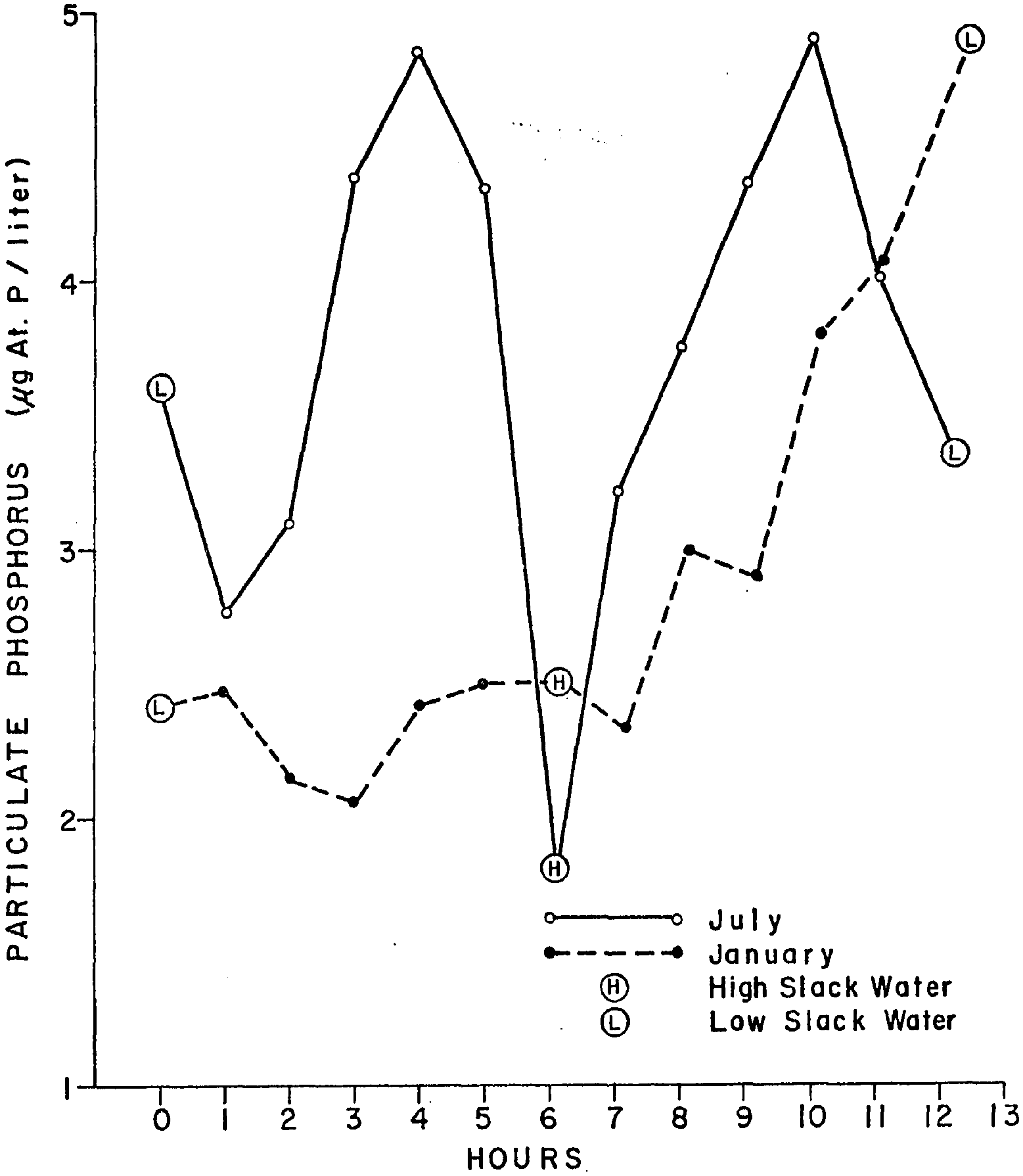

PARTICULATE PHOSPHORUS (μg At. P / liter)
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
L
H
July
January
H High Slack Water
L Low Slack Water

Figure 35. Variation in particulate phosphorus concentration over Carter Creek marsh summer and winter tidal cycles.

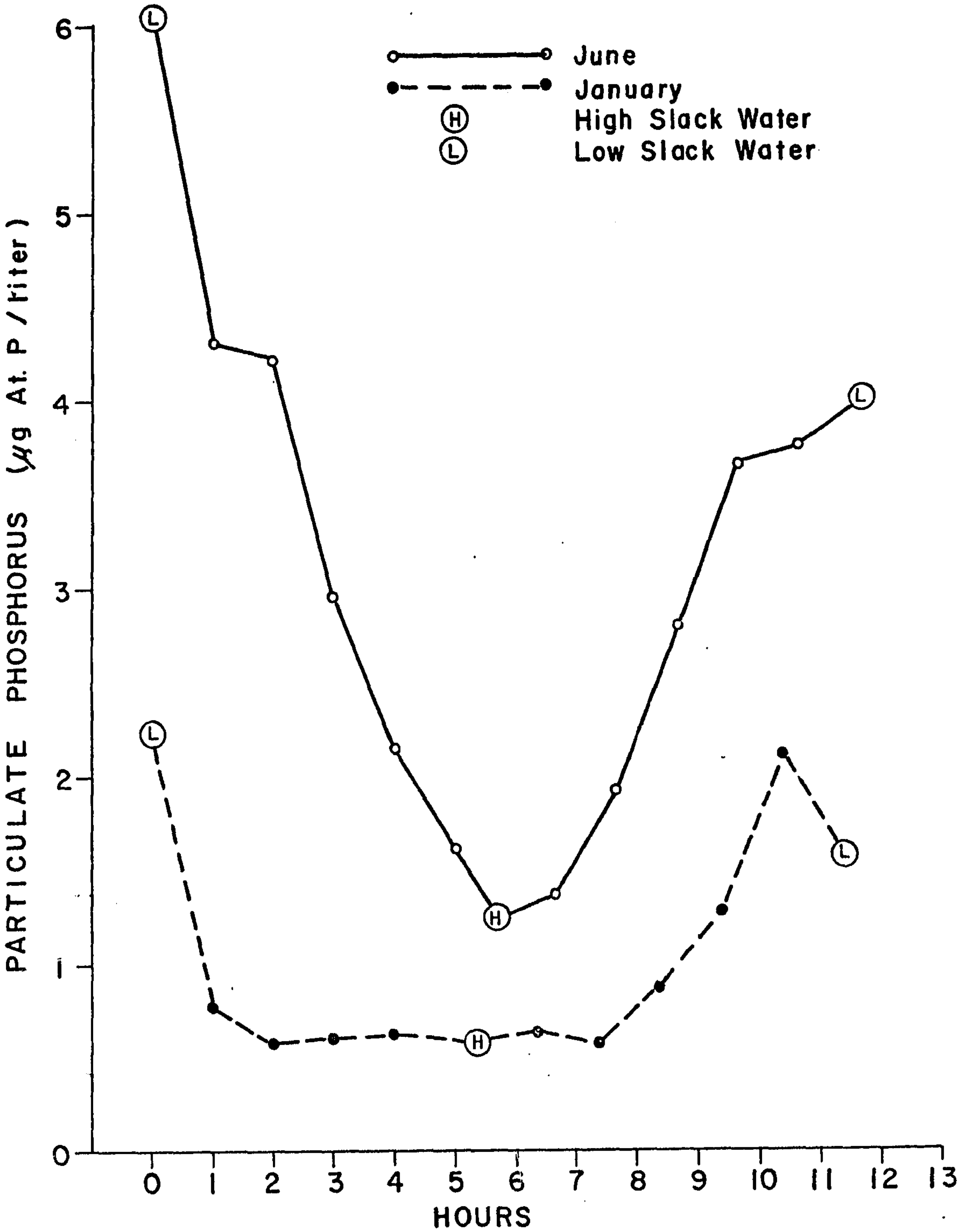

June
January
H High Slack Water
L Low Slack Water
PARTICULATE PHOSPHORUS (µg At. P / liter)
0
1
2
3
4
5
6
HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
L
H
L
L
H
L

Figure 36. Variation in nitrate concentration over Ware Creek marsh summer and winter tidal cycles.

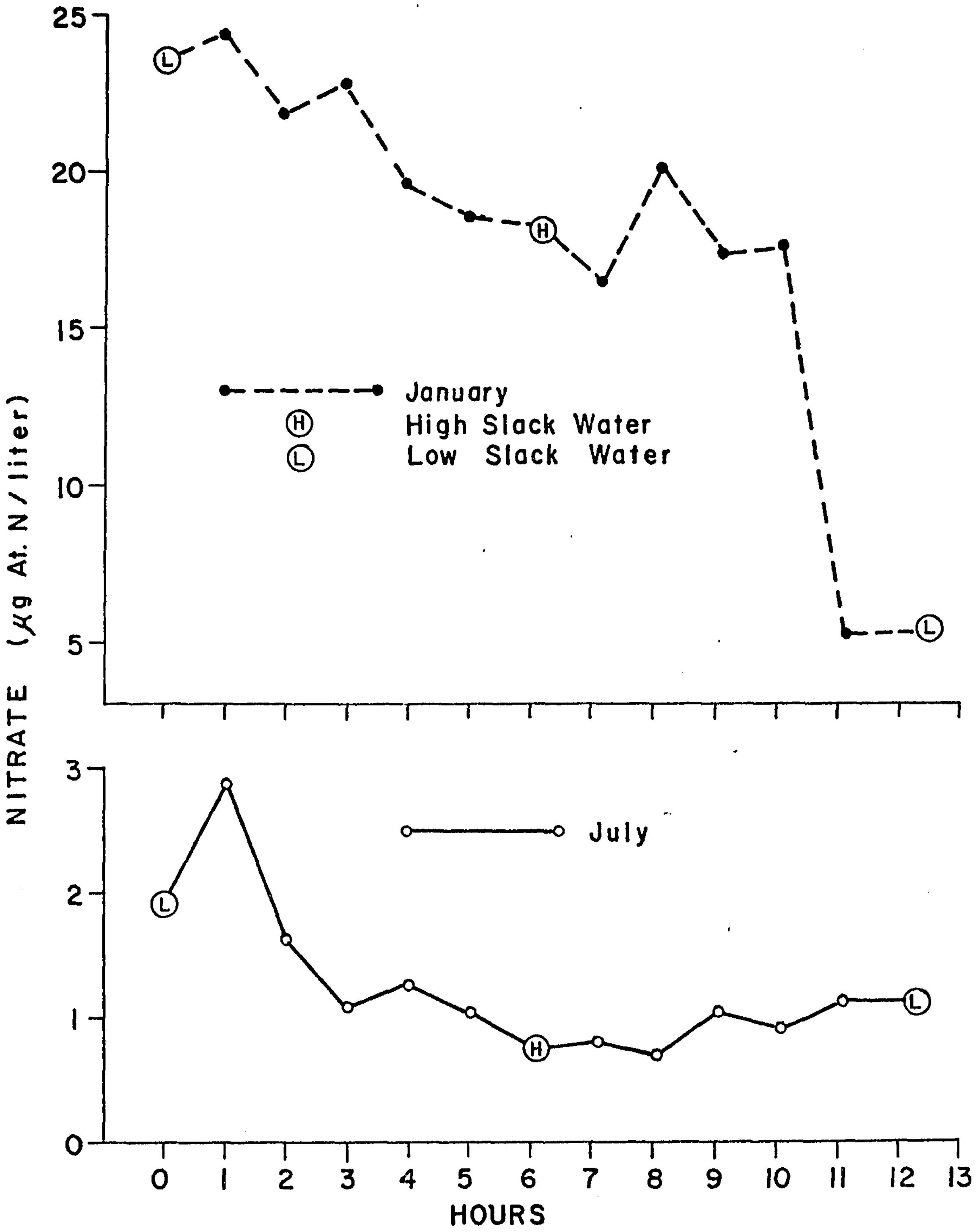

25
20
15
10
5
3
2
1
0
NITRATE (µg At. N/liter)
January
H High Slack Water
L Low Slack Water
July
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS

Figure 37. Variation in nitrate concentration over Carter Creek marsh summer and winter tidal cycles.

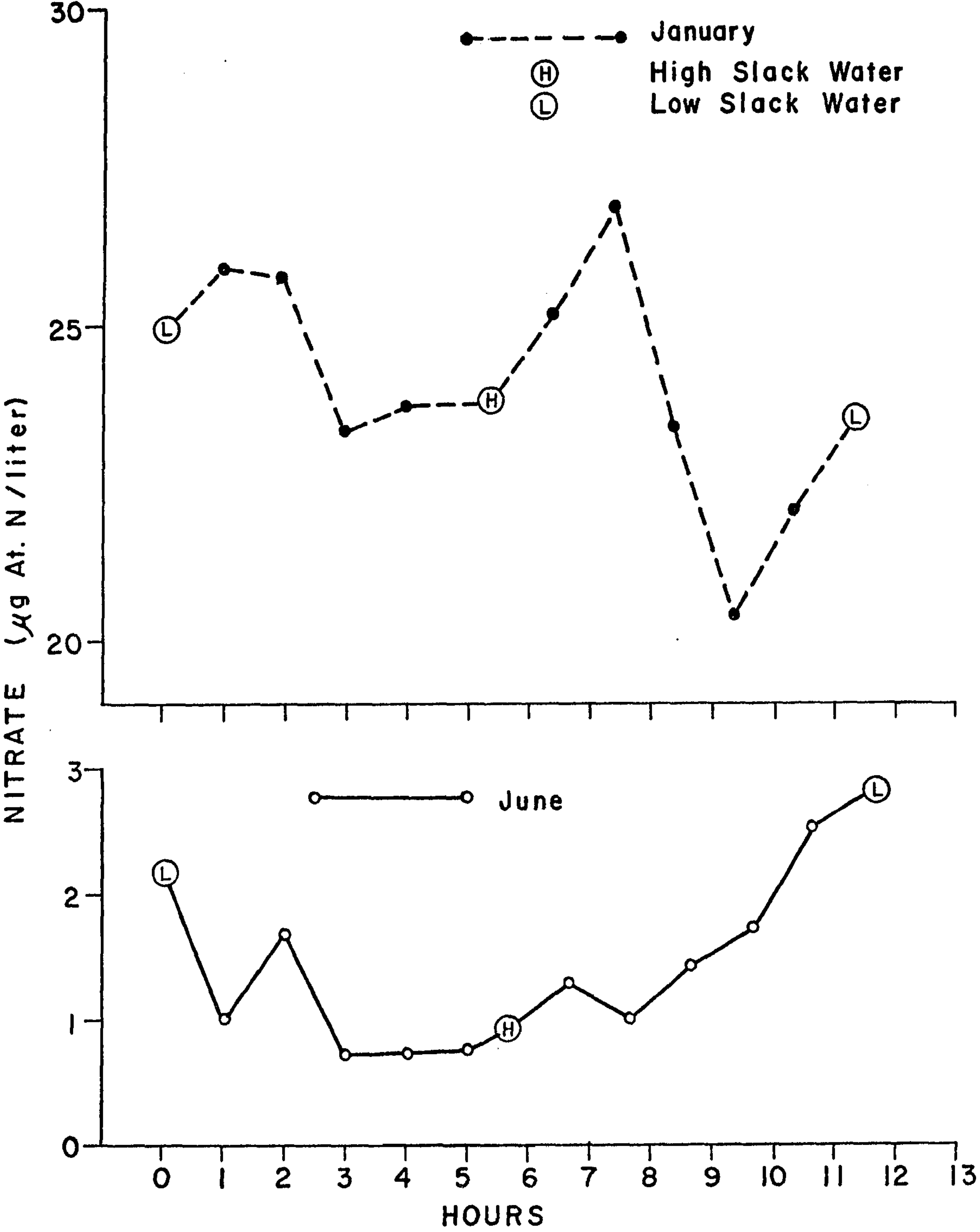

30
25
20
3
2
1
0
January
H High Slack Water
L Low Slack Water
June
NITRATE (µg At. N/liter)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS

Figure 38. Variation in nitrite concentration over Ware Creek marsh summer and winter tidal cycles.

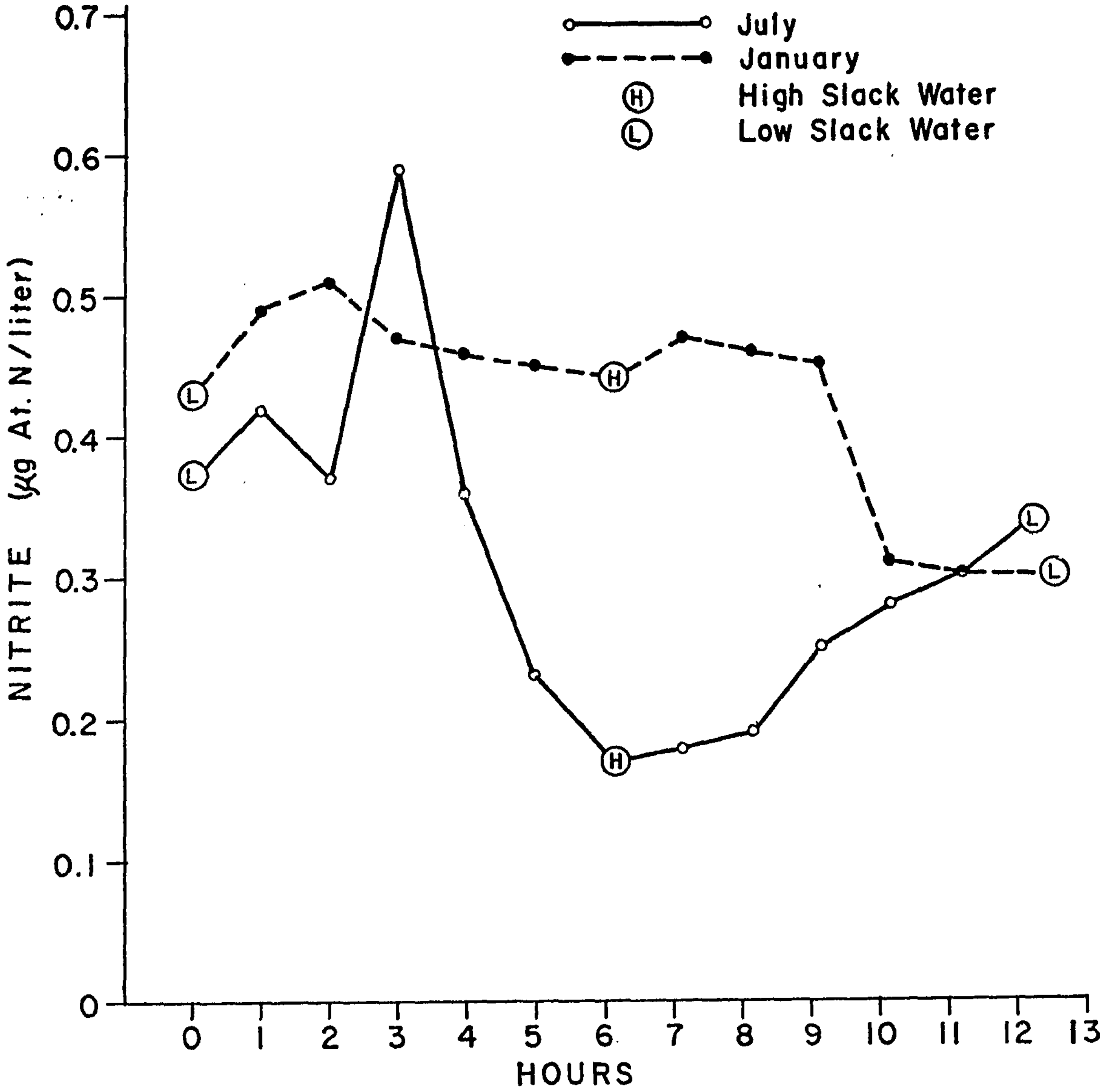

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NITRITE (µg At. N/liter)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
July
January
H High Slack Water
L Low Slack Water
L
L
H
H
L
L

Figure 39. Variation in nitrite concentration over Carter Creek marsh summer and winter tidal cycles.

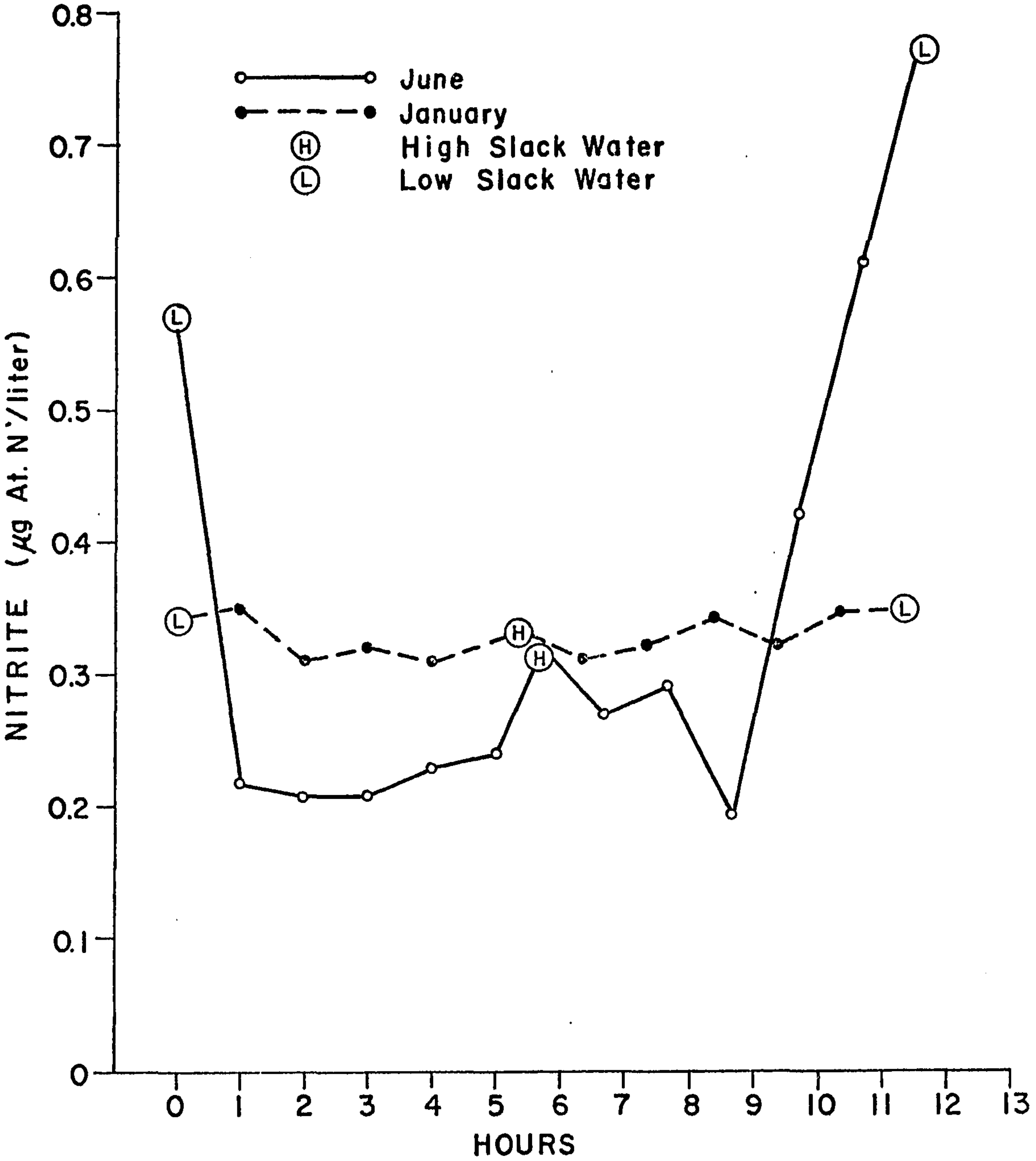

June
January
Ⓗ High Slack Water
Ⓛ Low Slack Water
NITRITE (µg At. N'/liter)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
L
H
L
H
L
L

Figure 40. Variation in ammonia concentration over Ware Creek marsh summer and winter tidal cycles.

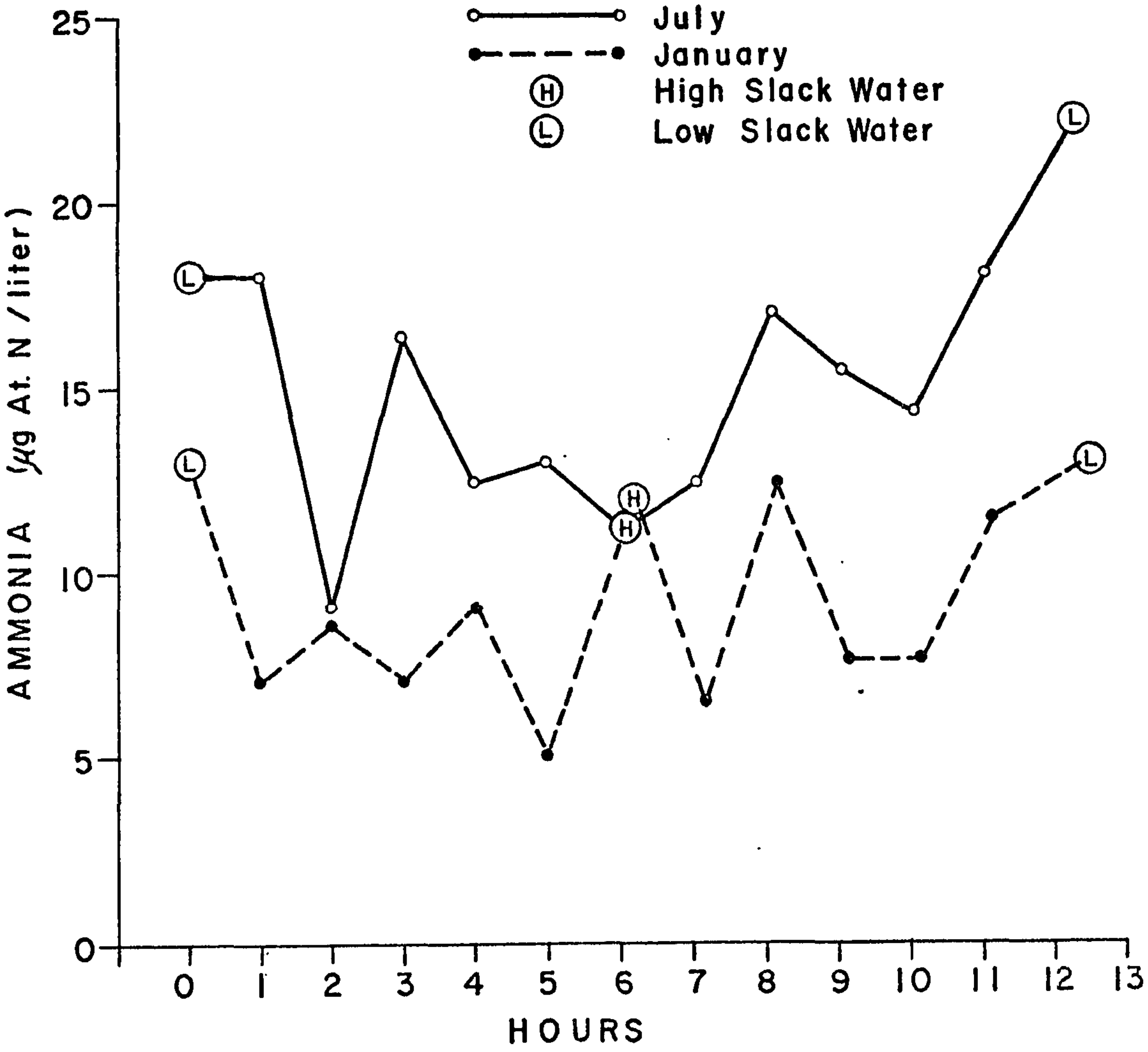

July
January
H High Slack Water
L Low Slack Water
AMMONIA (μg At. N / liter)
0
5
10
15
20
25
HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
L
H
H
L
L
L

Figure 41. Variation in ammonia concentration over Carter Creek marsh summer and winter tidal cycles.

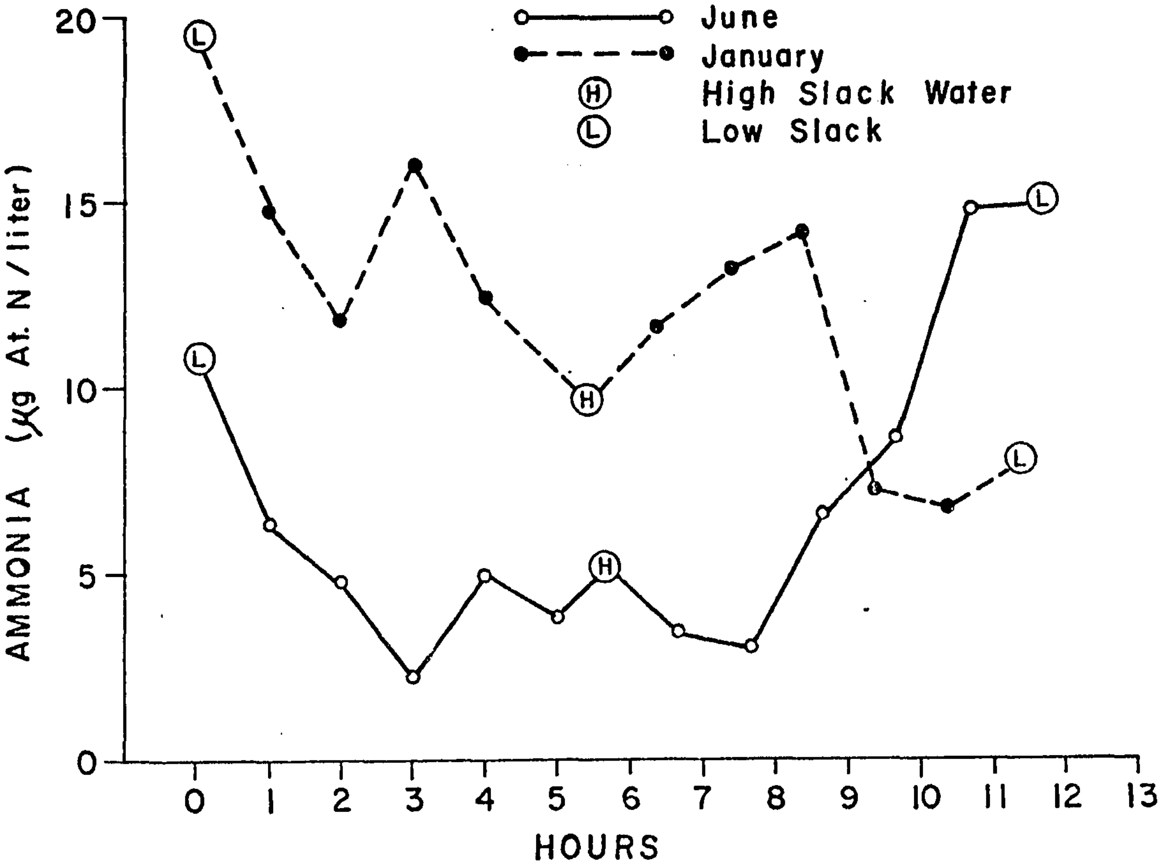

June
January
H High Slack Water
L Low Slack
AMMONIA (μg At. N / liter)
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
L
H
L
L
H
L

Figure 42. Variation in dissolved organic nitrogen concentration over Ware Creek marsh summer and winter tidal cycles.

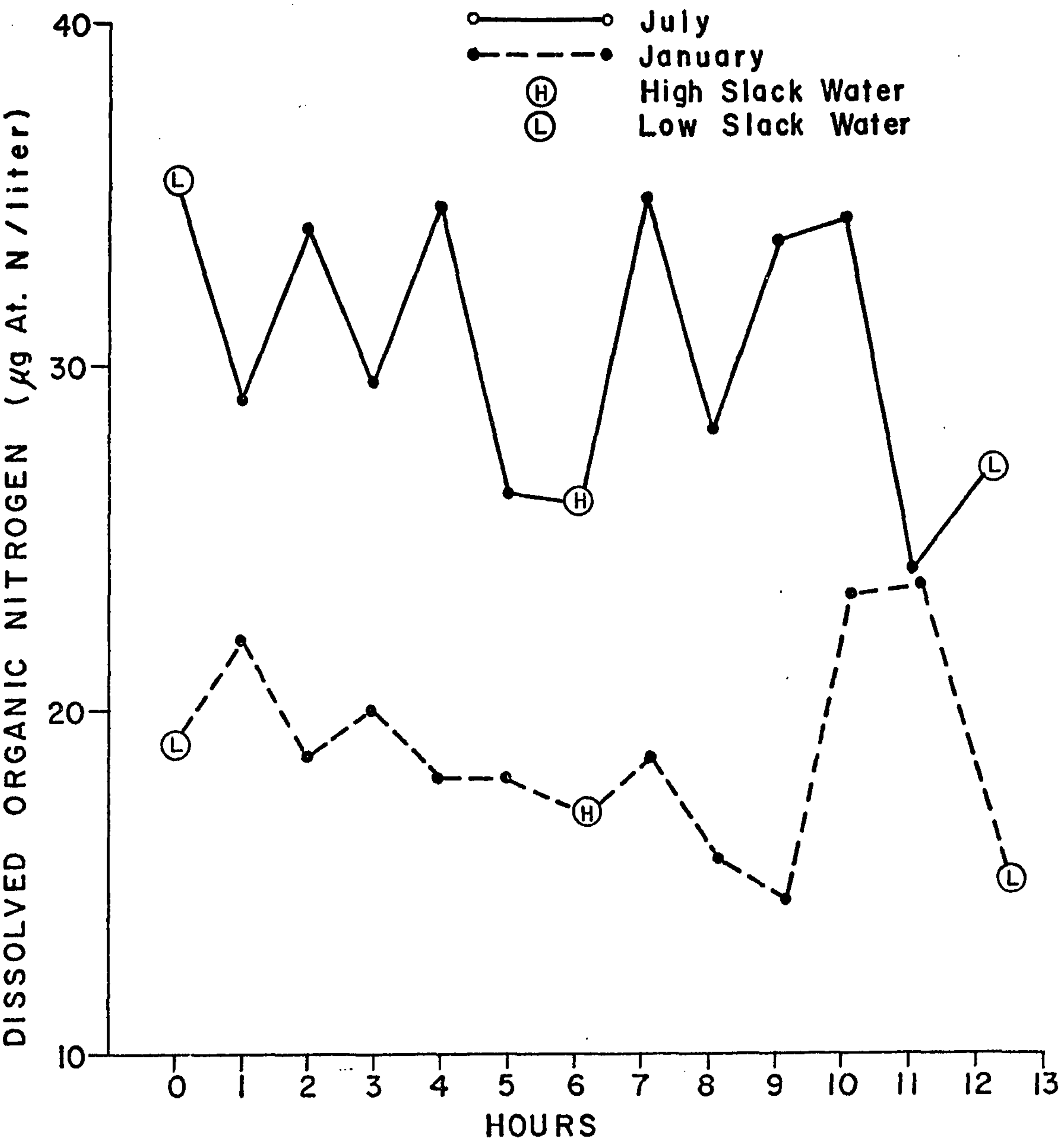

July
January
Ⓗ High Slack Water
Ⓛ Low Slack Water
DISSOLVED ORGANIC NITROGEN (µg At. N/liter)
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
L
H
L
L
H
L

Figure 43. Variation in dissolved organic nitrogen concentration over Carter Creek marsh summer and winter tidal cycles.

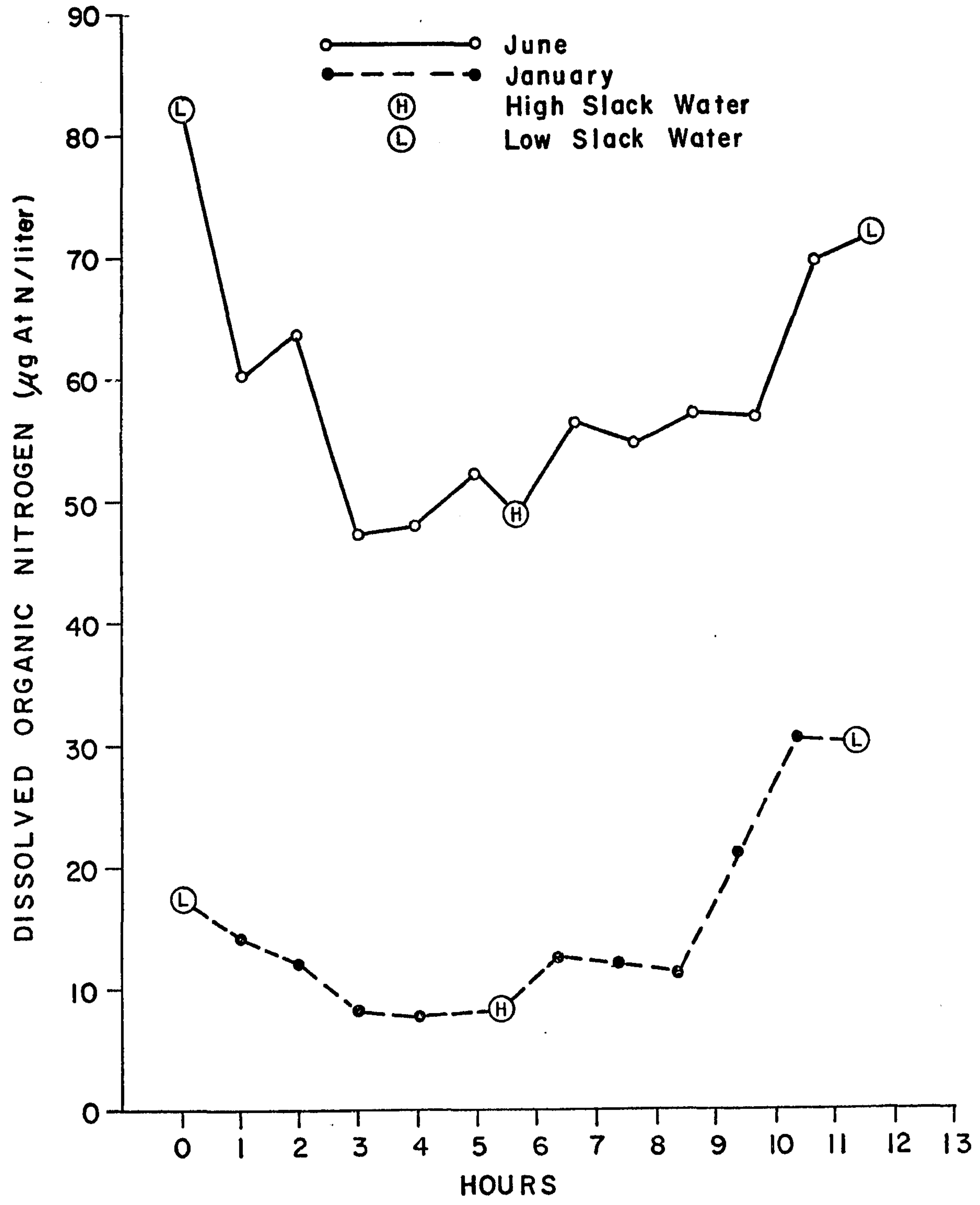
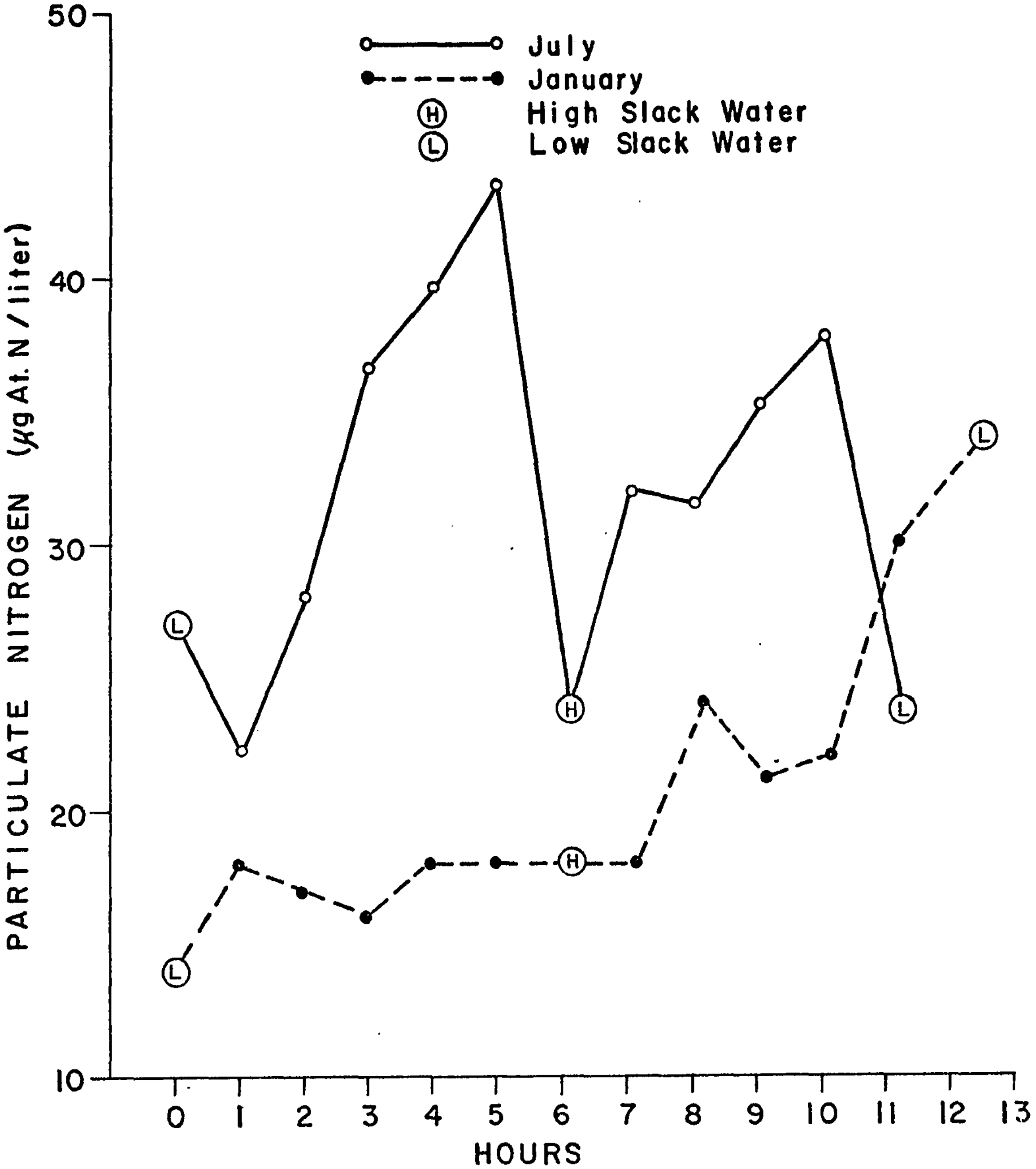

June
January
Ⓗ High Slack Water
Ⓛ Low Slack Water
DISSOLVED ORGANIC NITROGEN (μg At N/liter)
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
L
H
L
L
H
L

Figure 44. Variation in particulate nitrogen concentration over Ware Creek marsh summer and winter tidal cycles.



50
40
30
20
10
PARTICULATE NITROGEN (µg At. N / liter)
July
January
H High Slack Water
L Low Slack Water
L
H
L
H
L
L
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS

Figure 45. Variation in particulate nitrogen concentration over Carter Creek marsh summer and winter tidal cycles.

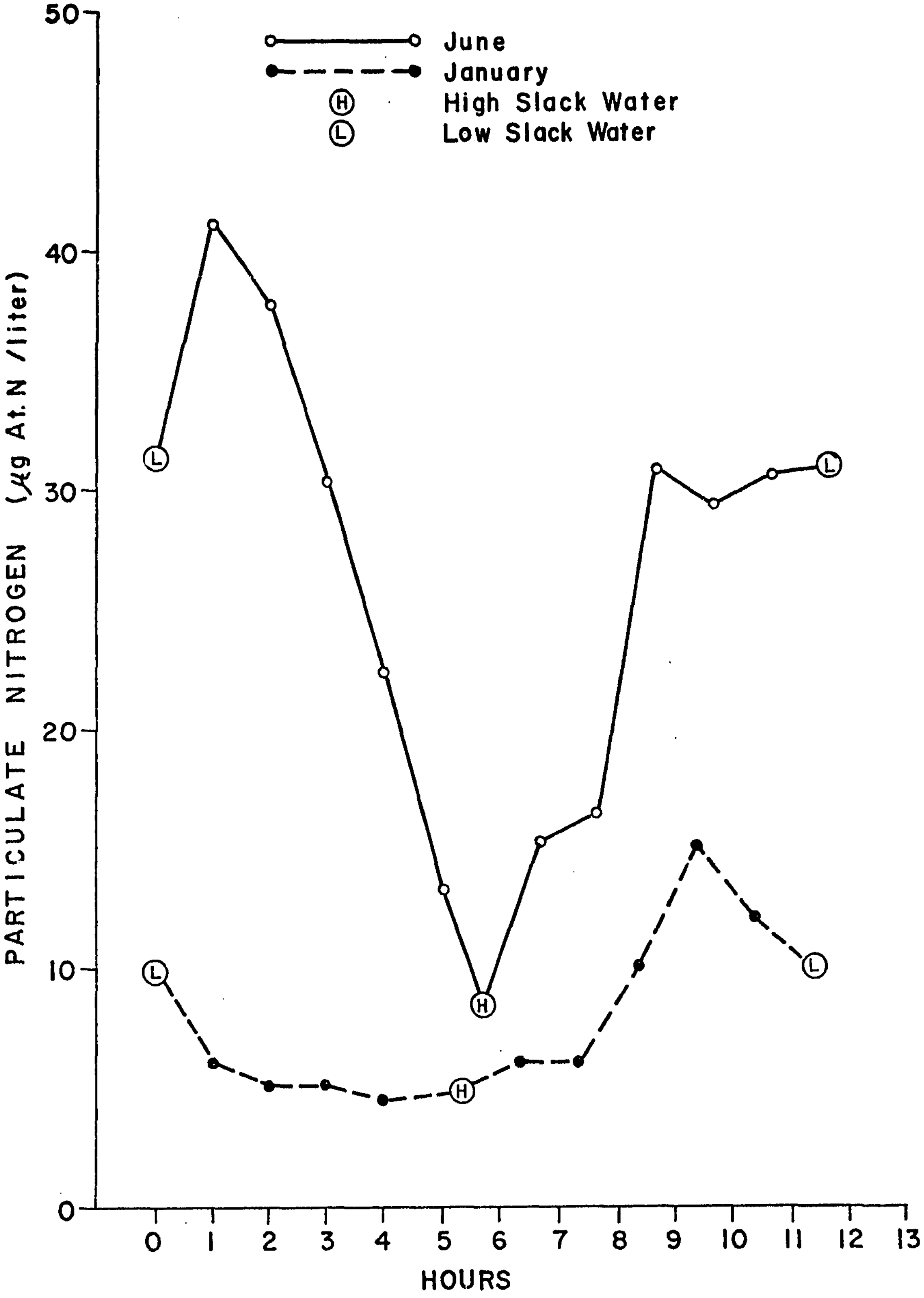

50
40
30
20
10
0
PARTICULATE NITROGEN (μg At. N /liter)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
HOURS
June
January
H High Slack Water
L Low Slack Water
L
H
L
L
H
L

Table 4

Ware Creek

Tidal Phosphorus Transport

Sampling Date	Tidal Prism m^3	Tidal Transport	DIP grams P	DOP grams P	PP grams P
1/23/72	19,600	Flood	+ 346	+ 198	+ 1,139
		Ebb	- 338	- 202	- 1,098
		Net	+ 8	- 4	+ 41
3/4/72	19,900	Flood	+ 378	+ 257	+ 1,059
		Ebb	- 518	- 267	- 867
		Net	- 140	- 10	+ 192
4/17/72	39,000	Flood	+ 384	+ 497	+ 3,378
		Ebb	- 420	- 587	- 4,209
		Net	- 36	- 90	- 831
5/17/72	39,400	Flood	+1,410	+ 723	+ 2,337
		Ebb	-1,495	- 775	- 2,598
		Net	- 85	- 52	- 261
6/14/72 Day	24,500	Flood	+ 762	+ 585	+ 3,550
		Ebb	-1,007	- 789	- 3,617
		Net	- 245	- 204	- 67
6/15/72 Night	34,300	Flood	+1,222	+ 749	+ 4,476
		Ebb	-1,347	- 715	- 5,679
		Net	- 125	+ 34	- 1,203
7/28/72	45,200	Flood	+1,657	+ 746	+ 5,606
		Ebb	-1,392	- 648	- 5,391
		Net	+ 265	+ 98	+ 215
8/26/72	43,700	Flood	+ 795	+ 704	+ 4,495
		Ebb	- 841	- 769	- 4,954
		Net	- 46	- 65	- 459
9/24/72	54,100	Flood	+1,102	+ 436	+10,717
		Ebb	- 792	- 412	- 6,773
		Net	+ 310	+ 24	+ 3,944
10/24/72	42,600	Flood	+ 748	+ 831	+ 3,377
		Ebb	- 590	- 926	- 2,659
		Net	+ 158	- 95	+ 718
11/24/72	39,100	Flood	+ 766	+ 393	+ 2,756
		Ebb	- 756	- 416	- 2,679
		Net	+ 10	- 23	+ 77
1/7/73	17,400	Flood	+ 461	+ 234	+ 1,271
		Ebb	- 518	- 230	- 1,583
		Net	- 57	+ 4	- 312

+ = input

- = output

Table 5

Carter Creek

Tidal Phosphorus Transport

Sampling Date	Tidal Prism m^3	Tidal Transport	DIP grams P	DOP grams P	PP grams P
3/7/72	4,100	Flood	+ 64	+ 47	+ 768
		Ebb	- 95	- 41	- 443
		Net	- 31	+ 6	+ 325
3/23/72	13,300	Flood	+ 125	+ 206	+ 436
		Ebb	- 135	- 228	- 384
		Net	- 10	- 22	+ 52
4/19/72	10,200	Flood	+ 128	+ 139	+ 1,411
		Ebb	- 120	- 157	- 933
		Net	+ 8	- 18	+ 478
5/19/72	43,700	Flood	+ 707	+ 669	+ 2,498
		Ebb	- 832	- 811	- 2,272
		Net	- 125	- 142	+ 226
6/17/72	13,300	Flood	+ 250	+ 289	+ 1,054
		Ebb	- 373	- 262	- 911
		Net	- 123	+ 27	+ 143
7/31/72 Storm	43,700	Flood	+ 723	+ 449	+ 5,427
		Ebb	- 856	- 575	- 6,953
		Net	- 133	- 126	- 1,526
8/29/72	24,100	Flood	+ 455	+ 456	+ 2,228
		Ebb	- 553	- 467	- 1,653
		Net	- 98	- 11	+ 575
9/27/72	26,700	Flood	+ 493	+ 325	+ 2,201
		Ebb	- 610	- 319	- 2,559
		Net	- 117	+ 6	- 358
10/27/72	27,200	Flood	+ 405	+ 565	+ 242
		Ebb	- 491	- 587	- 401
		Net	- 86	- 22	- 159
11/27/72	4,300	Flood	+ 111	+ 47	+ 558
		Ebb	- 154	- 50	- 292
		Net	- 43	- 3	+ 266
1/11/73	8,800	Flood	+ 253	+ 70	+ 175
		Ebb	- 299	- 86	- 195
		Net	- 46	- 16	- 40

+ = input

- = output

Table 6

Ware Creek

Tidal Nitrogen Transport

Sampling Date	Tidal Prism m^3	Tidal Transport	NO_3^- grams N	NO_2^- grams N	NH_4^+ grams N	DON grams N	PN grams N
1/23/72	19,600	Flood	+1,992	+ 80	+ 940	+ 8,390	+ 6,679
		Ebb	-1,537	- 87	-1,148	- 9,661	- 7,328
		Net	+ 455	- 7	- 208	- 1,271	- 649
3/4/72	19,900	Flood	+ 728	+ 86	+1,186	+ 1,185	+ 4,096
		Ebb	- 589	- 80	-1,527	- 2,395	- 3,196
		Net	+ 139	+ 6	- 341	- 1,210	+ 900
4/17/72	39,000	Flood	+ 706	+ 94	+2,362	+13,048	+ 9,233
		Ebb	- 571	- 79	-5,148	- 9,451	-11,851
		Net	+ 135	+ 15	-2,786	+ 3,597	- 2,618
5/17/72	39,400	Flood	+1,011	+ 177	+ 961	+13,429	+ 7,820
		Ebb	- 525	- 149	-1,795	-16,325	-10,050
		Net	+ 486	+ 28	- 834	- 2,896	- 2,230
6/14/72 Day	24,500	Flood	+ 425	+ 142	+1,768	+18,775	+ 8,601
		Ebb	- 266	- 143	-2,028	-18,082	-10,373
		Net	+ 159	- 1	- 260	+ 693	- 1,772
6/15/72 Night	34,300	Flood	+ 394	+ 221	+3,231	+24,426	+12,029
		Ebb	- 329	- 263	-3,479	-24,408	-12,479
		Net	+ 65	- 42	- 248	+ 18	- 450
7/28/72	45,200	Flood	+ 862	+ 240	+8,486	+19,299	+22,459
		Ebb	- 556	- 144	-9,510	-19,689	-19,681
		Net	+ 306	+ 96	-1,024	- 390	+ 2,778
8/26/72	43,700	Flood	+ 314	+ 116	+1,865	+18,511	+17,887
		Ebb	- 264	- 138	-3,974	-20,617	-16,199
		Net	+ 50	- 22	-2,109	- 2,106	+ 1,688
9/24/72	54,100	Flood	+2,340	+ 747	+1,659	+24,542	+36,719
		Ebb	-1,468	- 563	-1,359	-27,664	-32,580
		Net	+ 872	+ 184	+ 300	- 3,122	+ 4,139
10/24/72	42,600	Flood	+2,765	+ 180	+3,886	+11,959	+10,804
		Ebb	-1,916	- 175	-3,101	-11,873	- 9,090
		Net	+ 849	+ 5	+ 785	+ 86	+ 1,714
11/24/72	39,100	Flood	+2,559	+ 105	+5,917	+ 7,357	+ 9,323
		Ebb	-1,705	- 98	-5,048	- 7,422	-10,945
		Net	+ 854	+ 7	+ 869	- 65	- 1,622
1/7/73	17,400	Flood	+4,931	+ 113	+1,827	+ 4,532	+ 4,265
		Ebb	-4,148	- 105	-2,245	- 4,285	- 5,275
		Net	+ 783	+ 8	- 418	+ 247	- 1,010

+ = input

- = output

Table 7

Carter Creek

Tidal Nitrogen Transport

Sampling Date	Tidal Prism m^3	Tidal Transport	NO_3^- grams N	NO_2^- grams N	NH_4^+ grams N	DON grams N	PN grams N
3/7/72	4,100	Flood	+ 516	+ 23	+ 244	+ 594	+ 3,494
		Ebb	- 435	- 25	- 244	- 810	- 2,187
		Net	+ 81	- 2	0	- 216	+ 1,307
3/23/72	13,300	Flood	+ 520	+ 49	+ 389	+ 2,618	+ 2,216
		Ebb	- 367	- 45	- 547	- 2,918	- 1,524
		Net	+ 153	+ 4	- 158	- 300	+ 692
4/19/72	10,200	Flood	+ 487	+ 46	+ 441	+ 4,009	+ 4,249
		Ebb	- 339	- 44	- 490	- 4,431	- 3,844
		Net	+ 148	+ 2	- 49	- 422	+ 405
5/19/72	43,700	Flood	+ 263	+ 167	+ 1,542	+11,148	+14,037
		Ebb	- 201	- 182	- 1,691	-14,044	-11,639
		Net	+ 62	- 15	- 149	- 2,896	+ 2,398
6/17/72	13,300	Flood	+ 166	+ 43	+ 764	+ 9,669	+ 4,488
		Ebb	- 250	- 57	- 1,025	-10,480	- 3,838
		Net	- 84	- 14	- 261	- 811	+ 650
7/31/72 Storm	43,700	Flood	+1,673	+ 250	+11,953	+18,351	+25,191
		Ebb	-1,653	- 239	- 7,734	-22,541	-30,112
		Net	+ 20	+ 11	+ 4,219	- 4,190	- 4,921
8/29/72	24,100	Flood	+ 150	+ 100	+ 1,149	+12,247	+ 9,373
		Ebb	- 150	- 88	- 845	-11,706	- 7,336
		Net	0	+ 12	+ 304	+ 541	+ 2,037
9/27/72	26,700	Flood	+ 266	+ 72	+ 861	+ 6,246	+ 9,405
		Ebb	- 427	- 42	- 988	-12,022	- 8,173
		Net	- 161	+ 30	- 127	- 5,776	+ 1,232
10/27/72	27,200	Flood	+ 292	+ 88	+ 1,241	+ 5,077	+ 1,748
		Ebb	- 124	- 68	- 1,167	- 7,288	- 2,861
		Net	+ 168	+ 20	+ 74	- 2,211	- 1,113
11/27/72	4,300	Flood	+ 914	+ 16	+ 996	+ 1,217	+ 2,629
		Ebb	- 867	- 15	- 791	- 1,045	- 1,453
		Net	+ 47	+ 1	+ 205	+ 172	+ 1,176
1/11/73	8,800	Flood	+3,001	+ 39	+ 1,650	+ 1,213	+ 620
		Ebb	-3,036	- 40	- 1,507	- 1,520	- 923
		Net	- 35	- 1	+ 143	- 307	- 303

+ = input

- = output

Table 8

Ware Creek

Annual Phosphorus Budget

	DIP grams P	DOP grams P	PP grams P
1/15/72 - 2/12/72	+ 381	- 183	+ 2,009
2/13 - 3/26	-14,037	- 992	+ 19,149
3/27 - 5/2	- 2,420	- 6,047	- 55,789
5/3 - 5/31	- 4,813	- 2,940	- 14,768
6/1 - 7/5	-21,196	-17,681	- 5,822
7/6 - 8/11	+17,554	+ 6,501	+ 14,252
8/12 - 9/10	- 2,623	- 3,765	- 26,472
9/11 - 10/8	+15,252	+ 1,189	+194,036
10/9 - 11/9	+ 9,052	- 5,431	+ 41,104
11/10 - 12/16	+ 634	- 1,493	+ 5,112
12/17/72 - 1/14/73	- 4,635	+ 330	- 25,530
1/15/72 - 1/14/73	- 6,851	-30,512	+147,281

1/15/72 - 1/14/73 DIP + DOP + PP = +109,918 grams P

+ = input

- = output

Table 9

Carter Creek

Annual Phosphorus Budget

		DIP grams P	DOP grams P	PP grams P
2/9/72	- 3/15/72	- 4,667	+ 877	+48,424
3/16	- 4/6	- 543	- 1,220	+ 2,832
4/7	- 5/4	+ 614	- 1,451	+37,811
5/5	- 6/3	- 5,513	- 6,324	+10,036
6/4	- 7/9	-11,429	+ 2,482	+13,305
7/10	- 8/14	- 6,834	- 6,423	-78,078
8/15	- 9/13	- 5,735	- 651	+33,536
9/14	- 10/12	- 6,398	+ 321	-19,532
10/13	- 11/12	- 4,745	- 1,212	- 8,754
11/13	- 12/20	- 7,756	- 499	+47,531
12/21/72	- 2/8/73	- 7,485	- 2,530	- 3,288
2/9/72	- 2/8/73	-60,491	-16,630	+83,823

2/9/72 - 2/8/73 DIP + DOP + PP = +6,702 grams P

+ = input

- = output

Table 10

Ware Creek

Annual Nitrogen Budget

	NO_3^- grams N	NO_2^- grams N	NH_4^+ grams N	DON grams N	PN grams N
1/15/72 - 2/12/72	+ 22,348	- 371	- 10,181	- 62,416	- 31,875
2/13 - 3/26	+ 13,825	+ 560	- 34,115	-120,942	+ 90,003
3/27 - 5/2	+ 9,086	+ 979	-187,387	+241,881	-176,042
5/3 - 5/31	+ 27,432	+ 1,557	- 47,054	-163,521	-125,895
6/1 7/5	+ 13,801	- 97	- 22,538	+ 59,980	-153,402
7/6 - 8/11	+ 20,236	+ 6,362	- 67,707	- 25,857	+183,803
8/12 - 9/10	+ 2,852	- 1,273	-121,402	-121,185	+ 97,151
9/11 - 10/8	+ 43,016	+ 9,044	+ 14,775	-153,588	+203,650
10/9 - 11/9	+ 48,555	+ 313	+ 44,940	+ 4,897	+ 98,288
11/10 - 12/16	+ 56,284	+ 453	+ 57,337	- 4,238	-107,001
12/17/72 - 1/14/73	+ 63,995	+ 664	- 34,222	+ 20,154	- 82,445
1/15/72 - 1/14/73	+321,420	+18,191	-407,554	-324,835	- 3,765

1/15/72 - 1/14/73 $NO_3^- + NO_2^- + NH_4^+ + DON + PN = -396,543$ grams N

+ = input

- = output

Table 11

Carter Creek

Annual Nitrogen Budget

		NO_3^- grams N	NO_2^- grams N	NH_4^+ grams N	DON grams N	PN grams N
2/9/72	- 3/15/72	+12,061	- 230	+ 83	- 32,156	_194,793
3/16	4/6	+ 8,385	+ 230	- 8,669	- 16,434	+ 37,853
4/7	- 5/4	+11,771	+ 189	- 3,839	- 33,396	+ 32,061
5/5	- 6/3	+ 2,757	- 690	- 6,594	-128,464	+106,354
6/4	- 7/9	- 7,807	-1,343	-24,296	- 75,532	+ 60,478
7/10	- 8/14	+ 1,010	+ 559	- 2,840	-214,336	-251,738
8/15	- 9/13	- 32	+ 727	+17,744	+ 31,565	+118,859
9/14	- 10/12	- 8,791	+1,674	- 6,933	-315,577	+ 67,229
10/13	- 11/12	+ 9,233	+1,125	+ 4,061	-121,678	- 61,255
11/13	- 12/20	+ 8,406	+ 225	+36,627	+ 30,697	+210,127
12/21/72	- 2/8/73	- 5,802	- 69	+23,321	- 50,159	- 49,337
2/9/72	- 2/8/73	+31,191	+2,397	+28,665	-925,270	+465,424

2/9/72 - 2/8/73 $NO_3^- + NO_2^- + NH_4^+ + DON + PN = -397,593$ grams N

+ = input

- = output

Table 12

Ware Creek Flood and Ebb Tide Simple and Partial Correlation Coefficients

Flood Tide Simple Correlation Coefficients

	Temp.	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.571**	0.220	-0.348*	-0.182

Flood Tide Partial Correlation Coefficients, Temperature Held Constant

	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.130	0.005	-0.048

Ebb Tide Simple Correlation Coefficients

	Temp.	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.525**	0.271	-0.234	-0.118

Ebb Tide Partial Correlation Coefficients, Temperature Held Constant

	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.173	0.087	-0.073

**Significant at the 1% level
*Significant at the 5% level

Table 13

Carter Creek Flood and Ebb Tide Simple and Partial Correlation Coefficients

Flood Tide Simple Correlation Coefficients

	Temp.	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.581**	-0.165	-0.538**	-0.020

Flood Tide Partial Correlation Coefficients, Temperature Held Constant

	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.108	-0.091	0.146

Ebb Tide Simple Correlation Coefficients

	Temp.	DIP	NO_3^-	NH_4^+
Prod./Chl.	0.651**	-0.156	-0.590**	-0.319

Ebb Tide Partial Correlation Coefficients, Temperature Held Constant

	DIP	NO_3^-	NH_4^+
Prod./Chl.	-0.143	-0.159	-0.191

**Significant at the 1% level
*Significant at the 5% level

DISCUSSION

Phosphorus Flux Through the Salt Marsh Ecosystem

The observed negative correlations between dissolved phosphorus concentrations, tide height, and water flow, along with the significant annual exports of dissolved inorganic and dissolved organic phosphorus from Ware Creek and Carter Creek marshes, suggest a release of dissolved phosphorus from marsh soils to the water column. This exchange may be mediated by phosphorus cycling within the salt marsh community (Pomeroy et al., 1969; Pomeroy, 1960; Kuenzler, 1961; Marples, 1966; Reimold, 1972), or by sediment-water equilibrium processes (Pomeroy et al., 1965; Upchurch, 1972). However, Pomeroy, Shenton, Jones, and Reimold, (1972) have indicated that metabolic processes predominate over sorption phenomena in the cycling of phosphorus within salt marsh-estuarine environments. With this information, and considering that: 1) the annual net output of dissolved phosphorus species from Ware Creek and Carter Creek marshes was exceeded by the annual net input of particulate phosphorus to the marshes, 2) sediments are accreting in salt marshes (Redfield, 1972, Meade, 1972) and salt marsh sediments are rich in phosphorus (Maye, 1972; Mendelssohn, 1973), 3) calculated atmospheric inputs of phosphorus to Ware Creek and Carter Creek marshes were small (Chapin and Uttormark, 1973), and 4) terrestrial influence on Ware

Creek and Carter Creek marshes was negligible; a salt marsh phosphorus flux scheme can be hypothesized. The resultant annual phosphorus cycle is characterized by influx of estuarine particulate phosphorus to marsh sediments followed by biotic mineralization of a fraction of the particulate phosphorus compartment of the marsh and subsequent efflux of dissolved phosphorus from the marsh to the estuary.

The observed phosphorus concentration and transport trends of Ware Creek and Carter Creek marshes can be explained within the context of this hypothesis by considering environmental parameters and the findings of other researchers (Review of Literature). Elevated dissolved phosphorus concentrations in Georgia salt marsh waters have been ascribed to both heterotrophic degradation of *Spartina* detritus (Pomeroy et al., 1969) and to pumping of dissolved inorganic phosphorus from subsurface sediments by *S. alterniflora*, followed by release to marsh waters via guttation (Reimold, 1972; Pomeroy et al., 1972). Pomeroy et al. (1972) further stated that because heterotrophic respiration in these salt marsh-estuarine environments is approximately equal in summer and winter, increased summer dissolved inorganic phosphorus concentrations of marsh waters are a result of increased rates of *Spartina* guttation. However, dissolved phosphorus concentrations of Ware Creek and Carter Creek marsh waters related better to degree of sediment-water contact, as inferred from dissolved phosphorus concentration, water flow and tide height correlations, than to *Spartina alterniflora* standing crop. Therefore, ingestion of detritus and associated microorganisms by marsh meiobenthos followed by excretion of dissolved inorganic and dissolved organic phosphorus by meiobenthos with diffusion of this phosphorus from marsh soils to the water column would appear to be the mechanism of primary importance in the movement of dissolved phosphorus all year in these marshes. The generally greater exports of dissolved phosphorus from the marshes in summer could be a result of increased temperature causing biotic mineralization rates to further increase over rates of dissolved phosphorus assimilation by photoautotrophs and *Spartina* detritus-degrading microorganisms.

The greater annual efflux of dissolved inorganic phosphorus from Carter Creek as compared to Ware Creek marsh was a result of the influx of dissolved inorganic phosphorus to Ware Creek during fall. These differences imply that marshes may vary with respect to nutrient flux. However, the September and October phosphorus inputs to Ware Creek were also associated with elevated dissolved inorganic phosphorus concentrations in Ware Creek at high slack water (reflecting estuarine concentrations) that exceeded low slack water concentrations. The fact that for essentially all other sampled Ware Creek and Carter Creek tidal cycles, dissolved inorganic phosphorus concentrations at low slack water were greater than high slack water concentrations and dissolved inorganic phosphorus was exported from the marshes, indicates that salt marsh sediments and biota may act to buffer estuarine waters with respect to dissolved inorganic phosphorus as suggested by Pomeroy et al., (1965). Significant net input of dissolved inorganic phosphorus into Ware Creek was also observed over the post-Hurricane Agnes tidal cycle of July, 1972. While this seemingly abnormal phosphorus influx to Ware Creek may have been a result of the hurricane, the rain storm over the corresponding Carter Creek July sampling negated any opportunity of observing a residual effect of Agnes on Carter Creek. However, the

Carter Creek July rainstorm did serve to reaffirm the hypothesis contending that metabolic processes predominate over sediment-water equilibrium processes in the release of dissolved inorganic phosphorus to marsh waters. This was evidenced by the apparently normal dissolved inorganic phosphorus concentrations and exports over the July tidal cycle in spite of the large quantities of marsh sediments that were suspended in the marsh water column.

Tidal variation in particulate phosphorus concentrations of Ware Creek and Carter Creek marsh waters was primarily a function of marsh physiography and tidal distribution of current velocities. Seasonal differences in salt marsh particulate phosphorus concentrations and flux can be explained on the basis of seasonal changes in marsh angiosperm detrital export and temporal variation in estuarine detrital and phytoplankton concentrations. Mendelssohn (1973) found significantly greater angiosperm litter standing crop in Ware Creek as compared to Carter Creek in the spring, but equally low angiosperm litter standing crops in the marshes in late summer. The fact that the annual angiosperm productivities of the two marshes were equivalent (Mendelssohn, 1973) suggests that Ware Creek marsh exported much of its angiosperm biomass in spring and summer while Carter Creek marsh exported more detritus in fall and winter. In general agreement with these observations were the Ware Creek export of particulate phosphorus in spring and summer (with the exception of the post-hurricane July tidal cycle), and the Carter Creek export of particulate phosphorus in fall. The large influx of particulate phosphorus to Ware Creek in fall may have indicated that this marsh served as a sink for detritus generated by other marshes or by a possible autumn estuarine phytoplankton die off. The fact that Carter Creek had significantly lower mean annual dead angiosperm standing crop than Ware Creek, while the two marshes had equivalent annual angiosperm productivities (Mendelssohn, 1973), may indicate that Carter Creek exported much of its angiosperm production shortly after its death. Seasonal particulate phosphorus transport trends of Carter Creek support this conclusion in that particulate phosphorus was exported only in fall even though estuarine detrital concentrations were high at that time, and estuarine particulate phosphorus inputs to the marsh exceeded marsh particulate phosphorus outputs over the remainder of the year. In light of the apparent dissimilar seasonal patterns of angiosperm detritus export from these two marshes of differing salinity regime and floral composition, it is to be expected that seasonal variation in influx-efflux of particulate material from a given salt marsh will be influenced by the seasonal patterns of angiosperm detritus export from other salt marshes within the same estuarine system.

Considering all three phosphorus species, the annual budgets indicated significantly greater import of phosphorus to Ware Creek than to Carter Creek marsh. This discrepancy is largely due to the great efflux of particulate phosphorus from Carter Creek over the July storm tidal cycle. The storm undoubtedly had a disproportionate influence on the calculated annual phosphorus budget due to the fact that rain storms of equally great magnitude did not constitute as large a fraction of the year's tidal cycles as they did of the sampled tidal cycles. Were the particulate phosphorus transport over this

July tidal cycle commensurate to either the June or August Carter Creek particulate phosphorus imports, the net annual inputs of phosphorus to Ware Creek and Carter Creek would have been more comparable. However, it is not meant to discount the obvious perturbation in particulate phosphorus flux through salt marshes induced by storms. Though it is probable that the substantial detrital efflux from salt marshes over storm tidal cycles is followed by detrital influx to the marshes over succeeding tidal cycles, as elevated estuarine seston concentrations again attain equilibrium levels, the quantitative aspects of storm induced detrital export from salt marshes over the long term remains to be elucidated.

Nitrogen Flux through the Salt Marsh Ecosystem

The magnitude of annual input or output of nitrogen to or from the salt marsh ecosystem is controlled by the seasonally varying rates in the concomitant processes of nitrogen assimilation, nitrogen mineralization (ammonification, autolysis, and excretion), nitrification, dissimilatory nitrogen reduction, and nitrogen fixation in the marsh and estuarine systems. Ware Creek and Carter Creek nitrogen flux data indicate that the annual salt marsh nitrogen cycle is characterized by 1) import of estuarine particulate nitrogen to the marsh from the estuary, 2) fixation of molecular nitrogen by marsh flora, 3) spring-summer ammonia export and year round dissolved organic nitrogen export from the marsh to the estuary, 4) fall, or fall and winter import of ammonia to the marsh from the estuary, and 5) year round nitrate and nitrite import to the marsh from the estuary.

The year round influx of both nitrate and nitrite to Ware Creek and Carter Creek could have been a result of photoautotrophic and bacterial nitrate and nitrite assimilation or bacterial dissimilatory nitrogen reduction in the marshes. Assimilation of these nitrogen species by marsh angiosperms, phytoplankton, edaphic and epiphytic algae undoubtedly accounts for some of the nitrate and nitrite import to the marshes. The increased fall, winter, and spring nitrate and nitrite import to the marsh could possibly be due to the increased nitrogen assimilation by marsh edaphic algae occurring at this time. This is a result of decreased marsh angiosperm standing crop allowing greater light penetration to the marsh soil and yielding increased edaphic algal production (Gallagher, 1971). Assimilation of nitrate and nitrite by microorganisms utilizing nitrogen poor *Spartina* detritus as an energy source could also explain the nitrate and nitrite imports to the marsh (Thayer, 1969; Ustach, 1969). Decreased nitrate and nitrite import to the marsh in summer might thus be a result of the lower organic carbon concentrations of marsh soils in summer causing a reduction in bacterial activity (Day, Smith, Wagner, and Stowe, 1973). However, considering the large denitrifying bacterial populations of salt marsh sediments (Daiber and Gooch, 1968), the rapid rate of denitrification as compared to assimilation (Painter, 1970), the high concentrations of ammonia in salt marsh waters and the preferential assimilation of ammonia-nitrogen by bacteria and photoautotrophs (Painter, 1970; Riley and Chester, 1971), it is hypothesized that nitrate losses to the marshes were predominantly due to denitrification. Further evidence of the significance of denitrification in salt marshes was provided by data indicating high rates of bacterial dissimilatory sulfate reduction in marsh soils (Gooch, 1968), a process which does not occur to a large extent until denitrification has depleted nitrate and nitrite (Horne, 1969).

Assuming that denitrification is of significance in marshes, the quantitative aspect of nitrate loss to Ware Creek and Carter Creek would be primarily a function of the importance of denitrification as opposed to nitrification in the marshes. The relative significance of these processes is dependent on the biochemical reaction rates as well as the abundance of the microorganisms responsible for denitrification and nitrification. Biochemical reaction rates and population densities of these bacteria are influenced by many factors, some of which are temperature, and availability of ammonia, nitrate, nitrite and organic carbon. Though nitrification and denitrification rates of several bacterial species have been found to increase with increasing temperatures to rate maxima at about 30°C (Dawson and Murphy, 1972; Painter, 1970), increased temperatures also correlate with increased estuarine phytoplankton productivity and decreased estuarine and consequently salt marsh nitrate concentrations (Figures 7, 16, 17, 26, 27, 28, and 29). Thus, the relative seasonal importance of the processes of denitrification and nitrification is not clear.

The fact that the processes of nitrification and denitrification require different environments within the marshes explains the seeming paradox of nitrate import to the marshes though low slack water nitrate concentrations were greater than high slack water concentrations (May to September in Ware Creek, and June to November in Carter Creek). The greater annual import of nitrate to Ware Creek than to Carter Creek together with the annual export of ammonia from Ware Creek and the annual import of ammonia to Carter Creek indicate that nitrification may have been of greater importance in Carter Creek than in Ware Creek marsh.

Ammonia concentrations in the waters of Ware Creek and Carter Creek marshes were significantly higher than York River estuarine ammonia concentrations as measured by Patten and Lacey (1961). Marsh ammonia concentrations correlated positively with dissolved inorganic phosphorus and concentrations of both nutrients correlated negatively with tide height such that the monthly marsh fluxes of the two nutrients were most often in the same direction. A cycle explaining these phenomena is the grazing of meiobenthos on detritus and associated microorganisms with concurrent release of ammonia and dissolved inorganic phosphorus via excretion. The generally greater late spring and summer exports of ammonia from the marshes could thus be a result of the temperature dependence of metabolism. Variation in the flux direction between ammonia and dissolved inorganic phosphorus may have been due to seasonal differences in the relative adsorption of ammonia and dissolved inorganic phosphorus on sediments, in detrital nitrogen to phosphorus ratios, in relative assimilation of ammonia versus phosphorus by photoautotrophs, and in nitrification rates. Though nitrification has been theorized as the cause of ammonia loss to the marshes in fall-winter, uptake of nutrients by marsh photoautotrophs or Thayer's (1974) hypothesis that *Spartina* detritus degrading microorganisms assimilate dissolved nitrogen and phosphorus from marsh waters, also provide possible explanations for the fall ammonia and dissolved inorganic phosphorus imports to Ware Creek and the fall-winter ammonia imports to Carter Creek. While these theories are plausible, the detection of increased nitrifying bacterial population densities from summer to fall (Daiber and Gooch, 1968) also evinces nitrification as a possible mechanism for the ammonia losses to the marshes in fall-winter. However, the influx of nitrate as well as ammonia to the marshes at this time indicates that a nitrogen cycling reaction in addition to nitrification was transpiring in the marshes. In light of the findings of Patrick and Tusneem (1972), that a significant amount of ammonia was lost from flooded soils through nitrification followed by denitrification, it is proposed that in Ware Creek and Carter Creek marshes, estuarine ammonia was oxidized to nitrate and nitrite in aerobic sediments, then with anaerobiosis of the sediments as a result of rising tide, or diffusion of nitrate and nitrite to anoxic sediments, nitrate and nitrite were denitrified to molecular nitrogen

The significant correlation between dissolved organic nitrogen and dissolved organic phosphorus concentrations in Ware Creek and Carter Creek marsh waters along with the annual export of both nutrient species from the marshes suggest that like mechanisms were responsible for their production and export. Since evidence has been presented that marsh dissolved organic phosphorus exports were a result of excretion by marsh heterotrophs, it is also possible that the excretion of dissolved organic nitrogen (urea, uric acid, amines, amino acids) by marine heterotrophs (Webb and Johannes, 1967; Campbell, 1973; Stanier, Doudoroff and Adelberg, 1963) was responsible for the dissolved organic nitrogen exports from the marshes. Thus, the generally greater late spring and summer dissolved organic nitrogen efflux from the marshes could have been a result of the increased biotic activity at that time.

The extremely high correlations between particulate nitrogen and particulate phosphorus concentrations in Ware Creek and Carter Creek waters and the generally parallel monthly transport trends of these nitrogen and phosphorus forms, indicate that flux of detrital nitrogen was controlled primarily by the processes influencing detrital phosphorus inputs and outputs to and from the marshes. However, while there was annual net input of particulate phosphorus to both marshes and particulate nitrogen input to Carter Creek, Ware Creek was essentially steady state with respect to particulate nitrogen. Possible reasons for these differences are the seasonally varying ratio of nitrogen to phosphorus in marsh and estuarine detrital materials and the differences in relative adsorption of nitrogen and phosphorus on sediments. The annual imports of particulate phosphorus and import or small export of particulate nitrogen to the marshes together with the observed significant annual exports of particulate carbon from the marshes (Moore, in press), suggest that on an annual average basis the particulate material exported from the marshes was poorer in nitrogen and phosphorus than the particulates imported to the marshes from the estuary.

Considering the annual transports of all nitrogen species, there was a net export of approximately 400 kg of nitrogen from both Ware Creek and Carter Creek marshes to the estuary. Nitrogen inputs to the marshes from rainfall would amount to less than 10 kg/ha-yr (Chapin and Uttormark, 1973), or 140 kg to Ware Creek and 100 kg to Carter Creek marsh. Therefore, a significant quantity of the nitrogen output from the marshes must have entered the system by a process other than tidal transport or rainfall. The detection of nitrogen fixation by bacteria and algae in salt marsh environments (Daiber and Gooch, 1968; Green and Edmisten, 1972) suggest this process may have been responsible for nitrogen contributions to the marshes. Taking the net marsh nitrogen effluxes less the nitrogen inputs from rainfall as minimal estimates (since nitrogen outputs via denitrification or detrital nitrogen incorporation into marsh sediments are ignored) of the rates of nitrogen fixation, Ware Creek marsh fixed 209 μg N/m^2-hour and Carter Creek marsh fixed 340 μg N/m^2-hour. These figures compare well with the mean rate of fixation measured by Brooks, Brezonik, Putnam, and Keirn (1971) of 3.07 ng N/g sediment-hour in the top 2-5 cm stratum of Florida estuarine sediments (sediments actively fixing nitrogen), which, assuming 2.6 g/cm^3 for estuarine sediment (Meade, 1972) is equivalent to 239 μg N/m^2-hour.

Effects of the Salt Marsh Ecosystem on Estuarine Productivity

The influence of salt marshes on estuarine productivity has been largely ascribed to the high productivity of marsh angiosperms, much of which is exported to the estuaries where it is the basis for the detritus food web (Odum and de la Cruz, 1967; Darnell, 1964; Teal, 1962; Day et al., 1973). However, salt marsh nutrient transformations and the resultant marsh nutrient budgets, as determined in this study, indicate that the marshes by exporting dissolved nitrogen and phosphorus function to sustain the high rate of primary production in the estuaries. In doing so, the salt marshes increase productivity of the higher trophic levels of the estuary and also serve to maintain estuarine community homeostasis (Caperon, Cattell, and Krasnick, 1971).

Though there were no detectable relationships between phytoplankton productivity indices and dissolved inorganic phosphorus and nitrogen concentrations in estuarine waters flooding into or ebbing from Ware Creek and Carter Creek marshes, the phosphorus and more notably the nitrogen limitation of phytoplankton productivity (i.e. the stimulation of phytoplankton productivity upon nutrient addition) in the York River estuary and other coastal waters is well documented (Fournier, 1966; Thayer, 1969; Copeland and Hobbie, 1972; Ryther and Dunstan, 1971). Therefore, it is significant that at the time of peak potential estuarine phytoplankton productivity (May to October), Ware Creek and Carter Creek marshes displayed greatest export of dissolved inorganic and dissolved organic phosphorus, ammonia and dissolved organic nitrogen, nutrient species determined to be assimilable by marine phytoplankton (O'Kelley, 1973; Johannes, 1964; Keeney, 1972; McCarthy, 1972; Hellebust, 1970). Nitrate, another nitrogen species utilized by phytoplankton, was imported to the marshes year round. However, there are few documented instances in which nitrate was assimilated by phytoplankton in the presence of ammonia (Harrison, 1973; Eppley, Coatsworth, and Solórzano, 1969) and it is generally accepted that ammonia is the nitrogen species preferentially assimilated by marine phytoplankton (Riley and Chester, 1971). Furthermore, during the growing season, ammonia exports from the marshes to the estuary generally exceeded nitrate imports to the marshes. Therefore, based on the observed nutrient exports, it is probable that salt marshes promote phytoplankton productivity in estuarine systems.

There are several ways, in addition to salt marsh nutrient contributions to the estuary, that the marshes can influence estuarine primary productivity. For example, the nutrient depleted state of *Spartina* detritus exported from marshes led Thayer (1969; 1974) to speculate that bacteria utilizing this detritus as an energy source must assimilate nitrogen and phosphorus from estuarine waters and thereby compete with phytoplankton for nutrients. However, it can be argued that these bacteria by converting cellulose into organics utilizable by other trophic levels function as primary producers.

Luxury uptake, the uptake of nutrients by phytoplankton in excess of the quantities required for optimal growth, has been demonstrated for both phosphorus and nitrogen (Foree, Jewell, and McCarthy, 1971). Phytoplankton in nutrient rich environments can thus store nutrients for utilization at times of low nutrient availability. It has not yet been demonstrated, however, whether estuarine phytoplankton tidally transported to the marshes can take advantage of the elevation in nutrient concentrations brought about by salt marsh nitrogen and phosphorus additions to estuarine waters within the marshes.

The meaning of the significant salt marsh exports of ATP and chlorophyll <u>a</u> plus phaeopigments (Moore, in press) and its effect on the estuarine system is not yet clear.

There has been much speculation concerning the capability of salt marshes to remove excess nitrogen and phosphorus from estuaries receiving municipal sewage discharges (Wass and Wright, 1969; Broome, Woodhouse, and Senaca, 1973; Flemer, 1972; Gosselink, Odum and Pope, in press; Valiela, Teal, and Sass, 1973; Nixon and Oviatt, 1973; Grant and Patrick, 1970; Bender and Correll, in press). This study has revealed that natural marshes export dissolved nitrogen and phosphorus to the estuaries. It is possible that increased estuarine biomass caused by nutrient enrichment of estuaries would result in greater estuarine detrital nitrogen and phosphorus imports to the marshes with consequent increased export of dissolved nitrogen and phosphorus from the marshes. However, this study has also provided evidence that marshes serve to buffer estuarine waters with respect to inorganic nitrogen and phosphorus. The apparent increase in scale of some marsh nutrient cycling reactions and reversal in direction of nutrient flux through the marshes in response to natural variation in estuarine nitrogen and phosphorus concentrations suggest that marshes might function to reduce excessive estuarine nutrient loads. However, the feasibility of marshes as natural tertiary treatment plants and the effect of sewage contamination of estuaries on contiguous salt marshes remains to be ascertained.

APPENDIX

Table A1

Ware Creek 1/23/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO$_3^-$	NO$_2^-$	NH$_4^+$	DON	PN
12.25	0	0.78	0.40	1.70	4.99	0.28	8.0	30.0	47.0
12.67	+ 155								
12.92	+ 319								
13.25	+ 879	0.65	0.39	1.88	7.68	0.32	4.0	27.0	21.0
13.58	+1,143								
14.05	+1,278								
14.25	+1,332	0.63	0.41	1.91	7.27	0.30	4.0	29.0	28.0
14.70	+1,976								
14.92	+2,037								
15.25	+1,136	0.55	0.29	1.96	7.02	0.28	3.0	30.0	30.0
15.58	+1,213								
15.92	+1,216								
16.75	+1,252	0.49	0.24	1.95	7.13	0.27	3.0	31.0	25.0
16.58	+1,215								
16.92	+ 999								
17.25	+ 716	0.51	0.27	1.44	7.37	0.29	3.0	39.0	8.0
17.58	0	0.51	0.29	1.12	7.41	0.24	2.0	41.0	5.0
17.92	- 807								
18.25	-1,090								
18.58	-1,095	0.48	0.30	1.42	6.97	0.29	6.0	34.0	26.0
19.00	-1,257								
19.25	-1,239								
19.58	-1,236	0.51	0.30	1.85	5.95	0.32	4.0	33.0	29.0
19.92	-1,283								
20.25	-1,237								
20.58	-1,147	0.55	0.33	1.92	5.73	0.34	4.0	32.0	31.0
20.92	-1,023								
21.25	- 983								
21.58	- 869	0.62	0.39	2.27	4.67	0.33	3.0	41.0	32.0
21.92	- 701								
22.25	- 625								
22.58	- 530	0.69	0.39	1.96	3.23	0.34	4.0	36.0	20.0
22.92	- 398								
23.25	- 291								
23.58	- 153								
23.75	0	0.82	0.40	1.94	2.92	0.34	5.0	37.0	17.0

Table A2

Ware Creek 3/4/72

Time	Flow (l/sec)	Nutrient Concentrations (μg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
09.00	0	1.00	0.60	4.22	1.59	0.28	8.0	4.0	26.0
09.33	+ 177								
09.67	+ 410								
10.00	+ 544	0.57	0.45	1.12	3.44	0.32	6.0	3.0	14.0
10.33	+ 583								
10.67	+ 627								
11.00	+ 921	0.54	0.45	1.31	2.70	0.28	3.6	3.4	13.0
11.33	+ 977								
11.67	+1,051								
12.00	+1,245	0.59	0.45	1.63	2.44	0.31	4.0	5.0	13.0
12.33	+1,385								
12.67	+1,525								
13.00	+1,490	0.65	0.41	2.02	2.35	0.32	4.6	4.4	15.0
13.33	+1,443								
13.67	+1,216								
14.00	+ 880	0.69	0.31	1.89	2.65	0.31	3.4	4.6	18.0
14.33	0	0.50	0.32	1.69	3.19	0.29	3.8	8.2	17.0
14.67	- 902	0.61	0.35	1.70	2.90	0.29	4.0	8.0	15.0
15.00	-1,222								
15.33	-1,453	0.68	0.40	1.73	2.31	0.29	4.4	7.6	11.0
15.67	-1,586								
16.00	-1,738								
16.33	-1,689	0.77	0.45	1.48	2.31	0.28	5.2	9.8	11.0
16.67	-1,607								
17.00	-1,660								
17.33	-1,488	0.83	0.44	1.42	1.86	0.29	6.2	9.8	10.0
17.67	-1,257								
18.00	-1,099								
18.33	- 925	1.09	0.47	0.76	1.76	0.30	6.4	7.6	11.0
18.67	- 673								
19.00	- 526								
19.33	- 377	1.37	0.47	1.12	1.40	0.28	7.2	5.8	16.0
19.67	- 242								
20.00	- 52								
20.33	0	1.40	0.72	0.98	1.65	0.33	7.8	3.8	18.0

Table A3

Ware Creek 4/17/72

Time	Flow (l/sec)	Nutrient Concentrations (μg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
09.62	0	0.70	1.18	2.10	0.96	0.17	6.0	22.0	20.0
09.95	+1,010								
10.28	+ 644								
10.62	+ 838	0.42	0.62	2.00	0.64	0.22	3.0	24.0	16.0
10.95	+1,335								
11.28	+1,609								
11.62	+1,800	0.37	0.43	2.64	0.61	0.15	7.0	25.0	16.0
11.95	+1,990								
12.28	+2,210								
12.62	+2.360	0.29	0.31	3.00	0.89	0.15	4.0	20.0	20.0
12.95	+2.477								
13.28	+2,463								
13.62	+2,502	0.25	0.37	2.68	1.22	0.18	6.0	24.0	14.0
13.95	+2,532								
14.28	+2,246								
14.62	+1,944	0.31	0.43	3.56	2.73	0.17	1.0	29.0	18.0
14.95	+1,367								
15.28	+ 493								
15.50	0	0.37	0.35	1.90	3.70	0.17	5.0	15.0	15.0
15.83	-1,771								
16.17	-2,229								
16.50	-2,415	0.26	0.40	2.64	1.80	0.15	2.0	15.0	18.0
16.83	-2,574								
17.17	-2,735								
17.50	-2,707	0.26	0.46	3.90	0.83	0.14	12.0	17.0	23.0
17.83	-2,842								
18.17	-2,768								
18.50	-2,721	0.31	0.51	3.88	0.55	0.14	11.0	20.0	24.0
18.83	-2,550								
19.17	-2,397								
19.50	-2,157	0.43	0.52	4.01	0.49	0.15	14.0	17.0	23.0
19.83	-1,773								
20.17	-1,439								
20.50	-1,076	0.65	0.65	3.36	0.56	0.13	9.0	18.0	22.0
20.83	- 683								
21.17	- 215								
21.33	0	1.01	0.81	2.28	0.89	0.17	11.0	20.0	20.0

Table A4

Ware Creek 5/17/72

Time	Flow (l/sec)	Nutrient Concentrations (μg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
11.25	0	2.02	0.65	3.33	0.87	0.29	3.0	33.0	25.0
11.58	+ 492								
11.92	+ 715								
12.25	+ 872	1.64	0.63	1.90	2.96	0.48	2.0	28.0	15.0
12.58	+1,091								
12.92	+1,346								
13.25	+1,757	1.68	0.72	1.80	2.54	0.43	2.2	30.8	14.0
13.58	+2,021								
13.92	+2,213								
14.25	+2,540	1.47	0.68	2.32	2.19	0.39	2.0	29.0	14.0
14.58	+2,727								
14.92	+2,777								
15.25	+2,823	1.09	0.56	2.13	1.45	0.29	1.4	18.6	16.0
15.58	+2,829								
15.92	+2,703								
16.25	+2,268	0.35	0.42	1.23	0.98	0.13	1.4	19.6	12.0
16.58	+1,701								
16.92	+ 348								
17.00	0	0.26	0.49	1.05	0.33	0.13	1.6	22.4	9.0
17.33	-1,712								
17.67	-2,374								
18.00	-2,641	0.53	0.57	1.83	0.58	0.19	2.0	28.0	16.0
18.33	-2,938								
18.67	-2,855								
19.00	-2,770	1.08	0.72	2.07	1.05	0.28	2.4	32.6	15.0
19.33	-2,576								
19.67	-2,656								
20.00	-2,409	1.53	0.61	2.25	1.61	0.30	2.4	33.6	18.0
20.33	-2,256								
20.67	-2,098								
21.00	-1.742	1.78	0.67	2.88	0.84	0.34	1.8	26.2	29.0
21.33	-1,542								
21.67	-1,502								
22.00	- 940	2.24	0.66	2.23	0.72	0.33	12.0	28.0	17.0
22.33	- 773								
22.67	- 377								
22.92	0	2.43	0.69	1.75	0.82	0.38	17.0	26.0	37.0

Table A5

Ware Creek 6/14/72

Time	Flow (l/sec)		Nutrient Concentrations (µg at/l)						
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
10.33	0	2.04	0.82	6.99	2.90	0.55	4.8	45.0	47.0
10.67	+ 263								
11.00	+ 620								
11.33	+ 800	1.36	0.85	4.67	1.72	0.46	8.6	55.4	23.0
11.67	+ 973								
12.00	+1,156								
12.33	+1,227	1.10	0.79	5.31	1.02	0.38	6.2	51.2	24.0
12.67	+1,479								
13.00	+1,626								
13.33	+1,779	1.06	0.77	5.42	1.31	0.43	5.4	58.0	29.0
13.67	+1,972								
14.00	+2,013								
14.33	+2,029	0.82	0.76	3.92	1.18	0.40	3.0	55.0	22.0
14.67	+1,673								
15.00	+1,417								
15.33	0	0.60	0.55	2.67	0.90	0.39	3.4	49.4	20.6
15.67	-1,369								
16.00	-1,784								
16.33	-1,989	0.73	0.70	3.46	1.00	0.32	6.0	43.6	26.0
16.67	-2,033								
17.00	-1,945								
17.33	-1,981	1.16	1.10	5.06	0.72	0.42	6.6	56.6	30.0
17.67	-1,718								
18.00	-1,524								
18.33	-1,662	1.60	1.30	5.80	0.47	0.45	6.8	56.0	36.0
18.67	-1,290								
19.00	-1,066								
19.33	- 811	2.15	1.26	6.10	0.49	0.47	4.0	58.0	32.0
19.67	- 654								
20.00	- 554								
20.33	- 505	2.39	1.40	6.04	1.32	0.55	6.2	54.0	36.0
20.67	- 354								
21.00	- 206								
21.33	- 110	2.95	1.27	6.52	1.12	0.60	6.2	61.6	35.0
21.67	0	1.88	1.31	4.08	0.82	0.55	8.2	49.0	23.0

Table A6

Ware Creek 6/14-15/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
21.67	0	1.88	1.31	4.08	0.82	0.55	8.2	49.0	23.0
22.00	+ 409								
22.33	+ 640								
22.67	+ 756	1.43	0.99	3.85	1.17	0.52	6.2	49.8	24.0
23.00	+ 923								
23.33	+1,098								
23.67	+1,196	1.60	0.80	4.88	0.73	0.34	7.0	52.2	24.0
24.00	+1,414								
00.33	+1,714								
00.67	+1,760	1.45	0.76	4.79	0.70	0.33	5.6	52.2	32.0
01.00	+2,159								
01.33	+2,433								
01.67	+2,346	1.07	0.75	4.38	0.94	0.57	8.2	52.8	26.0
02.00	+2,316								
02.33	+2,350								
02.67	+2,307	0 88	0.60	4.08	0.86	0.50	7.2	58.8	23.0
03.00	+2,129								
03.33	+1,870								
03.67	+ 742	0.49	0.30	2.29	0.41	0.45	3.4	43.4	13.6
03.92	0	0.48	0.41	2.03	0.34	0.48	5.2	39.8	12.0
04.25	-1,502								
04.58	-1,831								
04.92	-2,277	0.69	0.49	3.23	0.54	0.61	5.6	45.6	17.4
05.25	-2,186								
05.58	-2,514								
05.92	-2,424	0.99	0.60	5.29	0.88	0.61	9.6	40.0	19.4
06.25	-2,440								
06.58	-2,118								
06.92	-2,116	1.28	0.73	6.34	0.52	0.61	8.2	57.8	36.0
07.25	-1,799								
07.58	-1,502								
07.92	-1,353	1.95	0.86	6.42	0.85	0.26	6.6	65.2	33.0
08.25	-1,209								
08.58	- 962								
08.92	- 789	2.52	0.98	7.29	0.81	0.66	5.4	60.2	35.0
09.25	- 612								
09.58	- 498								
09.92	- 249								
10.17	0	2.88	1.03	7.70	0.95	0.71	5.2	57.8	46.8

Table A7

Ware Creek 7/28/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.75	0	2.35	0.82	3.62	1.90	0.37	18.0	35.4	27.0
09.08	+ 543								
09.42	+ 830								
09.75	+ 971	1.85	0.70	2.77	2.88	0.42	18.0	29.0	22.2
10.08	+1,180								
10.42	+1,490								
10.75	+1,862	1.77	0.75	3.11	1.61	0.37	9.0	34.0	28.0
11.08	+2,112								
11.42	+2,450								
11.75	+2,710	1.41	0.64	4.40	1.09	0.59	16.4	29.4	36.6
12.08	+2,938								
12.42	+2,717								
12.75	+3,162	0.87	0.46	4.82	1.26	0.36	12.4	34.6	39.6
13.08	+3,142								
13.42	+2,838								
13.75	+2,741	0.74	0.34	4.33	1.02	0.23	13.0	26.2	43.6
14.08	+2,151								
14.42	+1,658								
14.75	+ 351								
14.83	0	0.57	0.39	1.81	0.74	0.17	11.2	26.0	23.8
15.17	-1,992								
15.50	-2,376								
15.83	-2,959	0.66	0.34	3.21	0.78	0.18	12.4	34.8	26.0
16.17	-3,058								
16.50	-3,055								
16.83	-3,419	0.71	0.40	3.75	0.68	0.19	17.0	28.0	32.0
17.17	-3,255								
17.50	-3,039								
17.83	-2,834	1.00	0.49	4.35	1.03	0.25	15.4	33.6	31.2
18.17	-2,612								
18.50	-2,345								
18.83	-2,147	1.36	0.58	4.90	0.89	0.28	14.2	34.2	35.2
19.17	-1,791								
19.50	-1,573								
19.83	-1,317	1.84	0.62	3.99	1.25	0.30	18.0	24.0	38.0
20.17	- 928								
20.50	- 496								
21.00	0	2.01	0.72	3.35	1.21	0.34	22.2	27.0	23.8

Table A8

Ware Creek 8/26/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.00	0	1.09	0.54	3.42	1.00	0.19	9.6	34.4	8.0
08.33	+ 393								
08.67	+ 557								
09.00	+ 557	0.64	0.54	2.27	0.57	0.18	2.0	30.0	12.0
09.33	+ 782								
09.67	+ 990								
10.00	+1,315	0.62	0.52	2.74	0.55	0.19	1.8	35.2	10.6
10.33	+1,620								
10.67	+1,966								
11.00	+2,138	0.51	0.57	3.18	0.67	0.20	1.6	32.4	34.6
11.33	+2,456								
11.67	+2,774								
12.00	+2,837	0.51	0.54	3.64	0.46	0.19	2.2	32.8	30.6
12.33	+2,956								
12.67	+2,457								
13.00	+2,534	0.64	0.47	3.92	0.44	0.17	2.2	26.8	42.4
13.33	+2,619								
13.67	+2,287								
14.00	+1,372	0.70	0.48	2.84	0.44	0.21	10.8	23.2	22.0
14.33	+ 352								
14.50	0	0.80	0.50	2.11	0.43	0.23	4.1	30.2	21.6
14.83	-2,304								
15.17	-2,613								
15.50	-3,167	0.62	0.55	2.79	0.38	0.21	6.6	29.4	20.0
15.83	-3,284								
16.17	-3,269								
16.50	-3,332	0.56	0.58	3.75	0.43	0.23	3.2	34.8	37.0
16.83	-3,393								
17.17	-3,187								
17.50	-3,147	0.56	0.54	4.01	0.47	0.22	10.4	37.2	21.0
17.83	-2,690								
18.17	-2,347								
18.50	-1,978	0.59	0.60	4.86	0.39	0.23	6.0	34.2	29.8
18.83	-1,625								
19.17	-1,233								
19.50	-1,014	0.82	0.65	3.93	0.48	0.25	7.2	34.4	26.6
19.83	- 676								
20.17	- 339								
20.66	0	1.25	0.62	2.86	1.01	0.30	8.6	33.8	15.6

Table A9

Ware Creek 9/24/72

Time	Flow (l/sec)	Nutrient Concentrations (μg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.00	0	0.81	0.27	3.42	0.40	0.07	2.6	27.4	7.2
08.33	+ 884								
08.67	+ 984								
09.00	+1,144	0.73	0.34	3.59	0.96	0.18	1.4	29.6	11.0
09.33	+1,581								
09.67	+1,871								
10.00	+2,268	0.58	0.39	7.76	0.74	0.11	1.8	28.2	56.0
10.33	+2,429								
10.67	+2,965								
11.00	+3,185	0.43	0.24	8.79	1.50	0.36	1.8	30.8	62.4
11.33	+3,378								
11.67	+3,287								
12.00	+3,300	0.71	0.21	6.67	4.76	1.64	2.6	32.4	60.0
12.33	+3,117								
12.67	+2,829								
13.00	+2,677	0.80	0.21	5.39	5.19	1.80	2.8	35.2	48.0
13.33	+2,365								
13.67	+1,914								
14.00	+1,181	0.85	0.20	3.25	5.46	1.83	2.6	41.4	18.0
14.33	0	0.84	0.31	2.45	5.75	1.82	1.8	44.2	19.0
14.67	-2,285								
15.00	-2,557								
15.33	-2,749	0.66	0.28	2.68	4.01	1.44	1.6	38.4	26.0
15.67	-3,317								
16.00	-3,303								
16.33	-3,134	0.49	0.19	4.15	2.82	1.05	1.2	38.8	25.0
16.67	-2,904								
17.00	-3,122								
17.33	-3,067	0.36	0.25	4.14	1.24	0.52	1.4	36.6	59.0
17.67	-3,112								
18.00	-2,960								
18.33	-2,791	0.36	0.23	5.45	0.46	0.29	2.8	34.6	74.6
18.67	-2,961								
19.00	-2,601								
19.33	-2,328	0.38	0.25	4.39	0.30	0.19	1.8	32.2	42.0
19.67	-2,003								
20.00	-1,627								
20.33	-1,160	0.44	0.28	3.83	0.41	0.22	2.4	33.6	30.0
20.67	- 403								
20.92	0	0.64	0.35	2.23	0.26	0.20	2.6	27.8	6.6

Table A10

Ware Creek 10/24/72

Time	Flow (1/sec)	Nutrient Concentrations (µg at/1)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.00	0	0.69	0.60	2.21	1.28	0.23	10.0	12.0	10.0
08.33	+ 323								
08.67	+ 456								
09.00	+ 594	0.45	0.77	1.20	1.02	0.20	7.6	17.4	6.0
09.33	+ 730								
09.67	+1,063								
10.00	+1,449	0.42	0.57	2.84	1.01	0.21	8.2	13.8	16.0
10.33	+1,616								
10.67	+1,791								
11.00	+2,228	0.42	0.53	3.12	2.05	0.27	5.0	22.4	19.6
11.33	+2,483								
11.67	+2,651								
12.00	+2,933	0.43	0.76	3.24	3.25	0.28	5.4	20.6	31.0
12.33	+2,712								
12.67	+2,574								
13.00	+2,486	0.78	0.65	2.18	8.50	0.38	7.2	21.8	12.0
13.33	+2,452								
13.67	+2,338								
14.00	+1,811	0.82	0.48	1.70	8.94	0.38	7.6	19.8	14.6
14.33	+ 841								
14.63	0	0.85	0.68	0.61	9.03	0.41	5.4	20.0	7.6
15.00	-1,992								
15.33	-2,663								
15.67	-3,065	0.61	0.84	0.80	6.45	0.35	6.0	22.4	7.6
16.00	-3,030								
16.33	-2,609								
16.67	-2,507	0.41	0.81	1.71	3.71	0.35	8.2	15.8	14.6
17.00	-2,594								
17.33	-2,611								
17.67	-2,212	0.30	0.57	2.74	1.43	0.25	4.0	21.6	17.4
18.00	-2,371								
18.33	-2,126								
18.67	-1,897	0.32	0.63	2.89	0.42	0.31	1.0	22.2	20.0
19.00	-1,714								
19.33	-1,431								
19.67	-1,472	0.37	0.52	3.28	0.39	0.14	5.0	17.4	25.4
20.00	-1,284								
20.33	- 907								
20.67	- 507	0.44	0.75	2.29	0.38	0.09	6.6	18.2	16.8
21.25	0	0.61	0.69	1.50	0.53	0.10	5.4	21.0	8.0

Table A11

Ware Creek 11/24/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.67	0	1.08	0.37	2.42	1.36	0.16	15.0	15.0	12.4
09.00	+ 346								
09.33	+ 375								
09.67	+ 453	0.86	0.40	1.89	9.20	0.29	13.6	10.4	13.4
10.00	+ 573								
10.33	+ 903								
10.67	+1,207	0.83	0.39	2.06	6.52	0.25	14.6	9.4	22.4
11.00	+1,628								
11.33	+1,799								
11.67	+2,088	0.75	0.43	2.80	3.76	0.21	13.0	11.2	23.2
12.00	+2,212								
12.33	+2,329								
12.67	+2,443	0.61	0.29	3.04	2.76	0.19	10.8	13.6	20.2
13.00	+2,698								
13.33	+2,576								
13.67	+2,440	0.48	0.25	1.79	5.01	0.14	7.0	17.4	10.6
14.00	+2,294								
14.33	+1,921								
14.67	+1,264	0.45	0.26	1.11	5.24	0.16	9.0	14.8	9.2
15.00	+ 134								
15.13	0	0.45	0.21	0.88	5.10	0.17	7.0	13.2	11.2
15.50	-1,692								
15.83	-2,053								
16.17	-2,251	0.45	0.28	1.21	4.26	0.13	9.8	11.4	11.2
16.50	-2,476								
16.83	-2,683								
17.17	-2,701	0.48	0.35	1.87	3.01	0.15	6.4	16.2	17.2
17.50	-2,842								
17.83	-2,691								
18.17	-2,475	0.64	0.34	2.58	2.49	0.19	8.2	15.0	24.4
18.50	-2,522								
18.83	-2,327								
19.17	-1,962	0.79	0.36	2.99	2.88	0.22	12.0	10.4	26.4
19.50	-1,779								
19.83	-1,568								
20.17	-1,189	0.85	0.47	3.07	2.42	0.24	13.0	12.0	24.0
20.50	- 948								
20.83	- 673								
21.17	- 326	1.21	0.41	3.29	1.64	0.23	10.2	18.4	31.0
21.50	- 119								
21.75	0	1.50	0.42	2.65	1.33	0.26	12.6	7.8	17.2

Table A12

Ware Creek 1/7/73

Time	Flow (1/sec)	Nutrient Concentrations (μg at/1)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
07.67	0	1.50	0.43	2.42	23.55	0.43	13.0	19.0	14.0
08.00	+ 111								
08.33	+ 210								
08.67	+ 339	0.76	0.41	2.35	24.39	0.49	7.0	22.0	18.0
09.00	+ 364								
09.33	+ 485								
09.67	+ 405	0.85	0.39	2.15	21.83	0.51	8.6	18.6	17.0
10.00	+ 527								
10.33	+ 494								
10.67	+ 514	0.87	0.41	2.05	22.81	0.47	7.0	20.0	16.0
11.00	+ 693								
11.33	+1,063								
11.67	+1,127	0.88	0.46	2.42	19.51	0.46	9.0	18.0	18.0
12.00	+1,321								
12.33	+1,368								
12.67	+1,174	0.86	0.45	2.50	18.55	0.45	5.0	18.0	18.0
13.00	+1,082								
13.33	+ 758								
13.67	+ 232								
13.83	0	0.84	0.43	2.51	18.06	0.44	12.0	17.0	18.0
14.17	-1,067								
14.50	-1,352								
14.83	-1,525	0.87	0.40	2.32	16.37	0.47	6.4	18.6	18.0
15.17	-1,719								
15.50	-1,559								
15.83	-1,624	0.86	0.41	3.00	20.04	0.46	12.4	15.6	24.0
16.17	-1,423								
16.50	-1,285								
16.83	-1,128	0.95	0.45	2.89	17.28	0.45	7.6	14.4	21.2
17.17	- 901								
17.50	- 700								
17.83	- 589	1.24	0.44	3.79	17.55	0.31	7.6	23.4	22.0
18.17	- 526								
18.50	- 399								
18.83	- 298	1.38	0.51	4.07	6.16	0.30	11.4	23.6	30.0
19.17	- 222								
19.50	- 171								
19.83	- 111								
20.17	0	1.50	0.50	4.90	6.44	0.30	13.0	15.0	34.0

Table A13

Carter Creek 3/7/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
10.50	0	2.03	0.43	3.78	9.33	0.40	7.0	9.0	30.0
11.25	+ 40								
11.50	+ 57	0.59	0.41	5.58	18.63	0.46	5.6	12.4	47.0
12.50	+ 205	0.49	0.41	9.48	8.78	0.39	5.0	11.0	87.0
12.75	+ 260								
13.50	+ 548	0.48	0.33	7.05	8.64	0.40	4.0	10.0	78.0
14.50	+ 567								
14.67	0	0.50	0.35	3.35	8.14	0.39	4.0	10.0	30.0
14.83	- 181								
15.25	- 358								
15.50	- 447								
15.67	- 509	0.48	0.29	1.83	7.36	0.42	3.6	12.4	28.0
16.00	- 225								
16.17	- 284								
16.33	- 374								
16.67	- 167	0.61	0.39	4.14	7.36	0.43	4.4	16.6	42.0
17.17	- 216								
17.33	- 138								
17.67	- 80	1.62	0.25	6.29	7.63	0.43	5.6	16.4	59.0
18.00	- 30								
18.67	- 19	2.09	0.41	5.24	7.99	0.49	5.6	18.4	48.0
19.25	- 19								
19.67	- 11	1.87	0.31	7.00	7.85	0.50	5.4	18.6	64.0
20.17	- 14								
20.67	- 13	1.72	0.17	9.17	6.85	0.52	4.8	16.2	88.0
21.67	- 9	1.78	0.24	7.38	6.13	0.54	5.8	15.2	71.0
22.67	0	2.10	0.27	5.37	5.88	0.51	7.4	14.6	40.0

Table A14

Carter Creek 3/23/72

Time	Flow (l/sec)	Nutrient Concentrations (μg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
10.83	0	0.78	0.70	2.50	1.84	0.26	5.0	21.0	16.0
11.17	+ 84								
11.50	+ 228								
11.83	+ 316	0.38	0.48	1.66	3.82	0.28	3.6	15.4	8.0
12.17	+ 262								
12.50	+ 75								
12.83	+ 37	0.41	0.51	1.00	4.22	0.26	3.0	14.0	7.0
13.17	+ 458								
13.50	+ 398								
13.83	+ 402	0.33	0.49	1.38	3.69	0.29	2.0	13.0	13.0
14.17	+1,233								
14.50	+ 829								
14.72	+ 82	0.27	0.50	1.05	3.06	0.26	2.0	15.0	10.0
14.88	+ 172								
15.17	+ 721								
15.50	+ 263								
15.83	+1,745	0.33	0.52	0.93	2.12	0.26	1.6	12.4	14.0
16.17	+ 610								
16.50	+ 954								
16.83	+ 136	0.26	0.50	0.80	2.42	0.28	1.6	12.4	12.0
17.25	+ 112								
17.30	+1,517	0.25	0.49	0.91	2.31	0.25	2.2	15.8	12.0
17.75	+ 358								
17.83	0	0.24	0.48	0.80	2.42	0.22	2.2	15.0	10.0
17.92	- 480	0.22	0.62	1.36	1.90	0.28	2.6	15.4	8.0
18.25	-1,533								
18.58	- 454								
18.92	- 807	0.29	0.59	0.84	1.84	0.28	3.0	15.0	7.0
19.25	-1,257								
19.58	- 709								
19.92	- 985	0.26	0.50	0.82	1.89	0.26	3.0	16.0	7.0
20.25	- 843								
20.58	- 695								
20.92	- 457	0.53	0.55	0.82	2.14	0.11	3.4	16.6	8.0
21.25	- 150								
21.58	- 60								
21.92	- 121	0.93	0.47	0.94	1.93	0.07	3.6	15.4	8.0
22.25	- 188								
22.58	- 67								
22.92	0	0.90	1.06	0.86	1.73	0.25	6.0	13.0	21.0

Table A15

Carter Creek 4/19/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
09.00	0	1.15	0.53	2.48	2.12	0.24	10.0	22.0	19.0
09.33	+								
09.67	+ 50								
10.00	+ 176	0.50	0.42	7.96	1.98	0.26	11.0	26.0	56.0
10.33	+ 243								
10.67	+ 341								
11.00	+ 436	0.43	0.47	5.88	3.28	0.30	4.0	33.0	41.0
11.33	+ 504								
11.67	+ 636								
12.00	+ 797	0.43	0.41	4.91	4.67	0.36	4.0	28.0	30.0
12.33	+ 900								
12.67	+1,045								
13.00	+ 761	0.37	0.45	3.27	2.87	0.31	1.0	28.0	23.0
13.33	+ 751								
13.67	+ 499								
14.00	+ 488	0.35	0.43	2.88	2.70	0.31	1.0	23.0	19.0
14.33	0	0.36	0.48	2.36	2.46	0.33	1.0	33.0	17.0
14.67	- 350								
15.00	- 947								
15.33	- 855	0.30	0.46	2.12	2.32	0.31	2.0	31.0	12.0
15.67	- 877								
16.00	-1,011								
16.33	-1,005	0.32	0.48	2.22	2.54	0.31	2.0	30.0	25.0
16.67	- 946								
17.00	- 793								
17.33	- 920	0.31	0.53	2.44	2.32	0.27	6.0	30.0	28.0
17.67	- 482								
18.00	- 384								
18.33	- 254	0.66	0.58	5.40	1.94	0.29	6.0	34.0	45.0
18.67	- 203								
19.00	- 114								
19.33	- 81	1.25	0.45	13.12	2.45	0.41	6.0	33.0	118.0
19.67	- 46								
20.00	- 34								
20.33	- 29	1.30	0.46	14.23	2.40	0.42	10.0	39.0	111.0
20.67	0	1.24	0.50	9.06	2.38	0.42	10.0	38.0	72.0

Table A16

Carter Creek 5/19/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l) DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
10.00	0	0.98	0.70	2.27	0.20	0.50	4.8	34.2	11.0
10.33	+ 251								
10.67	+ 407								
11.00	+ 354	0.88	0.82	1.95	0.40	0.30	3.2	22.8	31.0
11.33	+ 632								
11.67	+ 370								
12.00	+ 730	0.71	0.72	2.01	0.45	0.25	2.8	21.2	34.0
12.33	+1,016								
12.67	+1.466								
13.00	+1,265	0.67	0.64	2.03	0.41	0.24	2.6	18.4	32.0
13.33	+1,405								
13.67	+2,370								
14.00	+2,882	0.73	0.57	2.31	0.37	0.25	3.6	26.4	30.0
14.33	+4,160								
14.67	+4,926								
15.00	+3,365	0.43	0.39	1.76	0.29	0.27	2.0	14.0	22.0
15.33	+4,361								
15.67	+5,055								
16.00	+2,662	0.30	0.39	1.42	0.71	0.30	2.0	15.0	11.0
16.33	+1,908								
16.67	+1,015								
17.00	0	0.26	0.41	1.27	0.34	0.39	2.0	14.0	12.0
17.33	-2,109								
17.67	-3,342								
18.00	-2,778	0.63	0.57	2.02	0.29	0.29	2.0	21.0	21.0
18.33	-3,586								
18.67	-4,026								
19.00	-4,235	0.65	0.62	1.56	0.41	0.25	3.0	26.2	16.0
19.33	-2,775								
19.67	-2,207								
20.00	-1,864	0.58	0.66	1.63	0.31	0.30	3.6	25.6	21.0
20.33	- 893								
20.67	- 929								
21.00	- 958	0.72	0.67	1.69	0.25	0.32	3.4	23.8	27.0
21.33	- 439								
21.67	- 434								
22.00	- 552	0.75	0.62	1.31	0.17	0.39	3.2	22.0	23.0
22.33	- 328								
22.67	- 322								
23.00	0	1.21	0.78	1.19	0.16	0.52	2.8	21.2	16.0

Table A17

Carter Creek 6/17/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
10.00	0	4.20	0.87	6.05	2.17	0.57	10.8	82.2	31.4
10.33	+ 111								
10.67	+ 104								
11.00	+ 176	1.11	1.14	4.29	0.99	0.22	6.4	60.2	41.2
11.33	+ 362								
11.67	+ 446								
12.00	+ 422	1.06	1.19	4.22	1.68	0.21	4.8	66.4	38.0
12.33	+ 624								
12.67	+1,012								
13.00	+ 908	0.60	0.65	2.95	0.72	0.21	2.2	47.2	30.4
13.33	+1,014								
13.67	+1,057								
14.00	+1,145	0.54	0.68	2.14	0.72	0.23	5.0	48.0	22.2
14.33	+1,410								
14.67	+1,265								
15.00	+1,342	0.38	0.48	1.60	0.73	0.24	3.8	52.4	13.2
15.33	+1,153								
15.67	0	0.38	0.60	1.23	0.93	0.32	5.2	48.8	8.6
16.00	- 867								
16.33	- 749								
16.67	- 772	0.49	0.57	1.37	1.27	0.27	3.4	56.4	15.2
17.00	-1.122								
17.33	-1,238								
17.67	- 467	0.66	0.57	1.91	0.99	0.29	3.0	54.6	16.4
18.00	- 460								
18.33	- 443								
18.67	- 740	0.89	0.70	2.79	1.43	0.19	6.6	57.0	30.8
19.00	- 707								
19.33	- 419								
19.67	- 461	1.61	0.72	3.65	1.70	0.42	8.6	56.8	28.6
20.00	- 351								
20.73	- 236								
20.67	- 151	3.02	0.84	3.74	2.50	0.61	14.8	69.6	30.6
21.00	- 98								
21.33	- 46								
21.67	0	3.56	0.92	4.01	2.80	0.77	15.0	71.4	32.0

Table A18

Carter Creek 7/31/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.67	0	5.06	1.04	11.57	1.90	0.38	16.2	31.8	174.6
09.00	+ 533								
09.33	+ 694								
09.67	+ 684	1.09	0.47	5.27	2.81	0.32	19.8	33.8	38.6
10.00	+ 980								
10.33	+ 955								
10.67	+1,105	0.68	0.36	3.64	2.84	0.42	23.4	33.2	28.2
11.00	+1,088								
11.33	+1,779								
11.67	+2,477	0.42	0.30	2.14	2.78	0.44	18.2	32.8	24.0
12.00	+2,324								
12.33	+2,083								
12.67	+4,507	0.38	0.28	1.96	2.36	0.45	23.0	26.8	26.0
13.00	+3,543								
13.33	+2,766								
13.67	+1,029	0.30	0.23	1.57	2.21	0.47	23.0	24.2	24.0
14.00	0	0.53	0.41	2.05	2.08	0.46	16.8	31.6	31.8
14.33	- 508								
14.67	-2,283								
15.00	-2,622	0.35	0.36	1.82	2.05	0.45	16.8	32.4	25.2
15.33	-3,469								
15.67	-2,692								
16.00	-3,308	0.46	0.37	1.43	1.56	0.34	11.4	37.0	21.8
16.33	-2,269								
16.67	-1,976								
17.00	-2,140	0.45	0.30	6.61	2.16	0.42	8.2	45.0	53.0
17.33	-2,730								
17.58	0								
17.90	+7,087								
17.94	0								
18.00	-6,814	0.67	0.41	7.89	3.41	0.33	14.8	30.0	75.2
18.33	-2,604								
18.67	-1,086								
19.00	- 830	1.63	0.60	11.23	5.58	0.44	12.4	51.8	92.6
19.33	- 508								
19.67	- 264								
20.00	- 169	2.01	0.73	13.71	6.14	0.56	16.8	51.6	130.0
20.33	- 42								
20.67	- 157								
21.00	- 128								
21.28	0	2.79	0.82	6.82	6.11	0.58	14.4	53.4	108.0

Table A19

Carter Creek 8/29/72

Time	Flow (1/sec)	Nutrient Concentrations (µg at/1)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.33	0	3.33	0.69	6.44	1.34	0.34	18.6	39.4	46.0
08.67	+ 110								
09.00	+ 199								
09.33	+ 230	1.25	0.64	4.98	0.91	0.29	10.0	44.0	38.4
09.67	+ 418								
10.00	+ 619								
10.33	+ 847	0.90	0.66	4.44	0.55	0.38	3.8	45.2	38.0
10.67	+1,024								
11.00	+1,024								
11.33	+1,380	0.69	0.69	3.53	0.53	0.30	3.8	44.2	33.0
11.67	+1,549								
12.00	+1,792								
12.33	+2.488	0.52	0.59	2.58	0.41	0.30	2.6	33.4	22.6
12.67	+4,265								
13.00	+3,427								
13.33	+1,612	0.42	0.55	2.10	0.29	0.25	2.8	29.2	25.0
13.67	0	0.48	0.64	2.05	0.28	0.29	1.8	37.8	17.4
14.00	- 292								
14.33	-1,409								
14.67	-3,530	0.43	0.63	1.85	0.52	0.15	2.4	30.8	21.8
15.00	-3,223								
15.33	-2,004								
15.67	-1,859	0.67	0.63	2.15	0.34	0.33	2.2	35.8	19.8
16.00	-1,643								
16.33	- 574								
16.67	- 883	0.85	0.60	2.31	0.35	0.30	1.6	38.4	23.0
17.08	- 563								
17.33	- 707								
17.67	- 731	1.23	0.58	3.05	0.52	0.35	3.8	38.4	22.8
18.00	- 475								
18.33	- 457								
18.67	- 331	2.22	0.68	3.23	0.65	0.36	4.2	37.8	30.0
19.00	- 206								
19.33	- 83								
19.67	- 32	2.69	0.69	4.67	0.79	0.44	9.6	37.8	29.2
20.00	0	2.60	0.65	5.48	0.63	0.42	12.8	35.6	45.4

Table A20

Carter Creek 9/27/72

Time	Flow (l/sec)	Nutrient Concentrations (μg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
07.83	0	1.68	0.36	4.05	1.37	0.47	22.6	15.4	44.0
08.25	+ 64								
08.50	+ 107								
08.83	+ 229	0.84	0.33	4.64	0.78	0.31	6.8	21.2	36.4
09.17	+ 336								
09.50	+ 417								
09.83	+ 852	0.65	0.40	4.90	0.98	0.33	3.4	19.6	39.0
10.17	+1,181								
10.50	+1,223								
10.83	+1,256	0.83	0.52	3.34	0.81	0.30	2.4	20.6	26.0
11.17	+1,035								
11.50	+2,086								
11.83	+2,291	0.55	0.38	2.16	0.70	0.13	2.0	17.0	23.8
12.17	+2,491								
12.50	+2,821								
12.83	+2,934	0.48	0.35	1.93	0.59	0.14	1.8	10.2	23.0
13.17	+1,982								
13.67	0	0.50	0.33	1.81	0.55	0.16	1.6	29.4	9.0
14.00	-1,873								
14.33	-2,509								
14.67	-2,840	0.60	0.40	2.09	1.22	0.06	2.8	29.2	14.0
15.00	-2,961								
15.33	-2,122								
15.67	-1,717	0.70	0.40	2.57	0.15	0.07	1.0	33.0	18.0
16.00	-1,336								
16.33	-1,306								
16.67	-1,074	0.85	0.41	2.90	0.33	0.11	1.2	33.8	24.0
17.00	- 959								
17.33	- 821								
17.67	- 684	1.01	0.31	2.10	0.43	0.14	2.6	35.4	12.0
18.00	- 458								
18.33	- 613								
18.67	- 398	1.32	0.37	11.24	5.82	0.38	9.0	38.0	84.0
19.00	- 213								
19.33	- 184								
19.67	- 137	1.07	0.42	19.52	11.35	0.39	19.0	46.0	150.0
20.00	- 77								
20.33	- 38								
20.50	0	1.49	0.46	8.56	11.88	0.87	21.4	38.6	57.6

Table A21

Carter Creek 10/27/72

Time	Flow (1/sec)	Nutrient Concentrations (μg at/1)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
08.00	0	1.80	0.68	1.55	2.20	0.28	8.0	23.6	10.4
08.42	+ 35								
08.67	+ 50								
09.00	+ 229	1.05	0.71	0.62	1.76	0.23	7.0	18.6	5.0
09.33	+ 324								
09.67	+ 354								
10.00	+ 639	0.69	0.55	0.43	1.34	0.27	5.4	13.4	5.2
10.33	+ 515								
10.67	+ 738								
11.00	+1,130	0.54	0.60	0.32	1.41	0.27	4.4	11.2	4.4
11.33	+1,350								
11.67	+1,406								
12.00	+1,826	0.60	0.71	0.18	1.00	0.26	2.6	16.0	3.4
12.33	+2,329								
12.67	+3,492								
13.00	+3,669	0.43	0.71	0.33	0.49	0.20	3.4	12.6	5.0
13.33	+3,224								
13.67	+2,097								
14.00	+1,128	0.40	0.64	0.19	0.14	0.22	1.4	13.4	5.2
14.33	0	0.55	0.90	0.45	0.07	0.27	3.0	12.2	4.8
14.67	- 911								
15.00	-2,545								
15.33	-2,355	0.49	0.77	0.40	0.24	0.17	1.2	17.0	5.8
15.67	-2,596								
16.00	-2,549								
16.33	-2,114	0.51	0.66	0.54	0.28	0.16	5.0	19.8	8.2
16.67	-1,662								
17.00	-1,011								
17.33	-1,079	0.63	0.57	0.67	0.44	0.19	3.0	22.6	11.4
17.67	- 873								
18.00	- 833								
18.33	- 619	0.78	0.63	0.37	0.61	0.17	3.8	21.6	8.3
18.67	- 692								
19.00	- 236								
19.33	- 283	1.16	0.61	0.39	0.67	0.19	3.0	25.2	4.8
19.67	- 187								
20.00	- 115								
20.33	0	1.42	0.86	0.52	0.72	0.23	3.4	19.6	8.0

Table A22

Carter Creek 11/27/72

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
10.33	0	2.40	0.52	5.81	11.04	0.21	22.5	43.8	43.4
10.67	+ 57								
11.00	+ 88								
11.33	+ 214	1.07	0.53	7.90	16.11	0.31	26.0	33.0	66.0
11.67	+ 274								
12.00	+ 179								
12.33	+ 154	0.94	0.40	6.32	16.39	0.30	17.2	17.0	62.6
12.67	+ 436								
13.00	+ 557								
13.33	+ 345	0.74	0.28	3.05	14.97	0.25	16.6	16.6	40.0
13.67	+ 158								
14.00	+ 565								
14.33	+ 161	0.72	0.31	2.02	13.66	0.24	10.8	20.0	22.2
14.67	+ 601								
15.00	0	0.64	0.29	1.82	13.86	0.22	11.4	16.0	26.6
15.33	- 82								
15.67	- 120								
16.00	- 316	0.69	0.24	1.44	13.91	0.21	8.2	15.8	28.8
16.33	- 569								
16.67	- 315								
17.00	- 290	0.77	0.33	1.46	15.88	0.24	14.8	15.6	15.6
17.33	- 456								
17.67	- 181								
18.00	- 195	1.63	0.50	1.65	13.54	0.26	14.6	19.4	18.0
18.33	- 259								
18.67	- 313								
19.00	- 128	2.09	0.53	5.75	12.92	0.30	16.0	19.8	40.0
19.33	- 54								
19.67	- 21								
20.00	- 10	2.20	0.51	4.96	13.01	0.27	16.0	21.6	39.4
20.33	- 8								
20.67	- 5								
21.00	- 5	2.57	0.50	3.71	12.17	0.26	16.0	21.0	37.0
21.33	- 1								
21.67	- 1								
22.00	- 0	2.80	0.48	6.75	11.36	0.27	21.2	18.0	51.8
22.33	- 0								
22.67	0	3.23	0.42	4.61	11.28	0.29	22.6	17.2	39.2

Table A23

Carter Creek 1/11/73

Time	Flow (l/sec)	Nutrient Concentrations (µg at/l)							
		DIP	DOP	PP	NO_3^-	NO_2^-	NH_4^+	DON	PN
09.00	0	1.97	0.41	2.22	24.89	0.34	19.6	17.4	10.0
09.33	+ 96								
09.67	+ 230								
10.00	+ 472	1.16	0.29	0.76	25.91	0.35	14.8	14.2	6.0
10.33	+ 288								
10.67	+ 460								
11.00	+ 805	0.91	0.27	0.56	25.75	0.31	11.8	12.2	5.0
11.33	+ 714								
11.67	+ 446								
12.00	+ 914	0.90	0.25	0.59	23.28	0.32	16.0	8.0	5.0
12.33	+ 948								
12.67	+ 92								
13.00	+ 869	0.86	0.25	0.61	23.68	0.31	12.4	7.6	4.4
13.33	+ 753								
13.67	+ 186								
14.00	+ 199								
14.33	0	0.89	0.22	0.58	23.78	0.33	9.8	8.2	4.8
14.67	- 646								
15.00	- 472								
15.33	- 818	0.90	0.25	0.63	25.15	0.31	11.6	12.4	6.0
15.67	- 627								
16.00	- 737								
16.33	- 816	1.01	0.35	0.57	26.86	0.32	13.2	11.8	6.0
16.67	- 706								
17.00	- 662								
17.33	- 561	1.28	0.34	0.86	23.39	0.34	15.0	11.0	10.0
17.67	- 407								
18.00	- 222								
18.33	- 145	1.93	0.45	1.27	20.39	0.32	7.2	20.8	15.0
18.67	- 97								
19.00	- 43								
19.33	- 24	1.92	0.45	2.09	22.07	0.34	6.8	30.2	12.0
19.67	- 12								
20.00	- 9								
20.33	0	2.04	0.48	1.58	23.55	0.35	8.0	30.0	10.0

Table B1

Combined Sample Method

Water samples are collected at twenty minute intervals over a tidal cycle. In the lab, these samples are divided into flood tide and ebb tide groupings. The samples within each group are then mixed together to form a liter combined sample, such that each twenty minute subsample is represented in the combined sample by a volume proportional to the instantaneous marsh creek water transport at the time the twenty minute sample was taken. Flood tide and ebb tide combined samples prepared in this manner should have nutrient concentrations approximating the mean concentrations of all flood tide waters and all ebb tide waters over the tidal cycle sampled. The concentrations of the combined samples multiplied by the marsh tidal prism produces an estimate of flood tide and ebb tide nutrient transport. Any residual nutrient transport represents net nutrient influx or efflux to or from the marsh. Listed below are representative Ware Creek marsh combined sample concentrations, and nutrient transports calculated by both the combined sampling and the hourly sampling (see Materials and Methods) methods.

Table B1 (Continued)

	Combined sample NO_3^- concentrations µg at N/1		Combined sample calculated NO_3^- transport grams N	Hourly sample calculated NO_3^- transport grams N
1/23/72	Flood Ebb	7.26 6.29	+266	+455
3/4/72	Flood Ebb	2.75 2.20	+153	+139
4/17/72	Flood Ebb	1.22 0.82	+218	+135
5/17/72	Flood Ebb	2.02 1.50	+287	+486
6/14/72	Flood Ebb	1.28 0.70	+199	+159
7/28/72	Flood Ebb	1.58 1.15	+272	+306
8/26/72	Flood Ebb	0.36 0.40	-24	+50
9/24/72	Flood Ebb	3.70 2.65	+795	+872
10/24/72	Flood Ebb	5.15 4.02	+674	+849
11/24/72	Flood Ebb	4.60 3.04	+854	+854
1/7/73	Flood Ebb	19.80 17.30	+609	+703

+ = input

- = output

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