INVESTIGATIONS CONCERNING THE ALGAL COMMUNITIES OF THE LOWER RED RIVER, MONTGOMERY COUNTY, TENNESSEE

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LARRY DOUGLAS CARPENTER

INVESTIGATIONS CONCERNING THE ALGAL COMMUNITIES OF THE LOWER RED RIVER, MONTGOMERY COUNTY, TENNESSEE

An Abstract

Presented to

the Graduate Council of

Austin Peay State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Larry Douglas Carpenter

June 1983

ABSTRACT

A study of algal communities found in the lower Red River drainage system, Montgomery County, Tennessee was made. Quarterly samples were taken from five depths at 11 stations on the Red River, Big West Fork Creek, and the Cumberland River from summer, 1977 through spring, 1978. Parameters investigated were phytoplankton identification and quantification, chlorophyll a concentrations, and Carbon-14 primary productivity analysis. Selected physical and chemical tests were conducted to support the biological data. The algal flora included 149 taxa. Seasonally, the summer flora yielded the largest standing crop (average of 10 million cells per l), was most diverse with 91 taxa, and was dominated by blue-green algae (Cyanophyta). Centric diatoms (Order Centrales) dominated the smaller fall and winter floras while pennate diatoms (Order Pennales) dominated the spring. Cell counts and chlorophyll a concentrations were highest at a depth of 0.5 m while production was greatest at the surface. Production as well as algal standing crops increased at most downstream stations and reacted at points below municipal outfall. Results of physical and chemical tests are summarized and discussed.

INVESTIGATIONS CONCERNING THE ALGAL COMMUNITIES OF THE LOWER RED RIVER, MONTGOMERY COUNTY, TENNESSEE

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June 1983

To the Graduate Council:

I am submitting herewith a Thesis written by Larry Douglas Carpenter entitled "Investigations Concerning the Algal Communities of the Lower Red River, Montgomery County, Tennessee." I recommend that it be accepted in partial fulfillment of the requirement of the degree Master of Science, with a major in Biology.

Edward D. Chesler
Major Professor

We have read this thesis and recommend its acceptance:

Second Committee Member

Third Committee Member

Accepted for the
Graduate Council

William H. Ellis
Dean of the Graduate School

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Lastly, the personal sacrifices made and encouragement given by my father and mother, Doug and Margie Carpenter, made my education possible and will never be forgotten. To them, along with my sister Julie, this thesis is dedicated.

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CHAPTER I

INTRODUCTION

The study of both lentic and lotic waters has received much attention in recent years as human activities have greatly altered these ecosystems. Rarely can pristine systems be found for study. This is especially true in the midsouth where impoundments and other alterations by the Corps of Engineers and the Tennessee Valley Authority have affected most major streams. Such factors as urbanization, industrialization, and agricultural chemicals have also had varied effects upon waterways. Even so, it is important that these altered systems receive attention. While comparisons with non-altered systems may not be possible, present studies will provide a data base to monitor future changes.

This study involved the algae and certain chemical and physical parameters of polluted waters in Tennessee.

Objectives of the Study

The objectives of this study were to: (1) determine the algal flora of the lower Red River and observe changes in seasonal abundance; (2) determine certain chemical and physical parameters of the area; (3) compare and correlate the results obtained.

The Study Area

The study area involved the lower Red River and parts of the Cumberland River and Big West Fork Creek. All sampling was conducted in Montgomery County, northern middle Tennessee, at approximately 36° 32' north latitude and 87° 22' west longitude.

The Red River enters Montgomery County from the northeast, flows in a westerly direction and discharges into the Cumberland River at river mile 125.4 (Figure 1). The Cumberland enters Montgomery County from the southeast and travels northwestward to the confluence of the Red River and then continues southwestward. Big West Fork Creek junctions with the Red River about 1.3 miles from the confluence of the Red and the Cumberland. The Cumberland River has a moderately swift current, but the other two streams are slow-moving except following heavy or persistent rains.

The primary study stream, Red River, has a total length of 98 miles; 83 are free-flowing, while the lower 15 are impounded (United States Army, undated). The total drainage area is 1,456 square miles. Most of this watershed is agricultural with scattered developments. The city of Clarksville (population 55,000) is located at the junction of the Red and Cumberland Rivers and Fort Campbell Kentucky, a United States Army Base, is found at the headwaters of West Fork Creek.

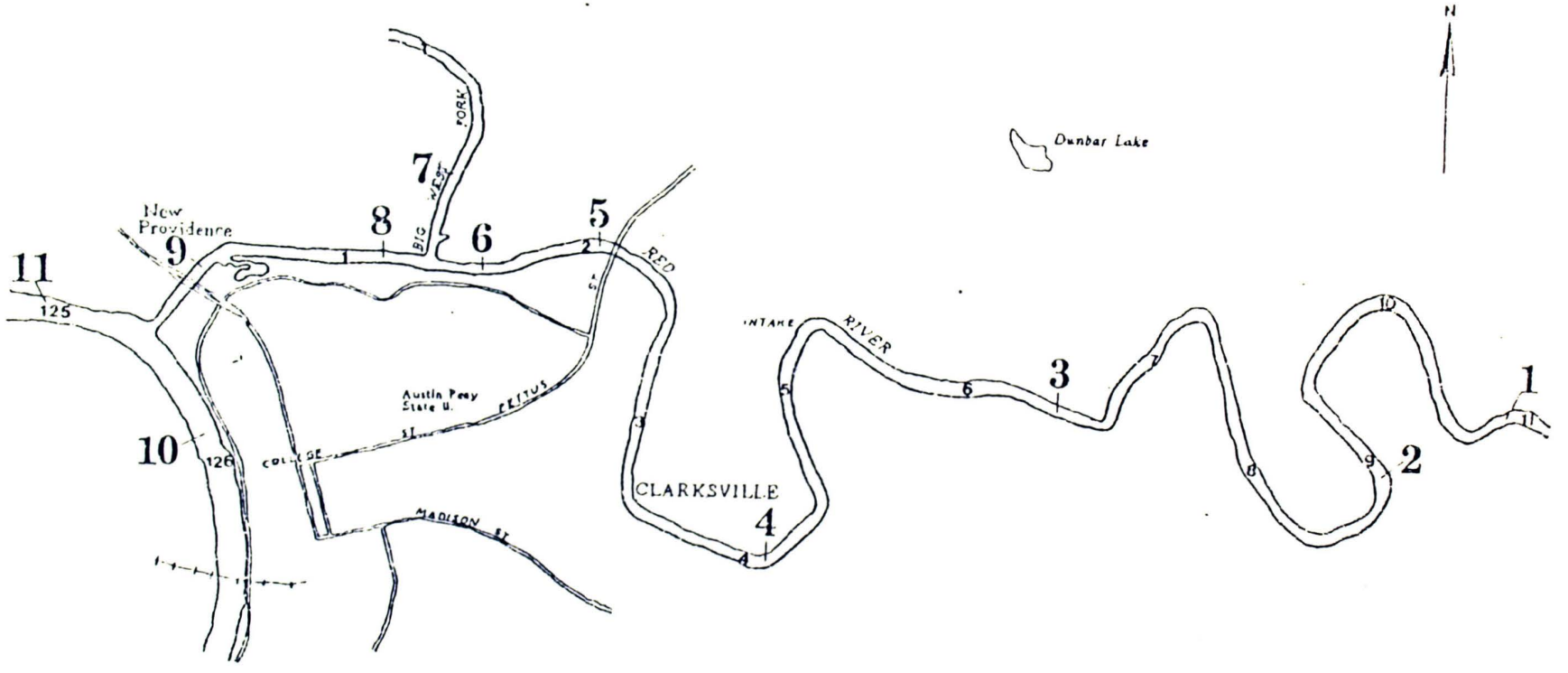

Figure 1. Map showing the Cumberland River, Big West Fork Creek, and Red River portions of the study area. Large numbers represent stations and small numbers indicate river miles.

Average discharge for the Red River is approximately 1,113 cubic feet per second (cfs) at Port Royal and the Cumberland River averages 21,480 cfs at Cheatham Dam (U. S. Geological Survey, 1977 and 1978). Monthly average discharges for the waterways are shown in Figures 2 and 3.

The approximate surface width of the Red River is 171 feet at the mouth and 106 feet 11 miles upstream at the most distal sampling site. The Cumberland River is about 390 feet in width at the confluence of the Red River.

The upstream portion of the watershed is rolling to hilly, well drained, sometimes cherty farmland. The soils are mostly of the Baxter-Mountview-Pembroke Associations. Banks of the Red River are approximately five percent limestone bluff and 95 percent reddish-clay loam. The lower watershed is primarily level, consists of Arrington-Lindside-Beason Association soils, and may be well or poorly drained (U. S. Department of Agriculture, 1975). The lowermost portions of the Red River watershed are susceptible to flooding (U. S. Geological Survey, 1977) and this is probably an important factor in replenishing algal flora stock from farm ponds (Patrick, 1972).

Physiographically, the area is located in the northwestern section of the Highland Rim (Fenneman, 1938). The climate is basically a temperate one with pronounced seasonal changes (U. S. Department of Agriculture, 1975). Precipitation averages 48 inches annually with most occurring in winter and least in fall. On the average,

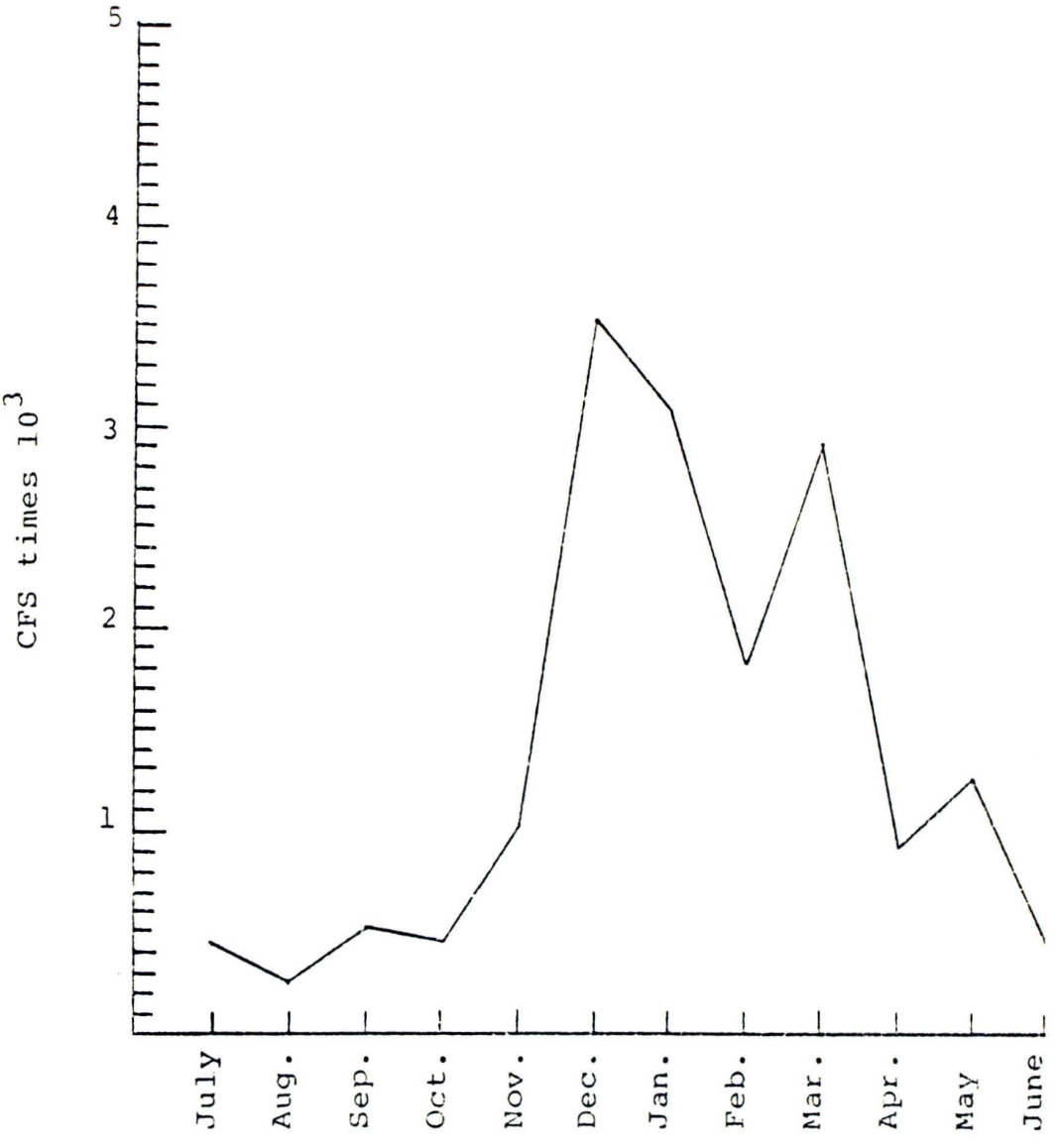

Figure 2. Red River discharge in cubic feet per second (CFS) times 10^3. Average values for each month from July, 1977 to June 1978 at Red River mile 25.5 (41.0 km), Port Royal, Tennessee (U. S. Geological Survey, 1977, 1978).

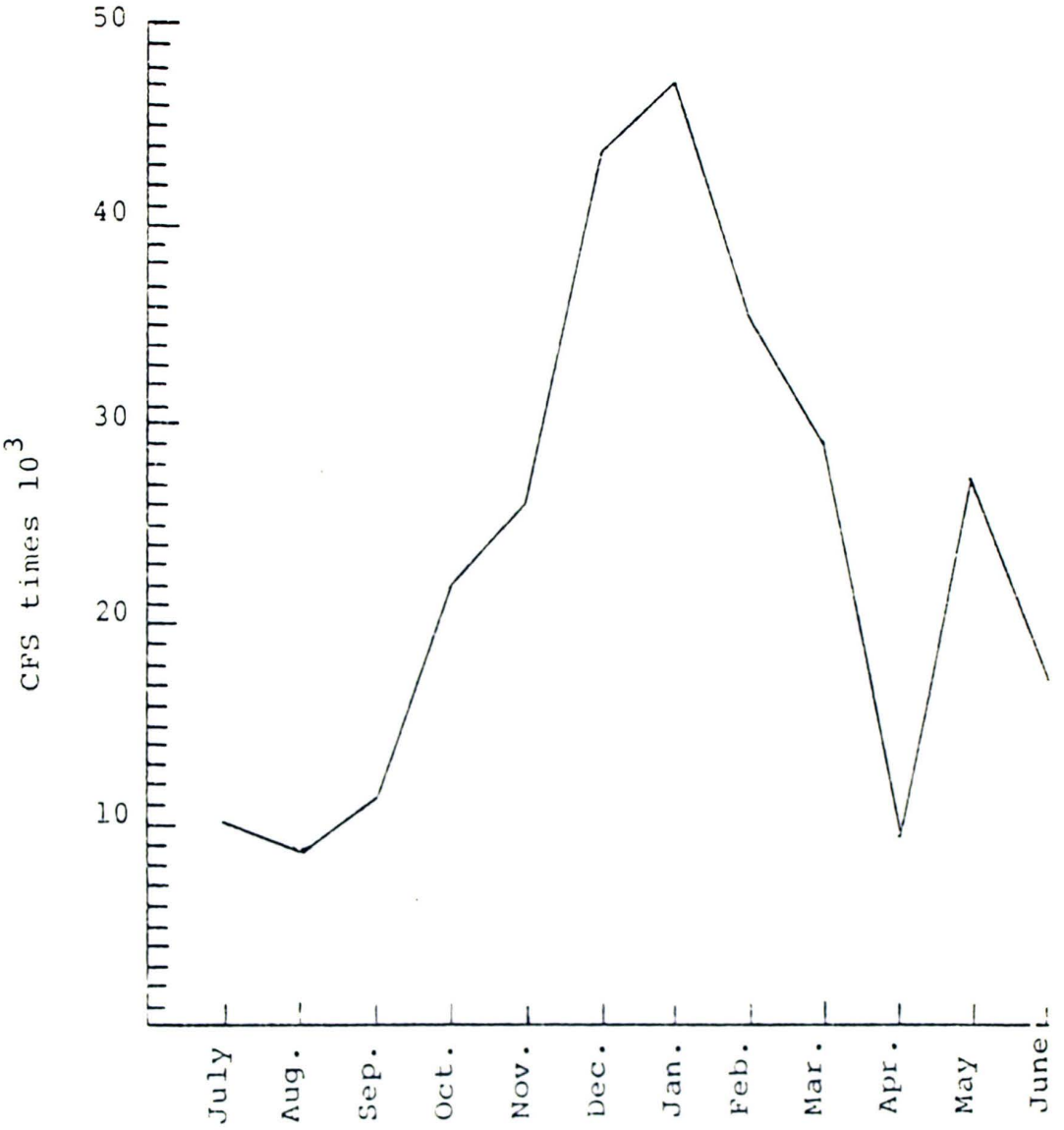

Figure 3. Cumberland River discharge in cubic feet per second (CFS) times 10^3. Average values for each month from July, 1977 to June, 1978 at Cumberalnd River mile 148.4 (238.8 km), Cheatham Dam, Tennessee (U. S. Geological Survey, 1977, 1978).

temperatures are less than 0° C for 79 days of the year and greater than 32° C for 71 days.

Review of the Literature

Algal floristic studies in Tennessee are limited. An early account by Eddy (1930) described the planktonic algae of Reelfoot Lake and Lackey (1942) listed similar forms from the Cumberland and Duck Rivers. Herman (Silva) Forest conducted the most extensive research and is credited with three important publications: Forest (1954), Silva (1953) and Silva and Sharp (1944).

Two papers concern algal floristics of the study area. A study of the Little West Fork Creek, Fort Campbell, Kentucky (U. S. Army, 1974) revealed 17 genera of diatoms from periphyton and Harned (1976) described 78 taxa from a Kentucky Farm pond.

In recent years phycological research has deviated from solely taxonomic studies. Efforts are now mostly physiological or attempt to show correlations between algal quality and quantity and human effects on the aquatic environment (Patrick, 1973). Examples are studies by Brinley (1940), Fogg (1975), Hohn and Hellerman (1963), Kline and Lowe (1975), Marshall (1968), Ratnasbapathy and Deason (1977), Seilheimer (1963), Staker, Hoshaw and Everett (1974), Stoermer (1978), Wager and Schumacher (1970), Whitford and Schumacher (1963), and Wujek, et al. (1980). The Class Bacillariophyceae has received much attention and has been studied extensively (Hohn and

Hellerman, 1963; Lowe and Kline, 1974; Van Landingham, 1964; Williams and Scott, 1962).

Studies in which many biotic, chemical and physical parameters were measured, such as those of Tryon, Hartman and Cummins (1965) on the Ohio River and Patrick, Cairns and Roback (1966) on the Savannah River, are priceless works which not only revealed the condition of the rivers at the time of testing, but also provide an excellent tool for comparing other lotic habitats as well as establishing historical accounts for future measurements of the same streams.

CHAPTER II

METHODS AND MATERIALS

Eleven sampling stations were established and each assigned a number (Figure 1). Station 1, the uppermost, was located 11 miles from the confluence of the Red and Cumberland River. Station 7 was on Big West Fork Creek, 0.4 miles upstream from the confluence with the Red River. Stations 10 and 11 were on the Cumberland River just above and below the mouth of the Red River. Others were located at intervals along the Red. This arrangement gave not only adequate representation of the lower Red River, but also indicated effects of Big West Fork Creek on the Red and of the Red on the Cumberland.

Samples were taken from each station during each of the four seasons. Summer samples were taken on 15, 16 and 17 July, 1977; fall on 21 October, 1977; winter on 3 March, 1978; spring on 12, 13, 15 and 20 May, 1978. An 18-foot Viking OMC inboard-outboard boat equipped with a 120 horsepower engine was used for data collection.

The data collected from each station included phytoplankton, periphyton, chlorophyll *a* concentration, primary productivity, and several other physical and chemical parameters. Methods for each of these are discussed separately.

Phytoplankton

Water samples for phytoplankton and chlorophyll a analysis were obtained from five depths at each station. The surface samples were collected by inverting a one liter Nalgene bottle approximately five cm beneath the surface. The 0.5, 1.0, 2.0 and 2.5 m samples were obtained by triggering a 4.5 l Van Dorn Bottle at each depth. From each of these depths, 100 ml samples were appropriately labelled and mixed with four ml of 10 percent formalin. Samples were stored on ice in a dark Styrofoam cooler while in the field. Five hundred ml samples were used for chlorophyll a analysis.

Upon receipt of the phytoplankton samples in the laboratory, proper bench sheets were filled out and the samples refrigerated until determinations could be made. All identifications were made with a Carl Zeiss Standard WL Research microscope.

In preparation for cell counts, each sample was stirred for one minute with an automatic stirrer at slow speed and then one ml portions were transferred to a Sedgewick-Rafter counting chamber. A cover slip was placed over the chamber, cells allowed to settle for several minutes, and identifications made at a magnification of 250 X. This magnification was too low for specific identifications in many cases but higher objectives were not used due to their shorter working distances. In samples where diatom

numbers were high, frustules were cleaned and mounted according to procedures of Hasle and Fryxell (1970), Patrick and Reimer (1966) and Zoto, Dillon, and Schlichting (1973). Procedures for phytoplankton and periphyton analysis followed Brooks (1975), Lund, Kipling and LeCren (1958), Nygaard (1951) and Weber (1968 and 1973).

Periphyton

The attached algae were not as extensively studied as was the phytoplankton; taxonomy only was considered. Periphyton samples were collected by placing 12.5 x 5.0 x 0.6 cm Plexiglas plates 0.5 m deep in well-lighted water at each station. The plates were positioned with their long axes paralleled to the water surface and fastened to an aluminum holder. The holder was attached to an anchor on one end and to a one-gallon plastic jug buoy on the other; this constantly kept the plates at a depth of 0.5 m. The plates were left in place for four weeks, at which time they were collected and frozen in bags until processing. Retrieval of the plates was less than 50 percent due to vandalism and destruction by flood waters.

In the laboratory one side of each plate was scraped first with a neoprene policeman and then with a glass microscope slide. The plate was rinsed into a 250 ml beaker and the residue preserved in a four ml solution of 10 percent formalin/100 ml water. The samples were diluted to 0.5, 1.0, 1.5, or 2.0 l for identification.

All algal identifications were made using the following taxonomic keys: Cocke (1967), Edmondson (1959), Hansmann (1973), Patrick and Reimer (1966), Prescott (1962, 1968, 1970, 1975, 1978), Smith (1950), Tiffany and Britton (1952), Tilden (1910), Vinyard (1974), Weber (1971) and Whitford and Schumacher (1973).

Chlorophyll a Concentration

Water for determining chlorophyll a concentration was obtained by methods previously described. Five hundred ml samples were field filtered through glass fiber filters, using a Millipore field filtering apparatus. The filter pads were folded and protected by a larger filter pad. Each filter pack was labelled and stored in a field desiccator on ice until return to the laboratory where the field desiccator, containing pads, was frozen until analysis could be made. The procedures were suggested by the American Public Health Association (1976), Brooks (1975) and Weber (1973).

Chlorophyll a and phaeophytin a concentrations were determined fluorometrically with an American Instrument Company Fluorocolorimeter, Number J4-7440. Procedures for these determinations followed those of the American Public Health Association (1976), Brooks (1975), Lorenzen (1966), Richards and Thompson (1952), Weber (1973) and Yentsch and Menzel (1963).

The frozen glass fiber filters were thawed and placed

in a glass tissue grinding tube to which 3 ml of 90 percent acetone and two drops of a saturated solution of calcium carbonate ($CaCO_3$) had been added. A Teflon pestle was attached to a conventional hand drill and each filter was ground for one minute on ice. A hand drill was found to be faster and to give more homogeneous results than a grinding motor. Prolonged grinding increases the temperature of the sample resulting in more rapid evaporation of the extract (Yentsch and Menzel, 1963).

The contents of the grinding tube and 90 percent acetone rinsate from the Teflon pestle and grinding tube were transferred to a screw-capped centrifuge tube. The tube was sealed, labelled, and placed in a refrigerator to steep for 24 hours. The volume was adjusted to 5 ml, centrifuged at high speed for four minutes on a clinical centrifuge, pipetted into a fluorescence test tube, and placed into the fluorocolorimeter for measurement.

The fluorocolorimeter was modified for chlorophyll measurements with a Corning CS-5-60, Number 5543 2-in^2, 4.9 mm thick-polished glass filter for excitation wavelengths and a Corning CS-2-60, Number 2408 2-in^2, 3.0 mm thick color filter for emission wavelengths (Yentsch and Menzel, 1963). The standard ultraviolet lamp (G. E. Number F4T4/BL) was replaced with a "blue lamp" which gives much greater excitation energy in the 430-450 µm region (Yentsch and Menzel, 1963). Chlorophyll *a* concentrations from phytoplankton have been found to exhibit

emission wavelengths in the range of 650 to 675 μm. The standard photomultiplier tube (RCA 931A) usually has little response to light above 650 μm and was replaced by a red sensitive photomultiplier tube (R 136). This change is believed to increase the sensitivity of the fluorometer at least ten times (Lorenzen, 1966).

Since chlorophyll in an acetone solution is destroyed when exposed to white light (Collins and Weber, 1978), serious errors in chlorophyll determination may result. As suggested by Blanck (1967) laboratory lights were covered with a green Plexiglas filter to minimize these errors. The green Plexiglas has been shown to have maximum transmission wavelengths at the same general range that chlorophyll a has minimum absorption.

Percent transmittance was recorded for each sample and computed to mg of chlorophyll a per m^3. Chlorophyll a concentrations were calculated by equations given by the American Public Health Association (1976).

Primary Productivity

The C-14 method for measuring primary productivity was conducted in summer, 1977 only and followed procedures of Brooks (1975) and Taylor (1971). Tests were conducted between 10:00 a.m. and 4:00 p.m. on 22, 23, 24 and 25 August, 1977. In the field, 120 ml samples of river water were taken from the same depths as for previous studies. Four speciman bottles were prepared for each sample. Two

of these were clear serum bottles (light bottles) and two were painted black and wrapped with black electrical tape (dark bottles). The light bottles measured total C-14 uptake while the dark bottles measured heterotrophic C-14 uptake. Each bottle, with water sample, was inoculated with one ml of water containing two microcurries μCi) of C-14. The bottles were secured to metered brass chains and suspended from floats to the same depths from which their water samples were taken. Incubation was for three hours, at which time the bottles were retrieved and immediately injected with 2 ml of 10 percent formalin to cease C-14 uptake. Bottles were stored on ice in the dark until they could be transferred to refrigeration.

In the laboratory, each bottle was filtered through a 0.45 mm cellulose-acetate membrane filter at 15 inches of mercury vacuum. Each was rinsed three times with distilled water and the rinse also filtered. The filters were stored in a dark desiccator until liquid scintillation counting. Results were computed as counts per minute. Although it is desirable to make corrections for incident radiation variations, this was not done due to radiometer failure.

Other Tests

Surface water nitrates (NO_3), phosphates (PO_4) and total hardness parameters were tested at all stations utilizing the Hach Chemical Company Field Test Kit in accordance with the Hach Methods Manual (1973). All data

are expressed as parts per million (ppm).

Dissolved oxygen in ppm and temperature in Centigrade was measured with a YSI Model 54 meter. These measurements were made at the surface and at one meter intervals to the river bed. The percent of oxygen saturation was determined using methods suggested by Reid (1961).

The hydrogen ion concentration was determined for surface water only with a Corning Model 610 pH meter. Turbidity was determined with a 20.5 cm Secchi-disk after it was determined that the Secchi-disk readings were as accurate as a submarine photometer for determining one percent light penetration. Readings were taken at each station and are reported in cm of light penetration as suggested by Tyler (1968).

CHAPTER III

RESULTS

The results obtained in each research category are presented below in the same order as described under methods and materials.

Phytoplankton and Periphyton

Algal classification varies considerably with different authors. In this outline, taxonomic arrangement and nomenclature follow the general scheme of Prescott (1970), except that the Cyanophyta is placed first in accordance with the phylogenetic scheme of Bold and Wynne (1978).

The algal flora included 149 taxa; 141 of these occurred in the phytoplankton community and 8 were strictly periphytic. Four divisions, 10 orders, 26 families and 70 genera were found (Table I). The Cyanophyta included 14 taxa, Chlorophyta 40, Euglenophyta 6, and Chrysophyta 89. Two of the three orders of Chrysophyta encountered, the Centrales and Pennales, revealed 17 and 70 taxa respectively.

Seasonally, the summer flora was most diverse with 91 taxa; 66 taxa were found in the fall, 62 in the winter, and 85 in the spring. The number of taxa occurring at each station for each season is shown in Table II.

The summer flora was largest in standing crop and

Table I. Identified algae from the lower Red River, Big West Fork Creek, and Cumberland River, Montgomery County, Tennessee.

Taxa	*Occurrence
DIVISION CYANOPHYTA	
Order Chroococcales	
Family Chroococcaceae	
Merismopedia tenuissima Lemm.	Su
Merismopedia sp.	Su-F
Order Oscillatoriaceae	
Family Oscillatoriaceae	
Lyngbya sp.	Su-F-W-Sp-8-9
Oscillatoria granulata Gard.	Su-F-Sp-8-9
Oscillatoria sp.	Su-F-W-Sp-8-9
Phormidium angustissimum West et West	Su-F-W-Sp-5
Spirulina sp.	Su-W
Family Nostocaceae	
Anabaena sp.	Su-F-Sp
Anabaenopsis circularis (West) Wol. & Mil.	Su
Aphanizomenon flos-aquae (L.) Ralfs.	Su-Sp-9

* Collections of algae from phytoplankton are represented by seasonal abbreviations, i.e., Su=summer phytoplankton, F=fall phytoplankton, W=winter phytoplankton, Sp=spring phytoplankton. Numbers represent stations where periphyton was collected on 26 August, 1977.

Table I. (continued)

Taxa	Occurrence
Cylindrospermum sp.	8-9
Nostoc sp.	Su-Sp
Family Hammatoideaceae	
Raphidiopsis curvata Fritsch	Su
Family Rivulariaceae	
Rivularia sp.	Su
DIVISION CHLOROPHYTA	
Order Volvocales	
Family Chlamydomonadaceae	
Chlamydomonas sp.	Su-F-W-Sp
Family Volvocaceae	
Eudorina sp.	Su-F-Sp
Pandorina morum (Muell.) Bory	Su-W
Pandorina sp.	Su-F
Platydorina caudata Kofoid	Su
Order Tetrasporales	
Family Gloeocystaceae	
Gloeocystis sp.	Su-F-W
Order Chlorococcales	
Family Chlorococcaceae	
Closteridium lunula Reinsch	Sp
Closteridium sp.	F-W
Schroederia setigera (Schroed.) Lemm.	Su-Sp

Table I. (continued)

Taxa	Occurrence
Tetraedron regulare Kuetz.	F
Tetraedron trigonum (Naeg.) Hansgirg	F
Family Oocystaceae	
Ankistrodesmus convolutus Corda	Su-F-W-Sp
Ankistrodesmus falcatus (Corda) Ralfs	Su-F-Sp
Ankistrodesmus sp.	F
Chlorella sp.	Su-F-W
Franceia ovalis (France) Lemm.	Su-W-Sp
Franceia sp.	Su
Treubaria crassispina G.M. Smith	Su-F-Sp
Treubaria sp.	Su
Family Micractiniaceae	
Micractinium pusillum Fresenius	Su-Sp
Family Scenedesmaceae	
Actinastrum gracillum G.M. Smith	Su-Sp
Actinastrum Hantzschii Lag.	Su-F-Sp
Crucigenia fenestrata Schmidlex	W
Scenedesmus abundans (Kirch.) Chodat	F
Scenedesmus acuminatus (Lag.) Chodat	F
Scenedesmus arcuatus Lemm.	Su-F
Scenedesmus bijuga (Turp.) Lag.	Su-F-Sp
Scenedesmus dimorphus (Turp.) Kuetz.	Su-F-W-Sp

Table I. (continued)

Taxa	Occurrence
Scenedesmus quadricauda (Turp.) Breb.	Su-F-W-Sp
Family Hydrodictyaceae	
Pediastrum Boryanum (Turp.) Meneg.	F
Pediastrum duplex Meyen	Su
Pediastrum simplex (Meyen) Lemm.	Su
Pediastrum sp.	Su
Order Zygnematales	
Family Zygnemataceae	
Mougeotia sp.	7-8-9
Spirogyra sp.	Su-F
Family Desmidiaceae	
Closterium sp. 1	Su
Closterium sp. 2	Su
Closterium sp. 3	Su
Closterium sp.	Su-F-W-Sp
Cosmarium sp.	Su-F-9
DIVISION EUGLENOPHYTA	
Order Euglenales	
Family Euglenaceae	
Euglena elastica Prescott	Su
Euglena sp.	Su-F-W-Sp
Phacus Spirogyra Drezepolski	Su
Phacus sp.	Su-F-Sp

Table I. (continued)

Taxa	Occurrence
Trachelemonas Girardiana (Pla.) Defl.	Sp
Trachelemonas sp.	W-Sp
DIVISION CHRYSOPHYTA	
Subdivision Xanthophyceae	
Order Mischococcales	
Family Sciadiaceae	
Ophiocytium capitatum Wolle	Su
Ophiocytium sp.	Su-Sp
Subdivision Bacillariophyceae	
Order Centrales	
Family Coscinodiscaceae	
Coscinodiscus lacustris Grun	Su-F
Coscinodiscus Rothii (Ehr.) Grun.	W-Sp
Coscinodiscus sp.	Su-F-W-Sp
Melosira ambigua (Grun.) O. Mull.	Su-F-W-Sp
Melosira distans (Ehr.) Kutz.	Su-F
Melosira granulata (Ehr.) Ralfs.	Su-F-W-Sp-5-7
Melosira herzogii Lemm.	Su-W-Sp
Melosira italica (Ehr.) Kutz.	F-Sp
Melosira varians Ag.	Su-F-W-Sp-8-9
Melosira sp.	Sp
Cyclotella bodanica Eulenst	Su-F-W
Cyclotella glomerata Bachman	Su-F-9

Table I. (continued)

Taxa	Occurrence
Cyclotella sp.	Su-F-W-9
Stephanodiscus sp.	F-W-Sp-8
Family Rhizosoleniaceae	
Rhizosolenia eriensis H.L. Smith	Su-Sp
Rhizosolenia minima Lavender	Su-Sp
Rhizosolenia sp.	Su-F-Sp
Order Pennales	
Family Fragilariaceae	
Asterionella formosa Hass	Su-Sp
Asterionella formosa var. *gracillima* Grun.	W
Diatoma tenue var. *elongatum* Lyngb.	Sp
Diatoma hiemale (Roth) Heib.	W-Sp
Diatoma vulgare Bory	Su-W-Sp-7
Diatoma sp.	W-Sp
Hannaea arcus (Ehr.) Patr.	Su
Fragilaria capucina Desm.	W-Sp
Fragilaria construens (Ehr.) Hust.	Sp
Fragilaria leptostauron (Ehr.) Hust.	Sp
Fragilaria sp. 1	Su
Fragilaria sp.	Su-F-W-Sp-7-8
Meridion circulare (Grev.) Ag.	Su-W-Sp
Opephora martyii Herib	W

Table I. (continued)

Taxa	Occurrence
Opephora sp.	W-Sp-9
Synedra actinastroides Lemm.	W-Sp-5
Synedra acus Kutz	Su-F-W-Sp
Synedra nana Meister	Sp
Synedra rumpens Kutz.	Su-W
Synedra ulna (Nitz.) Ehr.	Su-F-W-Sp-7-8
Tabellaria fenestrata (Lyngb.) Kutz.	9
Tabellaria flocculosa (Roth) Kutz.	W
Tabellaria sp.	Su-F-Sp
Family Achnanthaceae	
Achnanthes clevei Grun.	W
Achnanthes lanceolata (Breb.) Grun	W
Achnanthes laterostrata Hust.	F-Sp-7-8-9
Achnanthes sp.	F-W-Sp-8-9
Cocconeis diminuta Pant.	8
Cocconeis sp.	Sp
Rhoicosphenia curvata (Kutz.) Grun.	Sp
Family Naviculaceae	
Amphipleura pellucida Kutz.	W
Anomoeneis sphaerophora (Kutz.) Cleve	Sp
Diploneis elliptica (Kutz.) Cleve	F
Gyrosigma sp.	Su-F-Sp-5-7-8-9

Table I. (continued)

Taxa	Occurrence
Plagiotropis lepidoptera var. proboscidea (Cl.) Reim.	Sp
Navicula cuspidata (Kutz.) Kutz.	Su-W-Sp
Navicula cryptocephala Kutz.	F
Navicula lacustris Greg.	Su-W
Navicula lanceolata (Ag.) Kutz.	8
Navicula peregrina (Ehr.) Kutz.	Su-F-W-Sp
Navicula radiosa Kutz.	Su-F-Sp-8
Navicula salinarum Grun.	Su-F-W-Sp-7-8
Navicula vanheurckii Patr.	Su
Navicula sp. 1	Su-F-W-Sp-5-7-8-9
Navicula sp. 2	Su-F-W
Navicula sp.	Su-F-W-Sp-5-7-8-9
Neidium sp.	Sp
Pinnularia sp.	8
Pleurosigma sp.	Su-F-5-7-8-9
Stauroneis ignorata Hust.	F
Family Gomphonemaceae	
Gomphoneis olivaceum (Horne.) P. Dawson ex Ross & Sims	F-W-Sp-5-8
Gomphonema acuminatum Ehr.	Sp
Gomphonema angustatum (Kuetz.) Grun.	8
Gomphonema parvulum Kutz.	W

Table I. (continued)

Taxa	Occurrence
Gomphonema sp.	W-Sp
Family Cymbellaceae	
Cymbella affinis Kutz.	Sp
Cymbella tumida (Breb.) van Heurck.	Su-F-W-Sp-7-8-9
Cymbella sp.	Su-W-Sp-7
Family Nitzschiaceae	
Bacillaria paxillifer (O.F. Mull.) Hendy	Sp-7
Hantzschia amphioxys (Ehr.) Grun.	Sp-7
Nitzschia acicularis W. Smith	W-Sp-9
Nitzschia gracilis Hantzsch	Su-F-W-Sp-8-9
Nitzschia holsatica Hustedt	Su-F-Sp
Nitzschia sigmoidea (Ehr.) W. Smith	8-9
Nitzschia tryblionella Hantzsch	Sp
Nitzschia sp. 1	Su-W
Nitzschia sp.	Su-F-W-Sp-5-7-8-9
Family Surirellaceae	
Surirella guatemalensis Ehr.	Su-Sp
Surirella linearis W. Smith	Su-F-W-Sp-8
Surirella sp.	W-Sp

Table II. Total number of taxa identified at each station for all depths.*

Stations	Seasons			
	Summer	Fall	Winter	Spring
1	34	14	3	-
2	34	8	9	36
3	37	8	-	36
4	44	10	4	31
5	36	22	-	31
6	41	24	12	34
7	41	24	17	34
8	43	31	-	35
9	46	26	17	34
10	48	24	20	29
11	39	25	6	29

*Winter values are based on surface collections only. Winter stations nine and ten were sampled at all depths and yielded 12 and 31 taxa respectively; station eleven was sampled at surface and 0.5 m only and yielded 19 taxa.

numbers were successively smaller during fall, winter and spring (Figure 4). Average phytoplankton cell counts and chlorophyll a concentrations are shown in Figures 5, 6, 7 and 8 for each station. The major groups of algae making up the seasonal floras are shown in Figures 9, 10, 11 and 12. Chlorophycean algae were most abundant in summer and fall and their major constituents are shown in Figures 13 and 14 for each station.

Average phytoplankton and chlorophyll a concentrations for each depth and season are shown in Figures 15, 16, 17 and 18. The major groups occurring at each depth are presented in Figures 19, 20, 21 and 22. Ratios of Carbon-14 primary productivity results and phytoplankton cell counts are plotted with chlorophyll a concentrations at each station and depth in Figures 23, 24, 25, 26, 27 and 28.

Chlorophyll a Concentration

Seasonal chlorophyll a values are given in Tables III, IV, V and VI, Appendix I. The highest concentration, 119 mg/m^3, was found during summer (Table III) and the lowest, 4 mg/m^3, during fall (Table IV). Average concentrations for the four sampling periods were: summer-58 mg/m^3, fall-43 mg/m^3, winter-42 mg/m^3 and spring-17 mg/m^3.

Carbon-14 Primary Productivity

Net production results are given in Table VII,

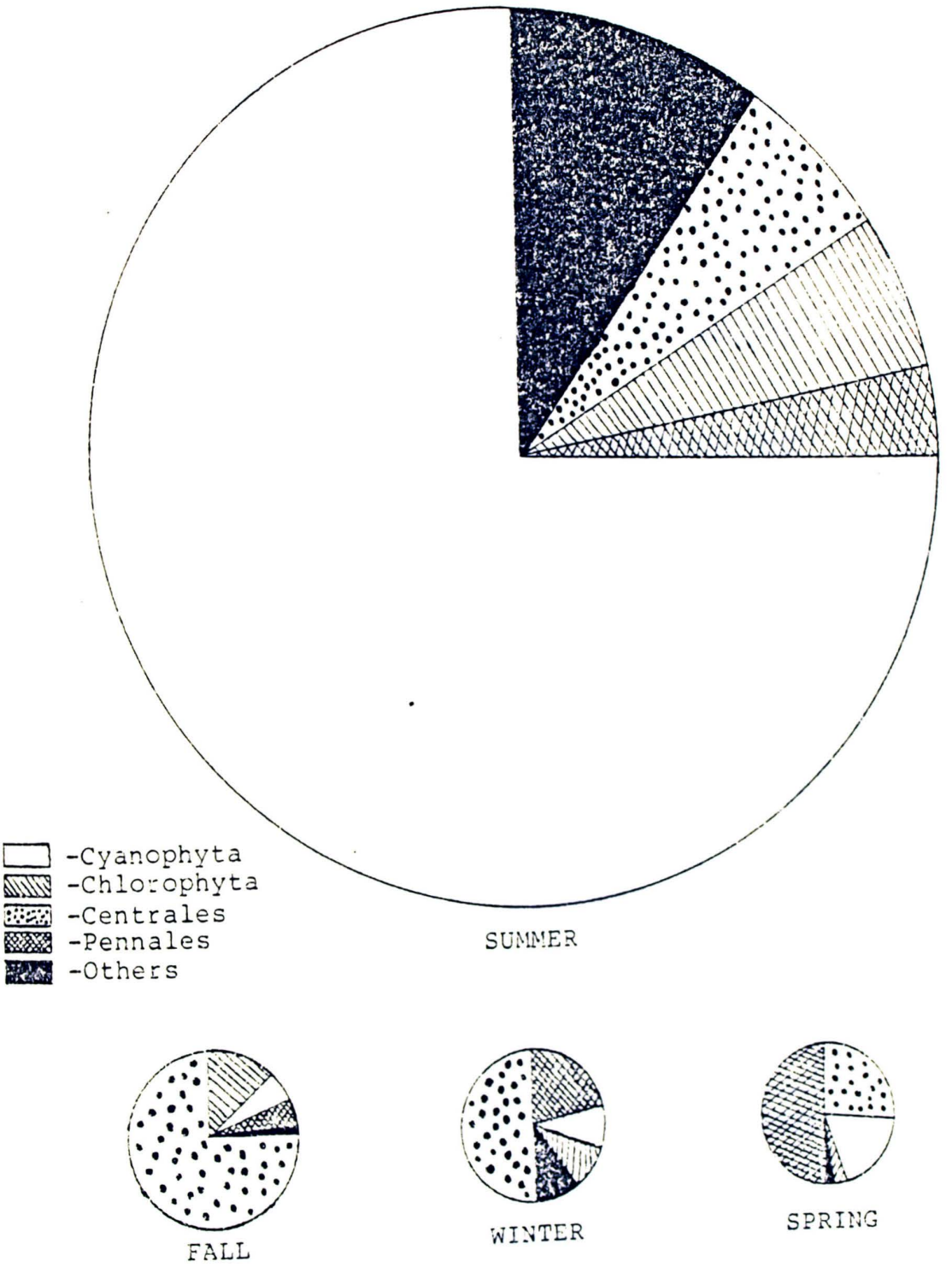

Figure 4. Relative size of seasonal phytoplankton floras and relative composition of major groups in each season.

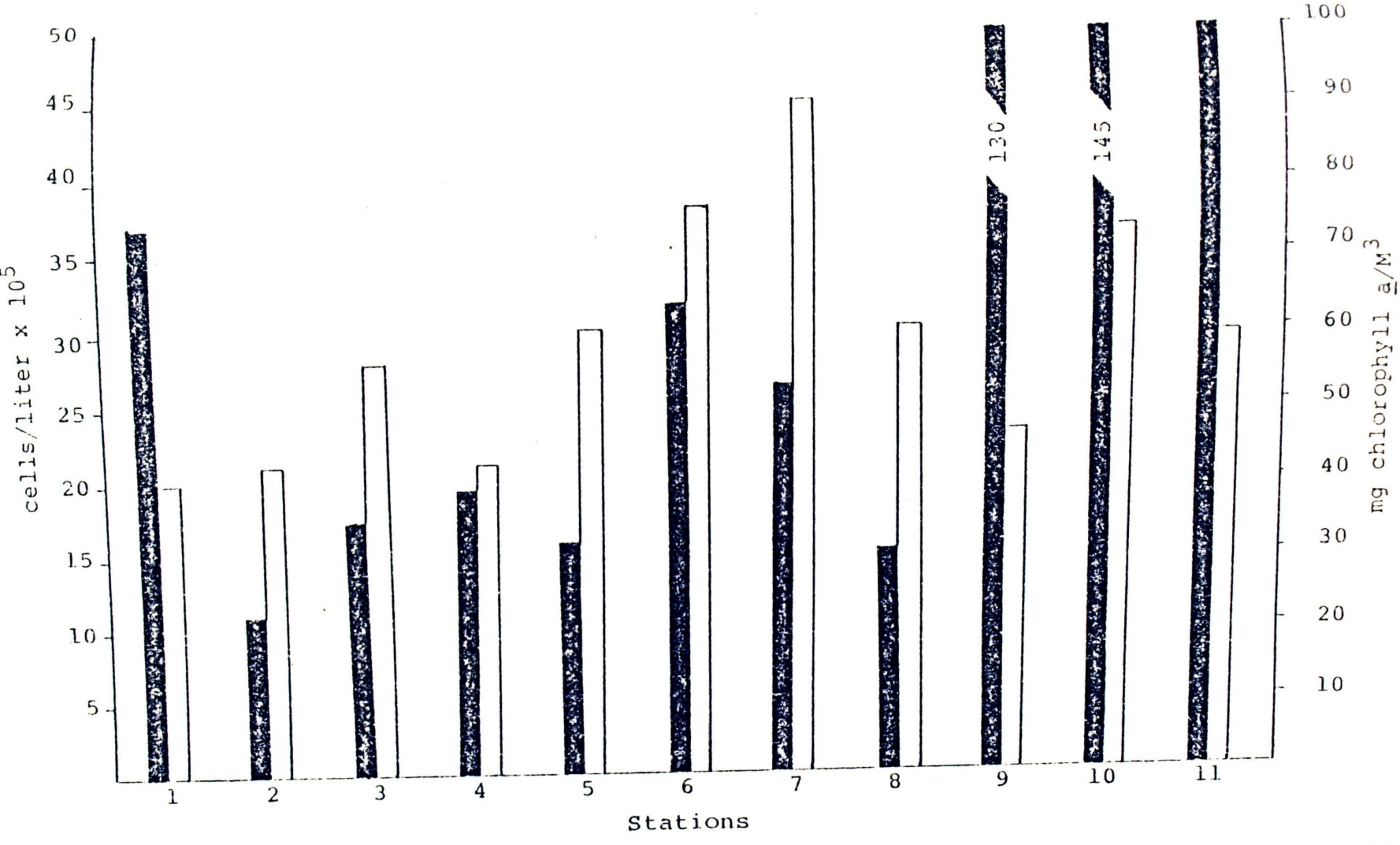

Figure 5. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in summer, 1977.

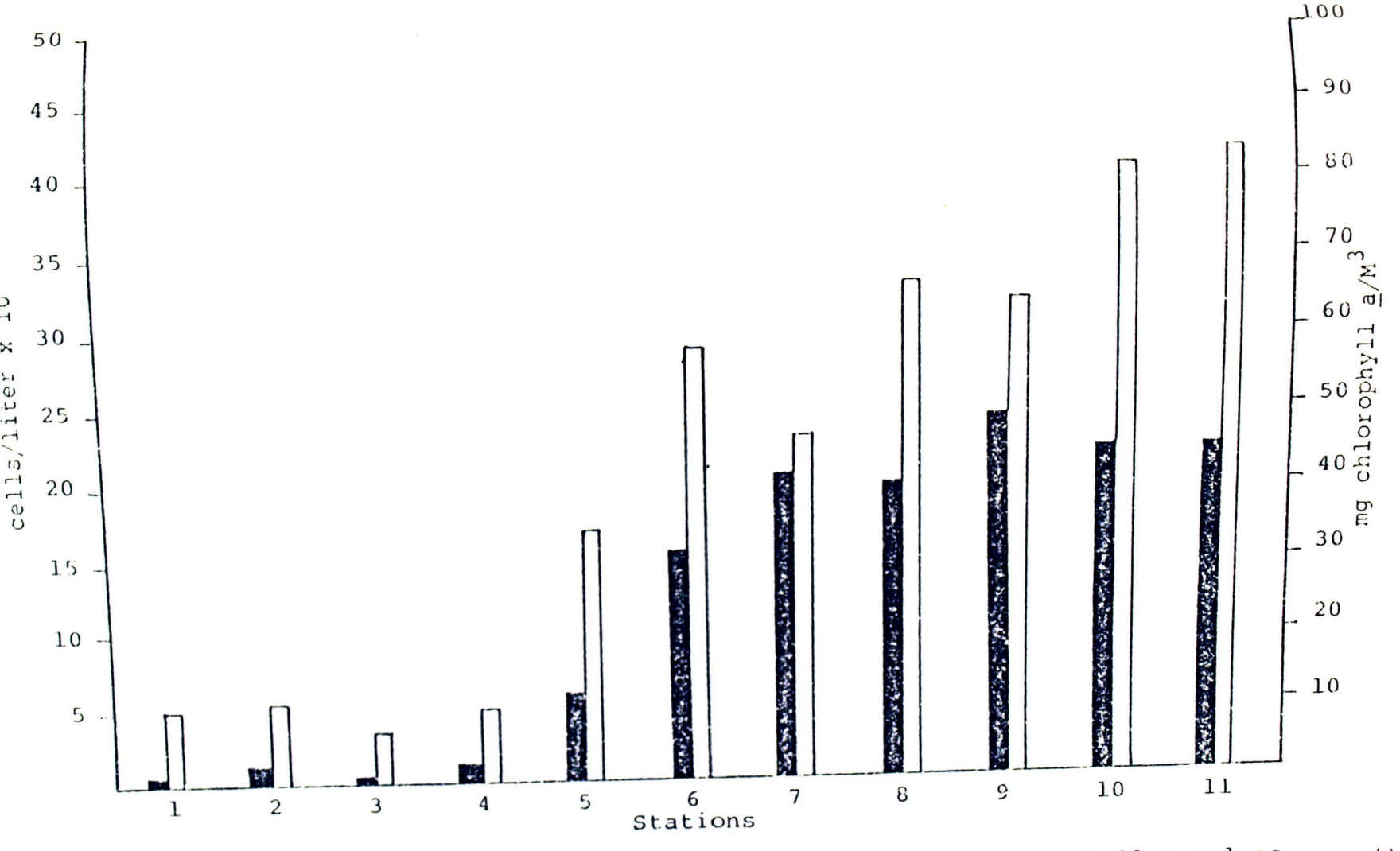

Figure 6. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in fall, 1977.

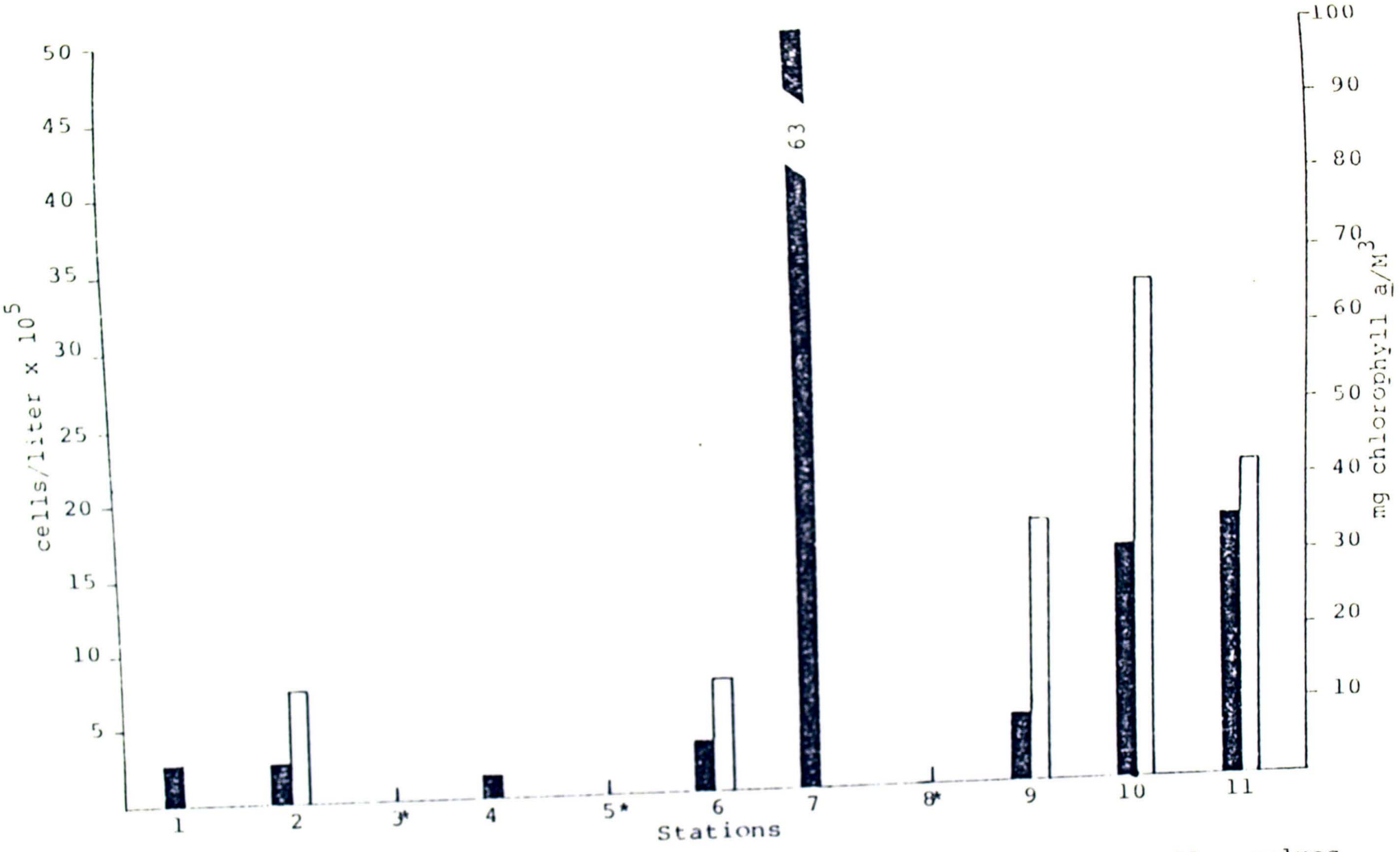

Figure 7. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in winter, 1978. *Indicates no sample taken.

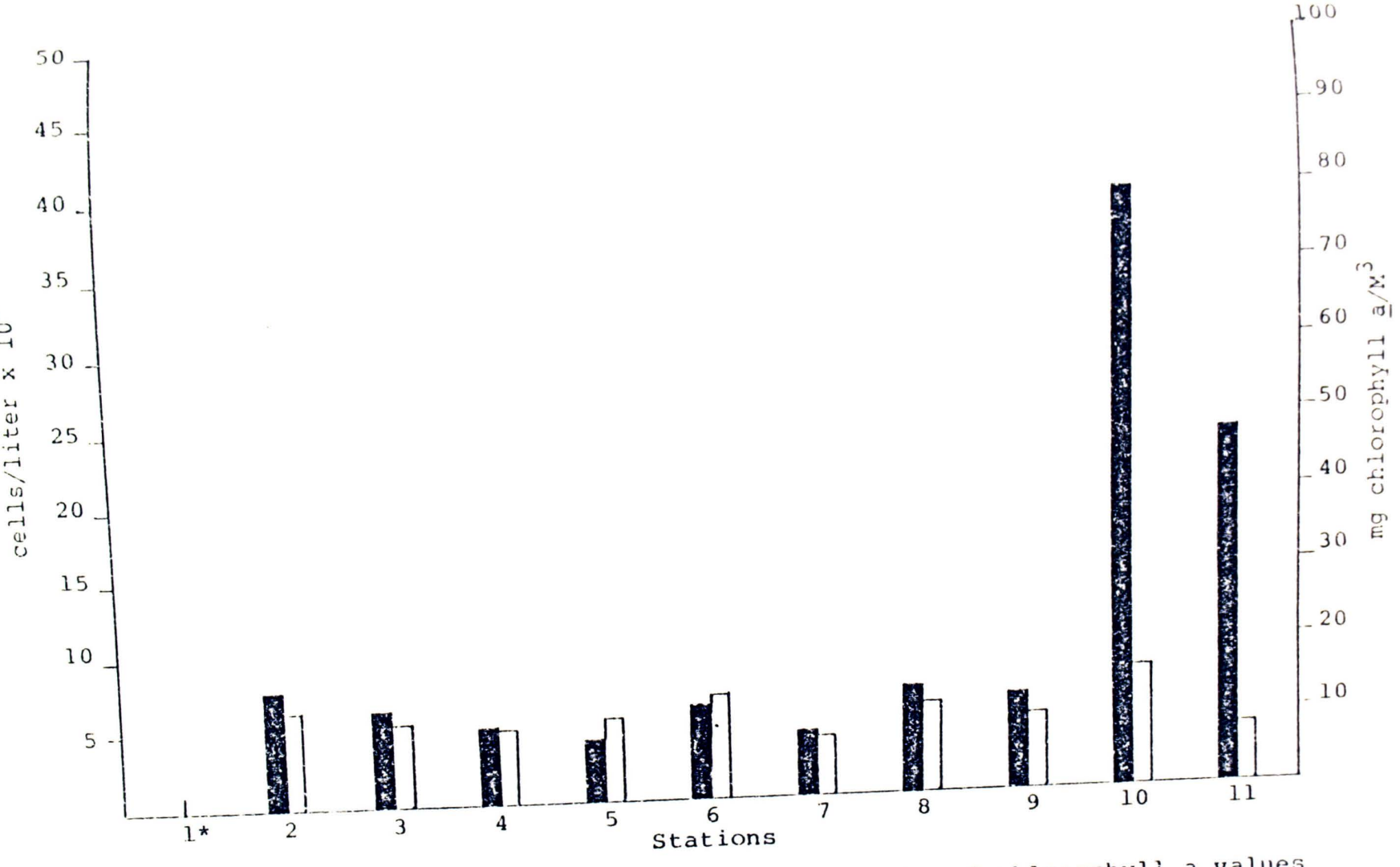

Figure 8. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in spring, 1978. *Indicates no sample taken.

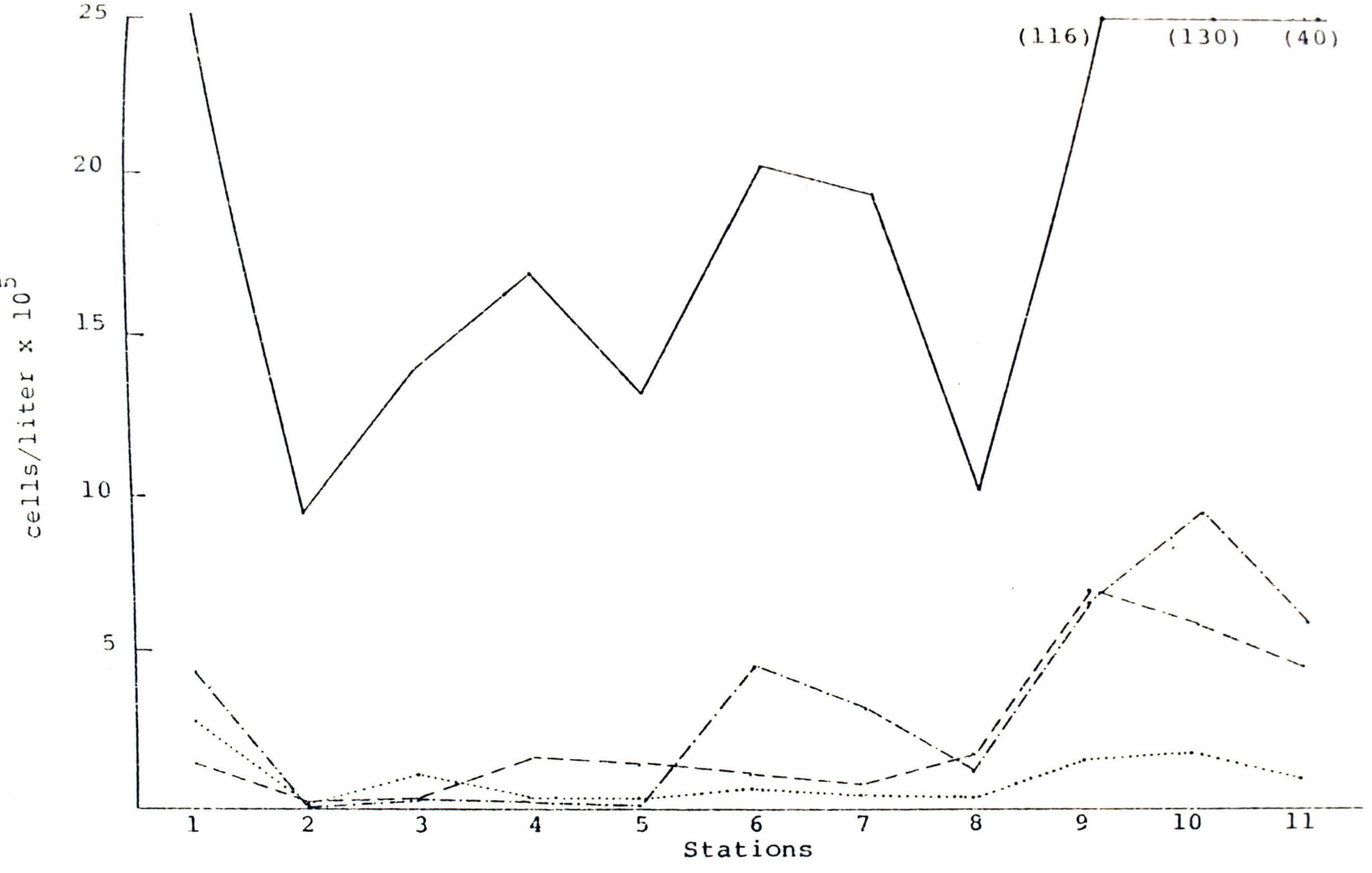

Figure 9. Average cell counts for all depths at each station for summer sampling, 1977. Cyanophyta (———), Chlorophyta (- - - -), Centrales (—·—·—), Pennales (·····).

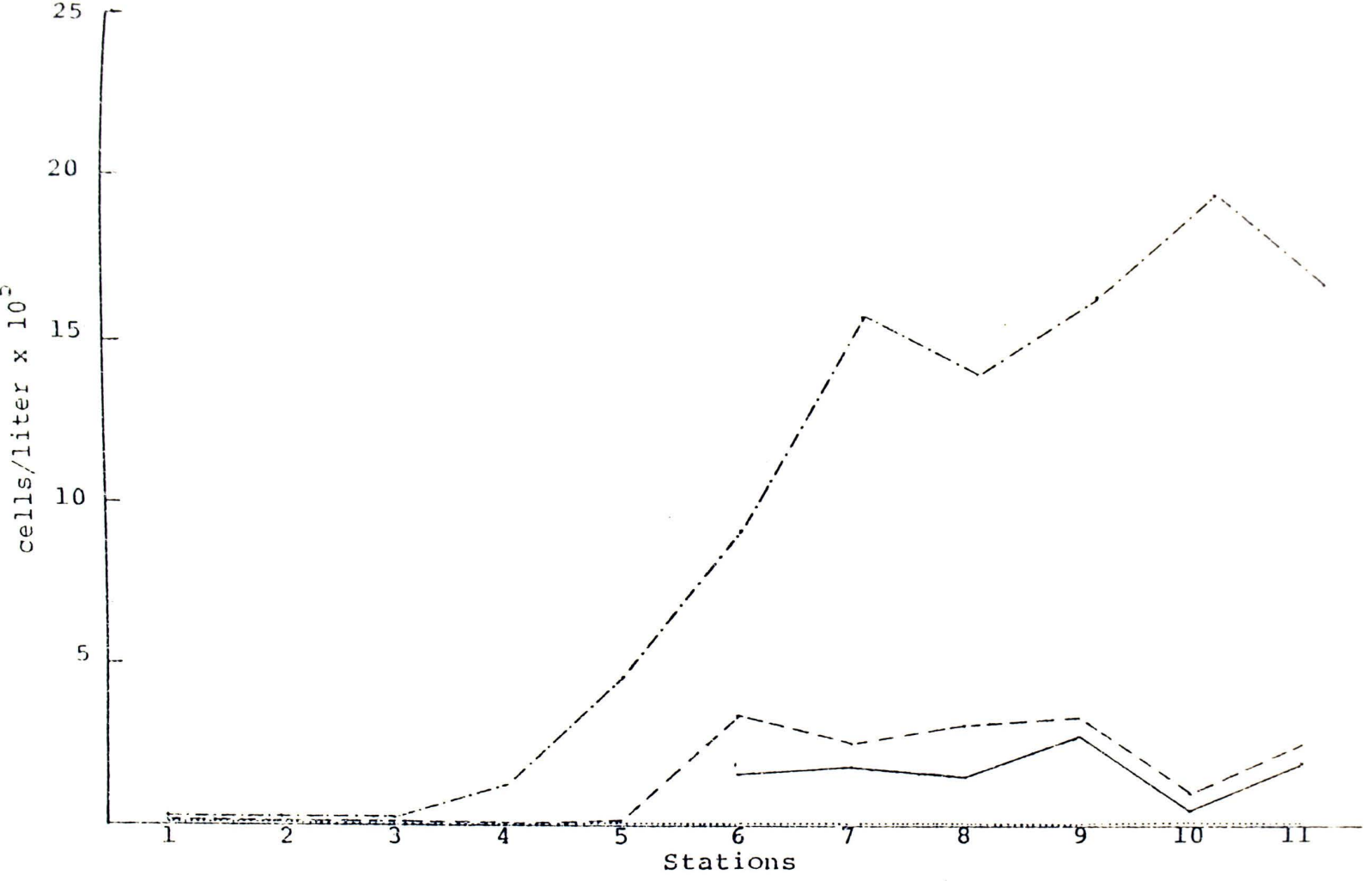

Figure 10. Average cell counts for all depths at each station for fall sampling, 1977. Cyanophyta (———), Chlorophyta (– – –), Centrales (–·–·–), Pennales (·····).

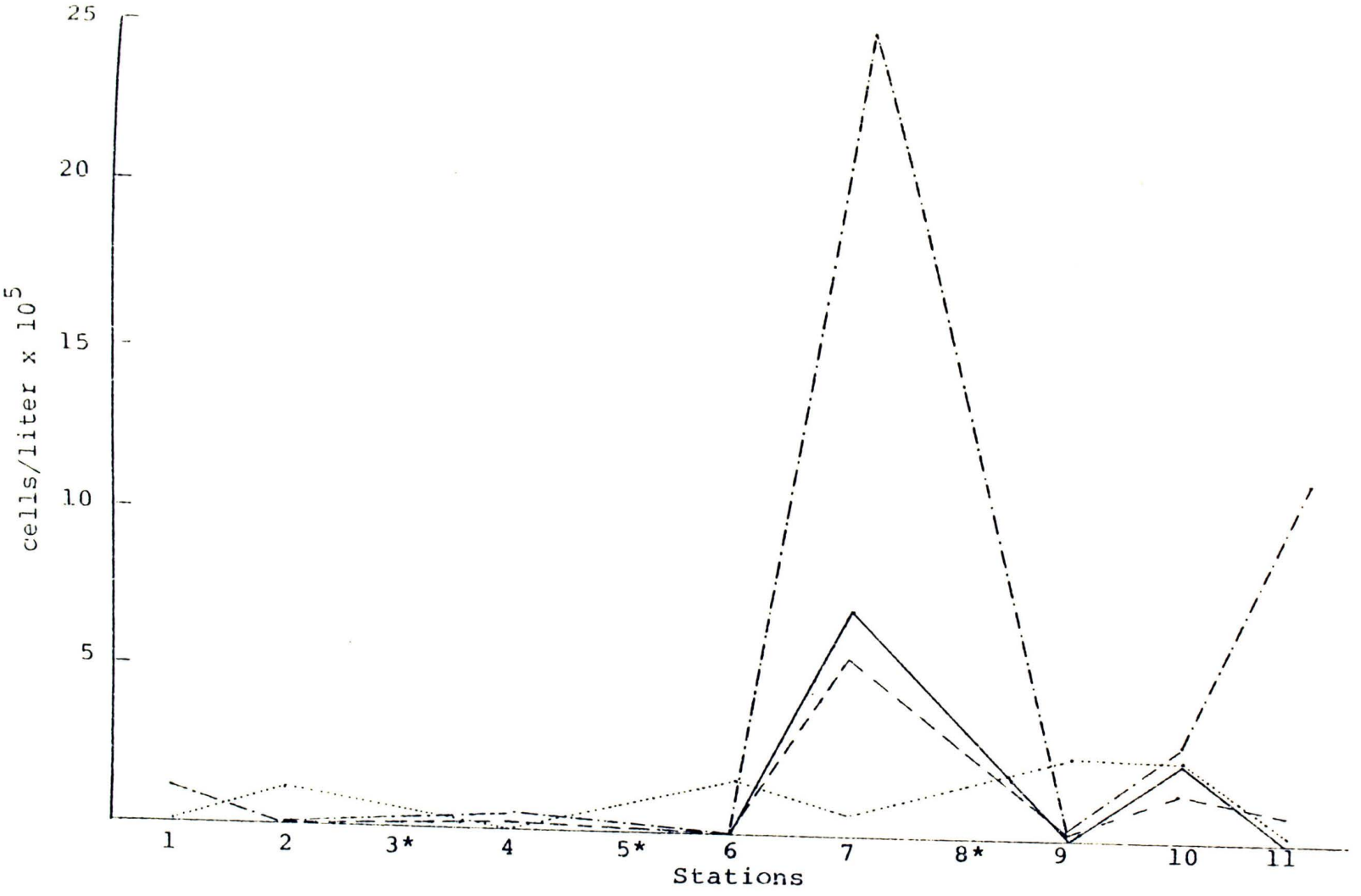

Figure 11. Average cell counts for all depths at each station for winter sampling, 1978. Cyanophyta (———), Chlorophyta (- - - -), Centrales (—·—·—), Pennales (·····).
*Indicates no sample taken.

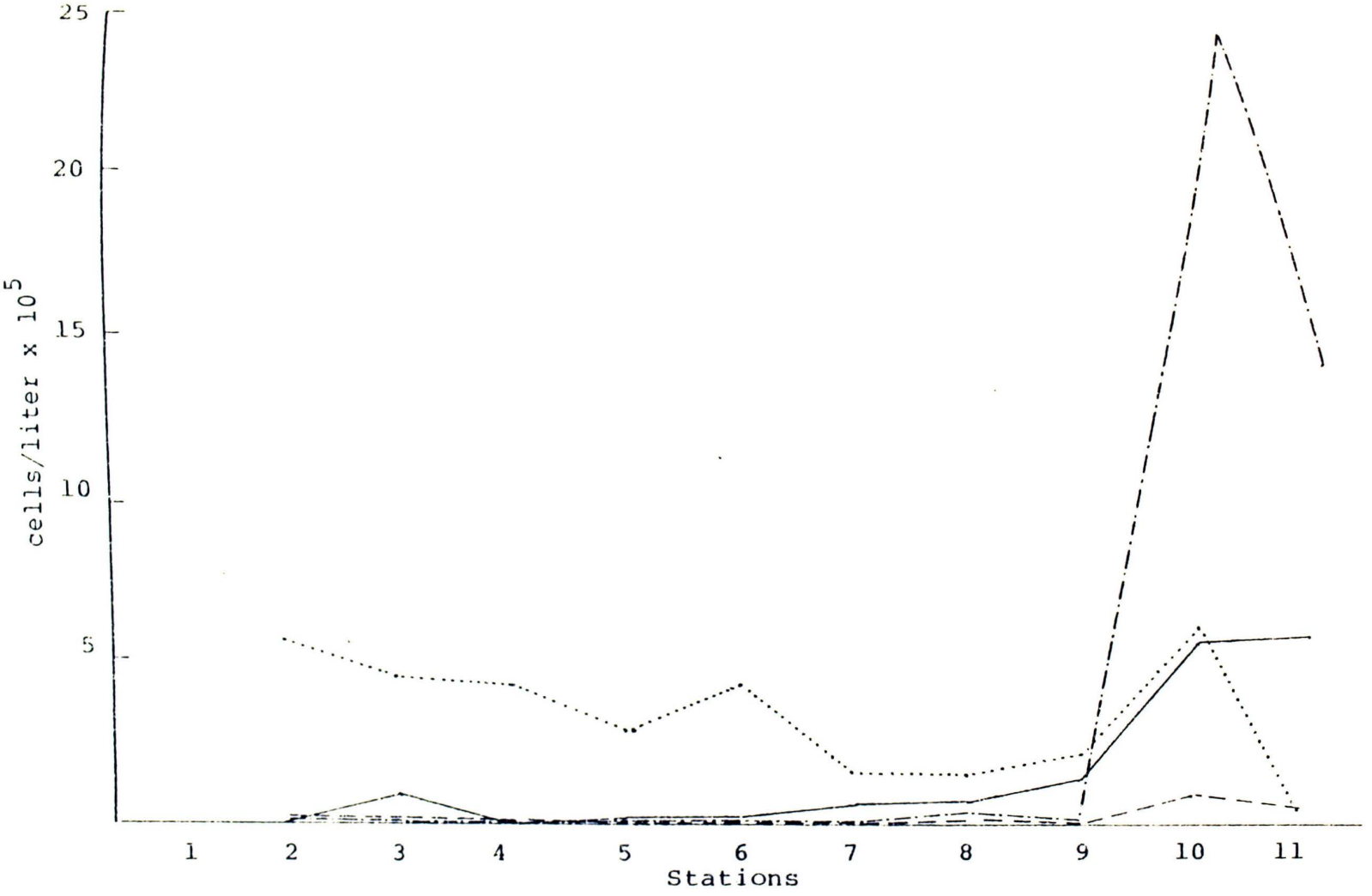

Figure 12. Average cell counts for all depths at each station for spring sampling, 1978. Cyanophyta (———), Chlorophyta (– – –), Centrales (–·–·–·), Pennales (·····). *Indicates no sample taken.

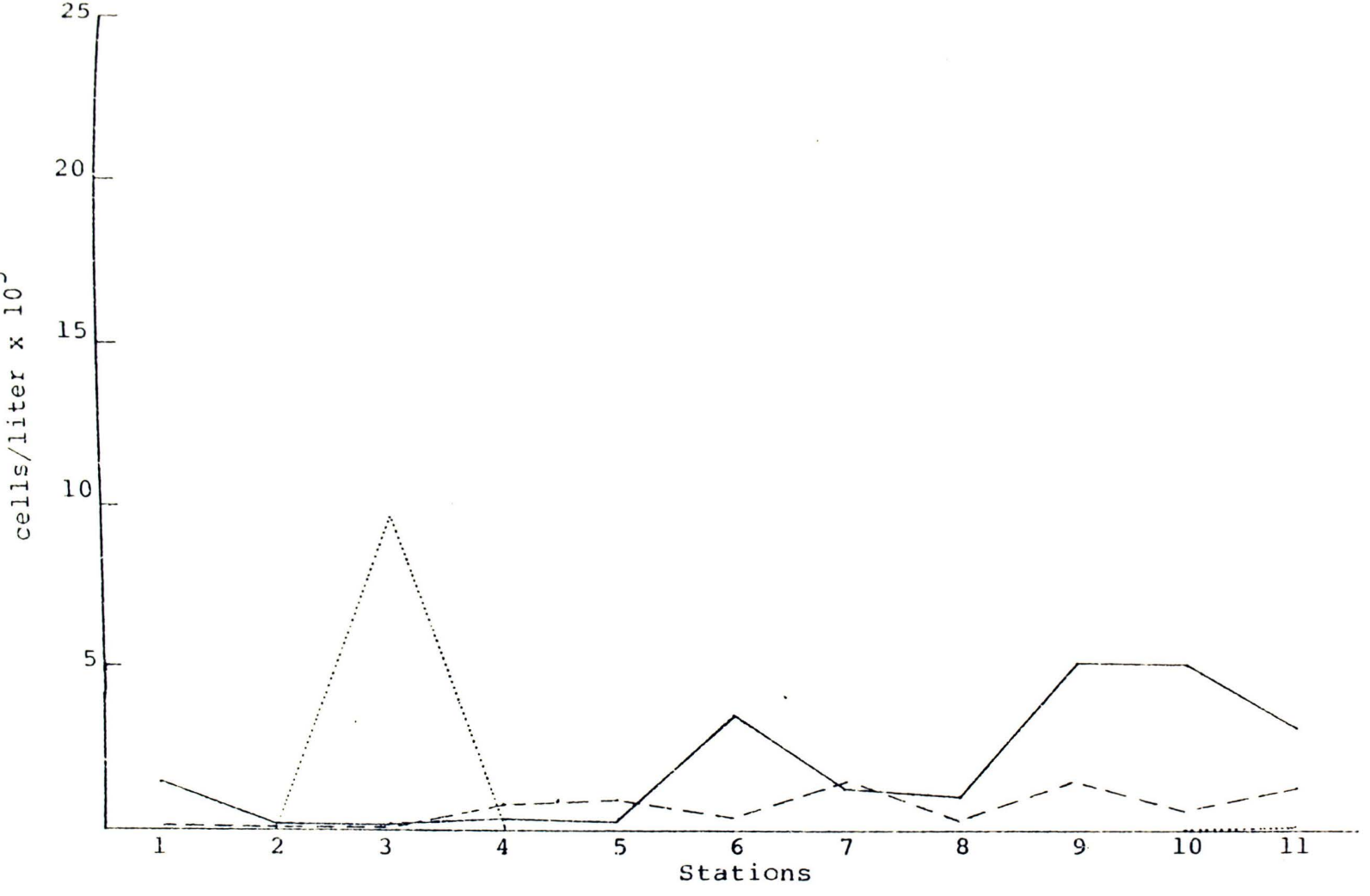

Figure 13. Coccoid (———), Flagellate (- - - -), and Filamentous (·····) Chlorophyta concentrations for summer sampling at each station, 1977.

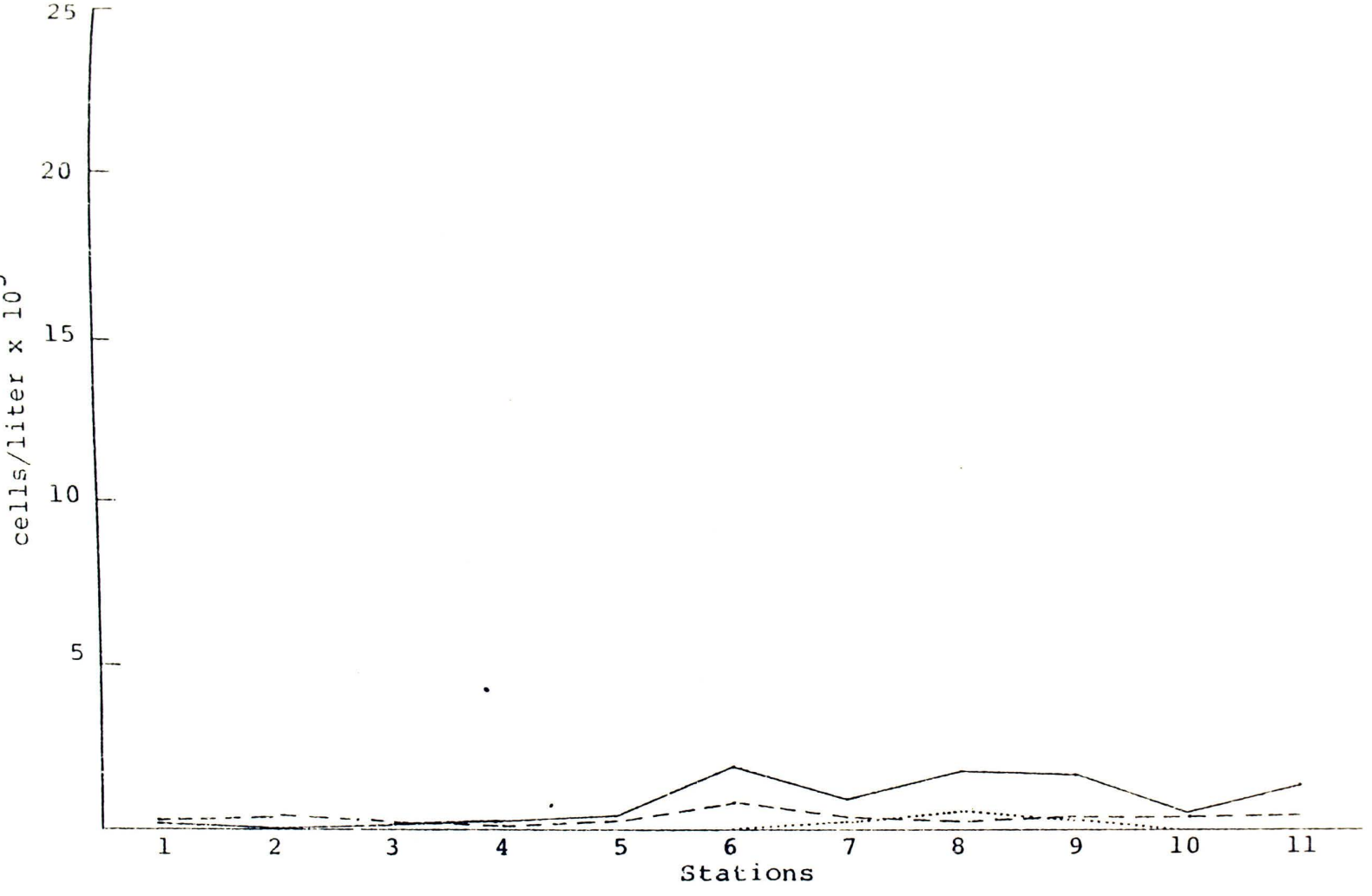

Figure 14. Coccoid (——), Flagellate (— — —) and Filamentous (·····) Chlorophyta concentrations for fall sampling at each station, 1977.

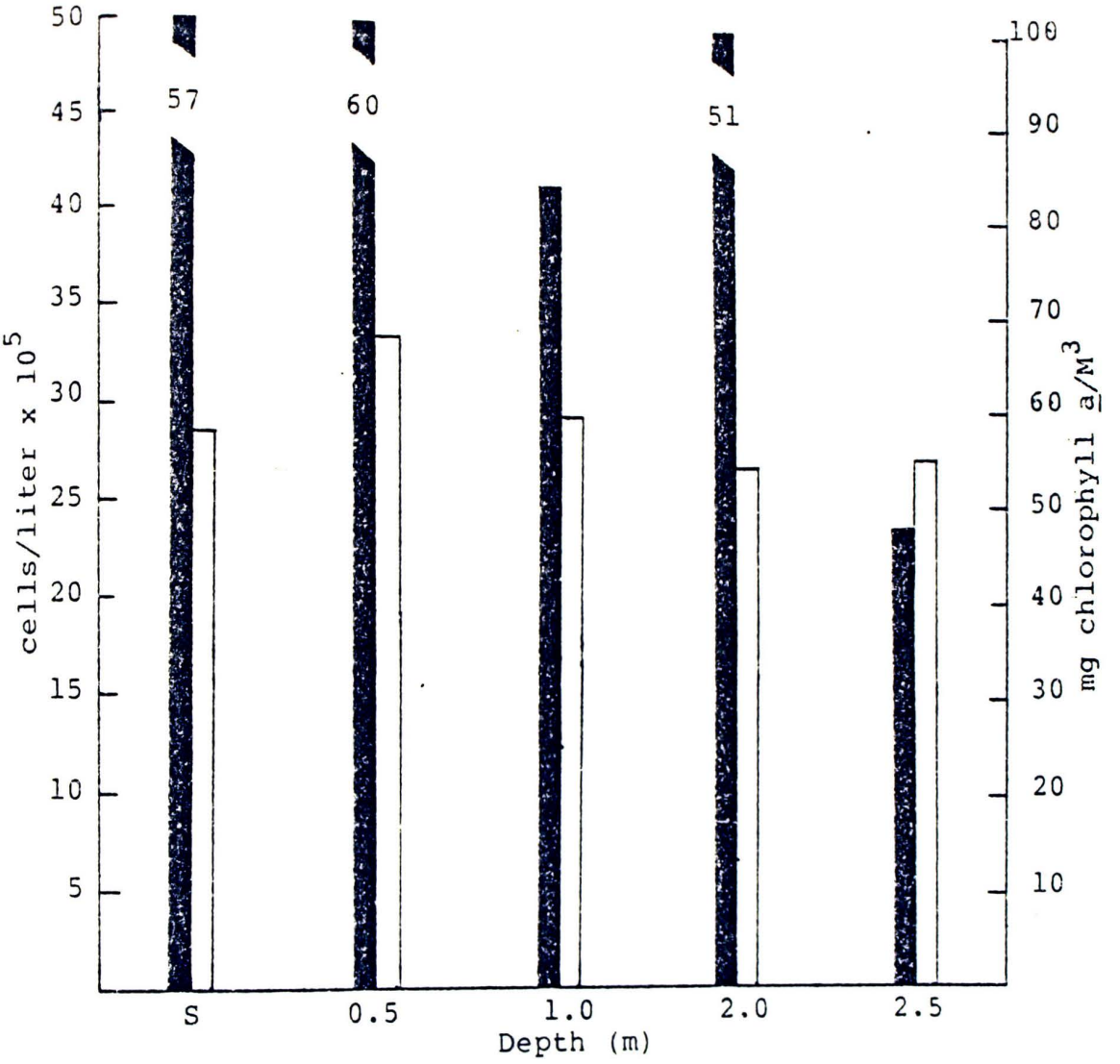

Figure 15. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in summer, 1977.

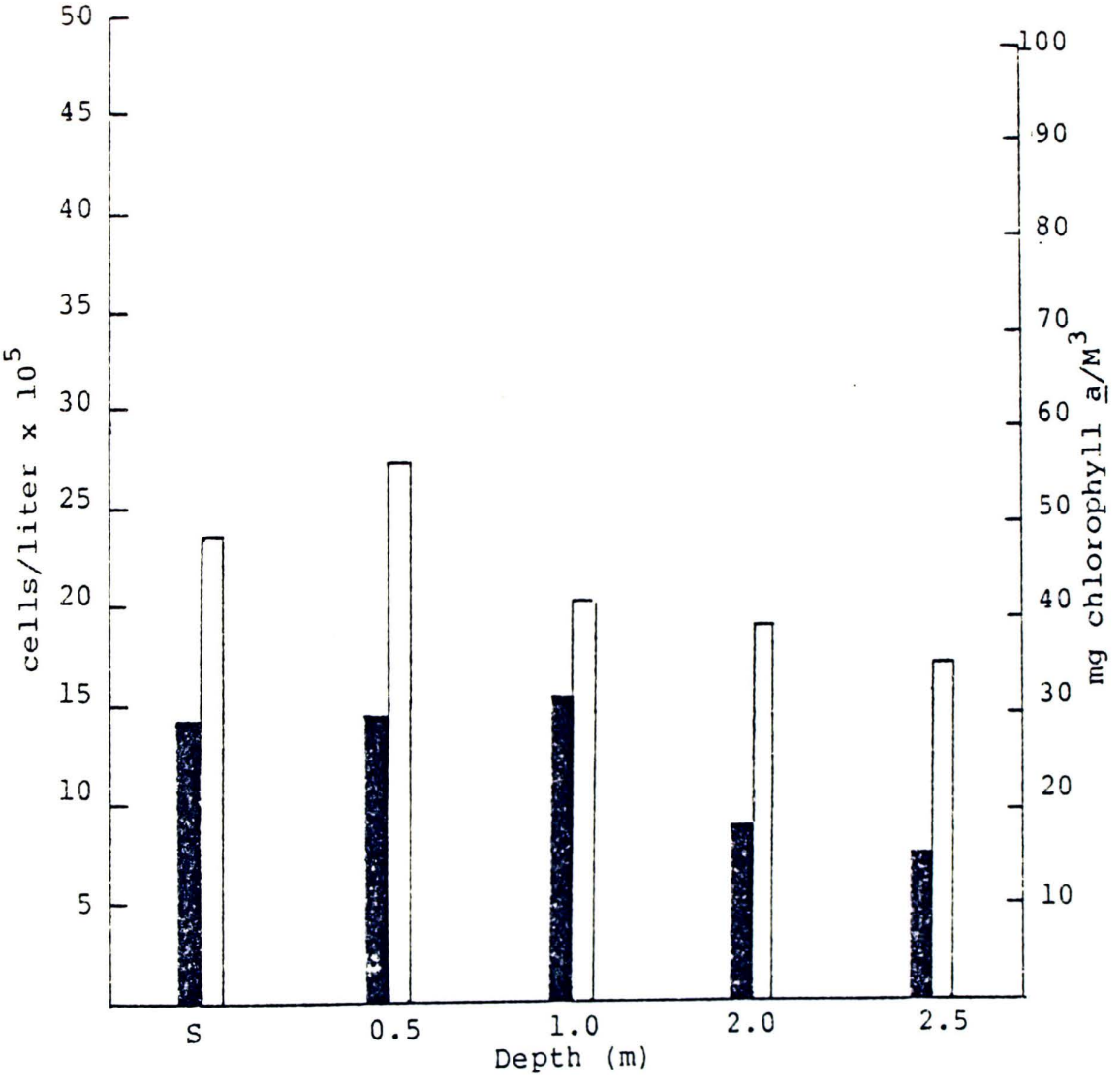

Figure 16. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in fall, 1977.

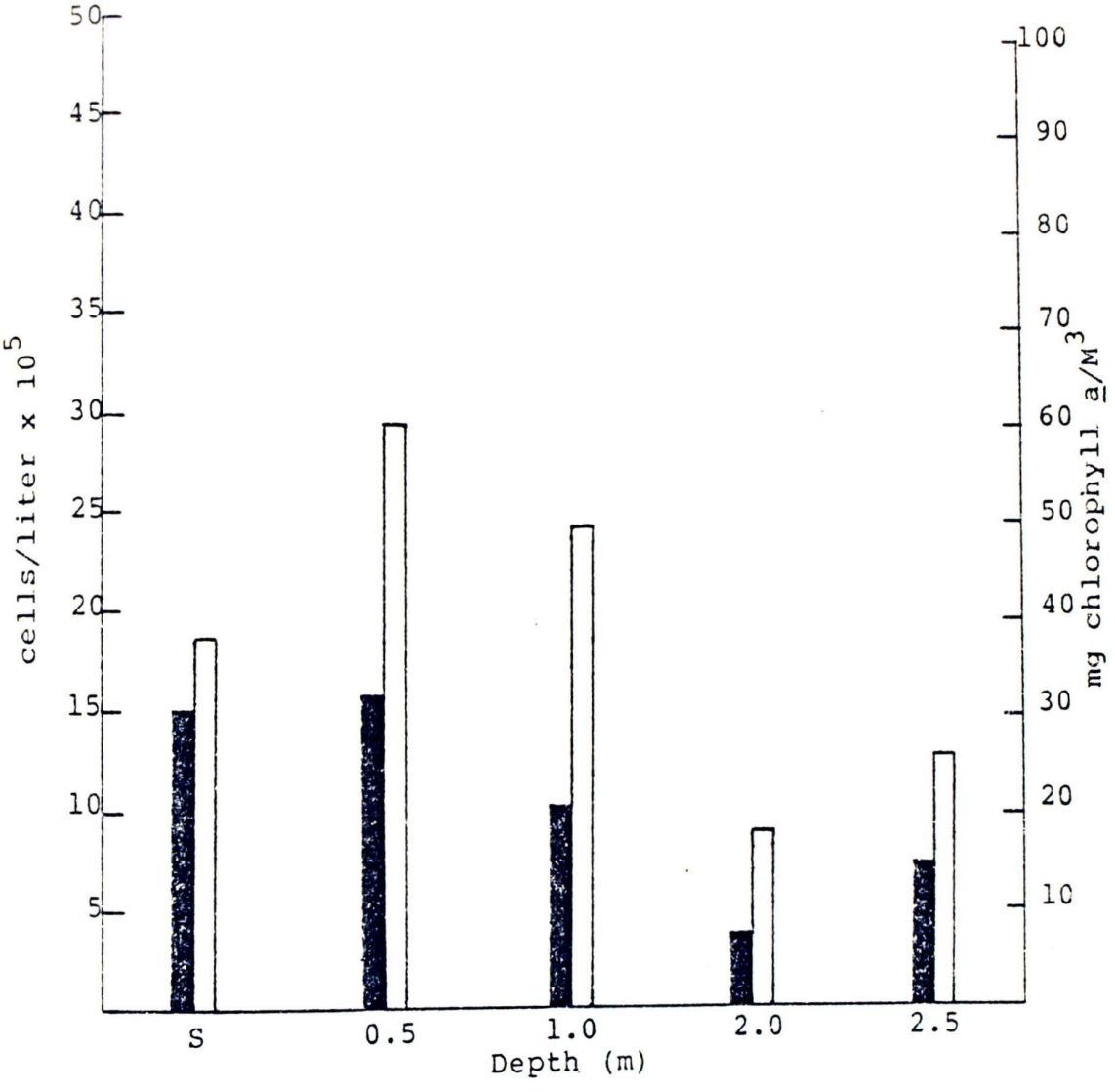

Figure 17. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in winter, 1978.

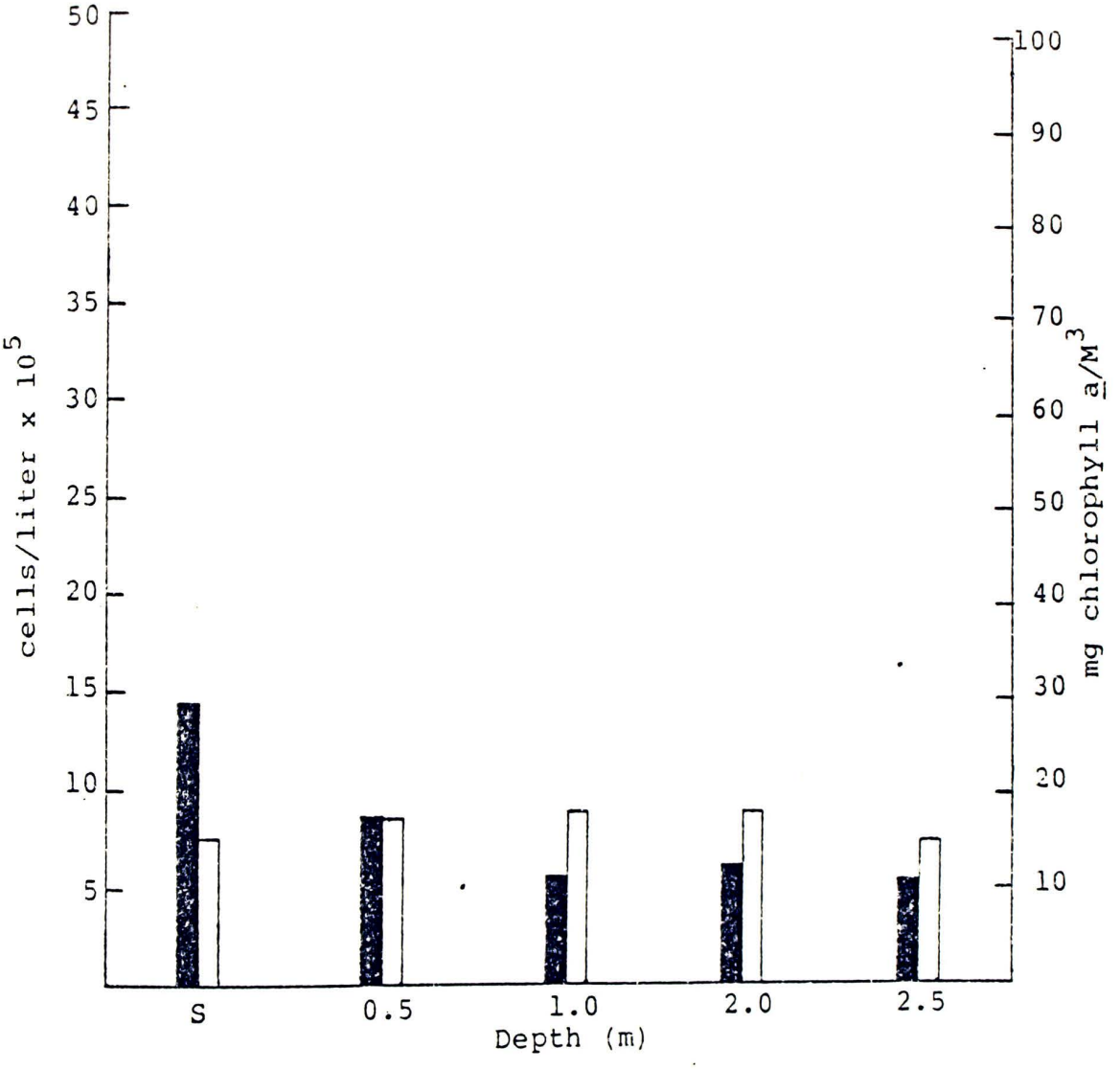

Figure 18. Average phytoplankton cell counts (solid bars) and chlorophyll a values (outlined bars) for collections made in spring, 1978.

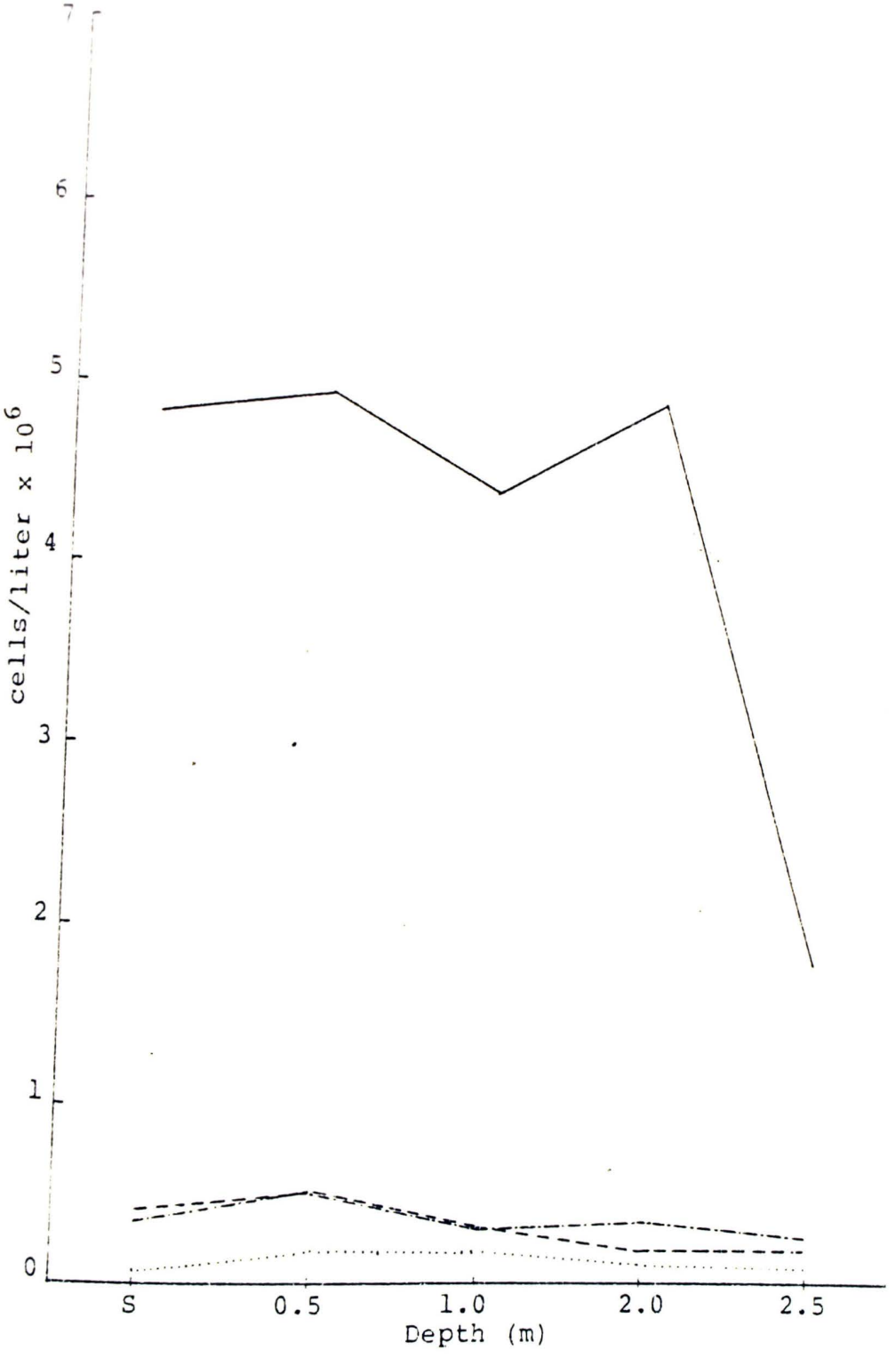

Figure 19. Average concentrations of major algal groups at sampled depths for summer sampling, 1977. Cyanophyta (———), Chlorophyta (– – –), Pennales (·····), Centrales (– · – · –).

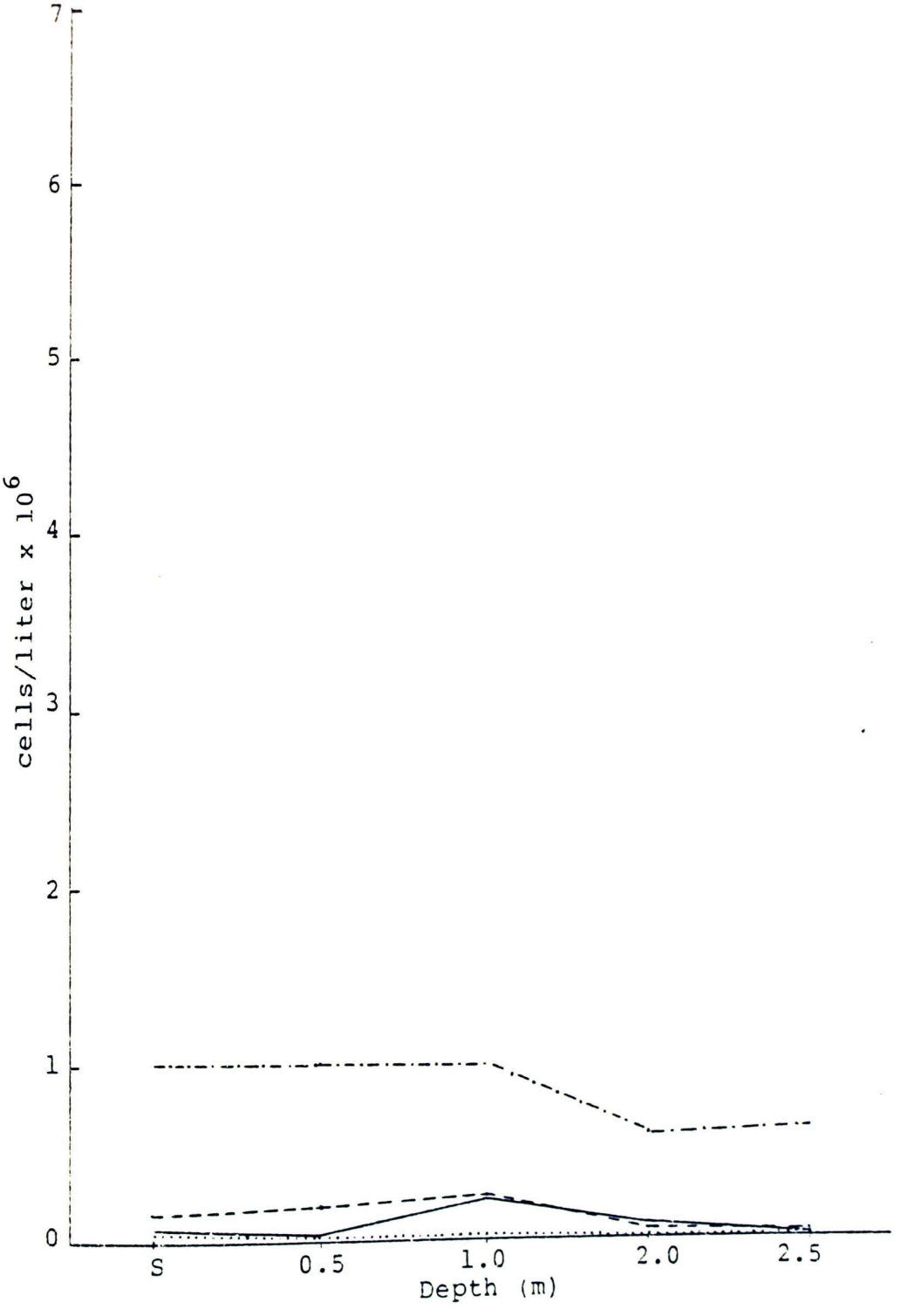

Figure 20. Average concentrations of major algal groups at sampled depths for fall sampling, 1977. Cyanophyta (———), Chlorophyta (– – –), Pennales (·····), Centrales (–·–·–).

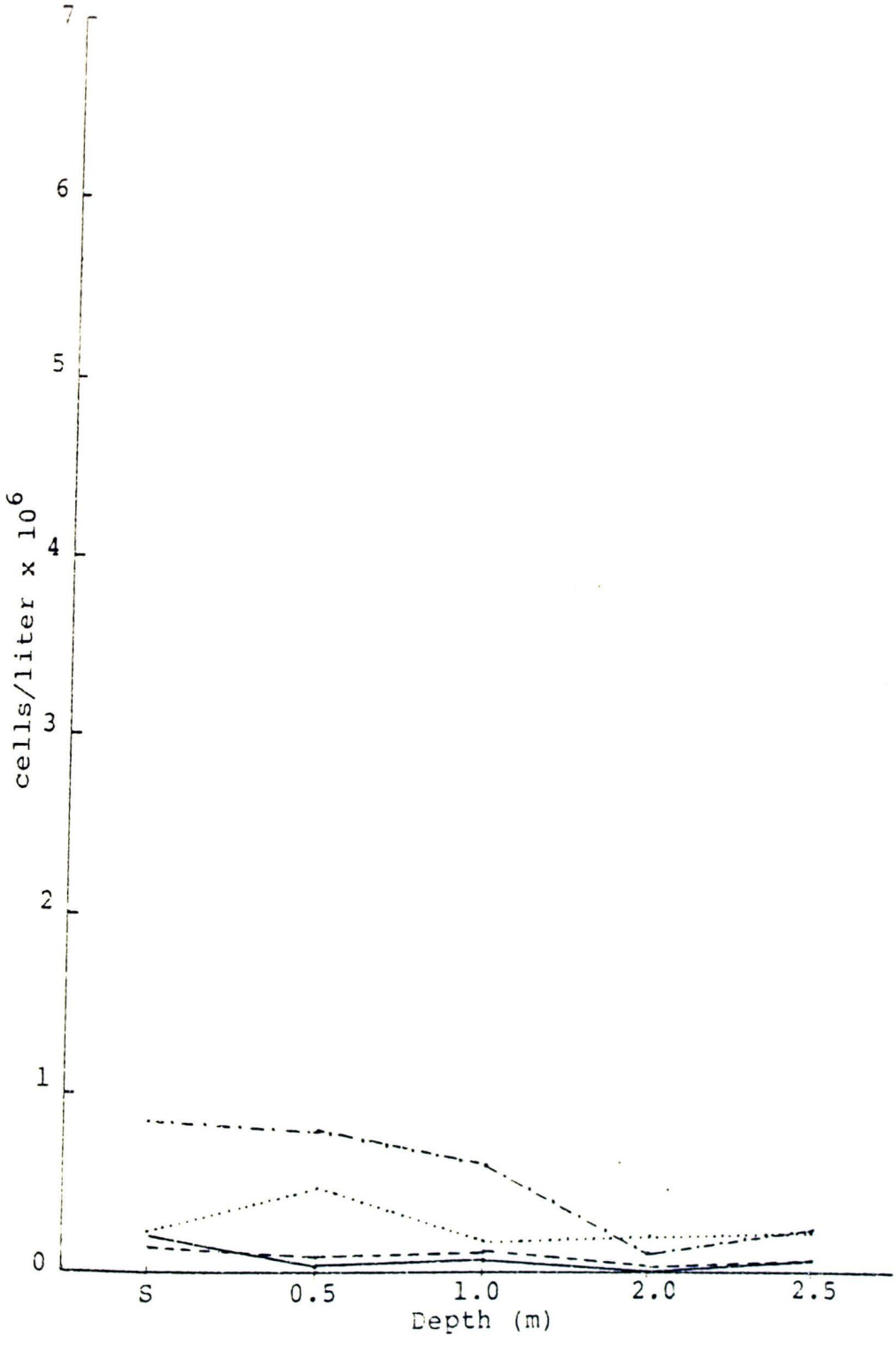

Figure 21. Average concentrations of major algal groups at sampled depths for winter sampling, 1978. Cyanophyta (————), Chlorophyta (– – – –), Pennales (·····), and Centrales (– · – · –).

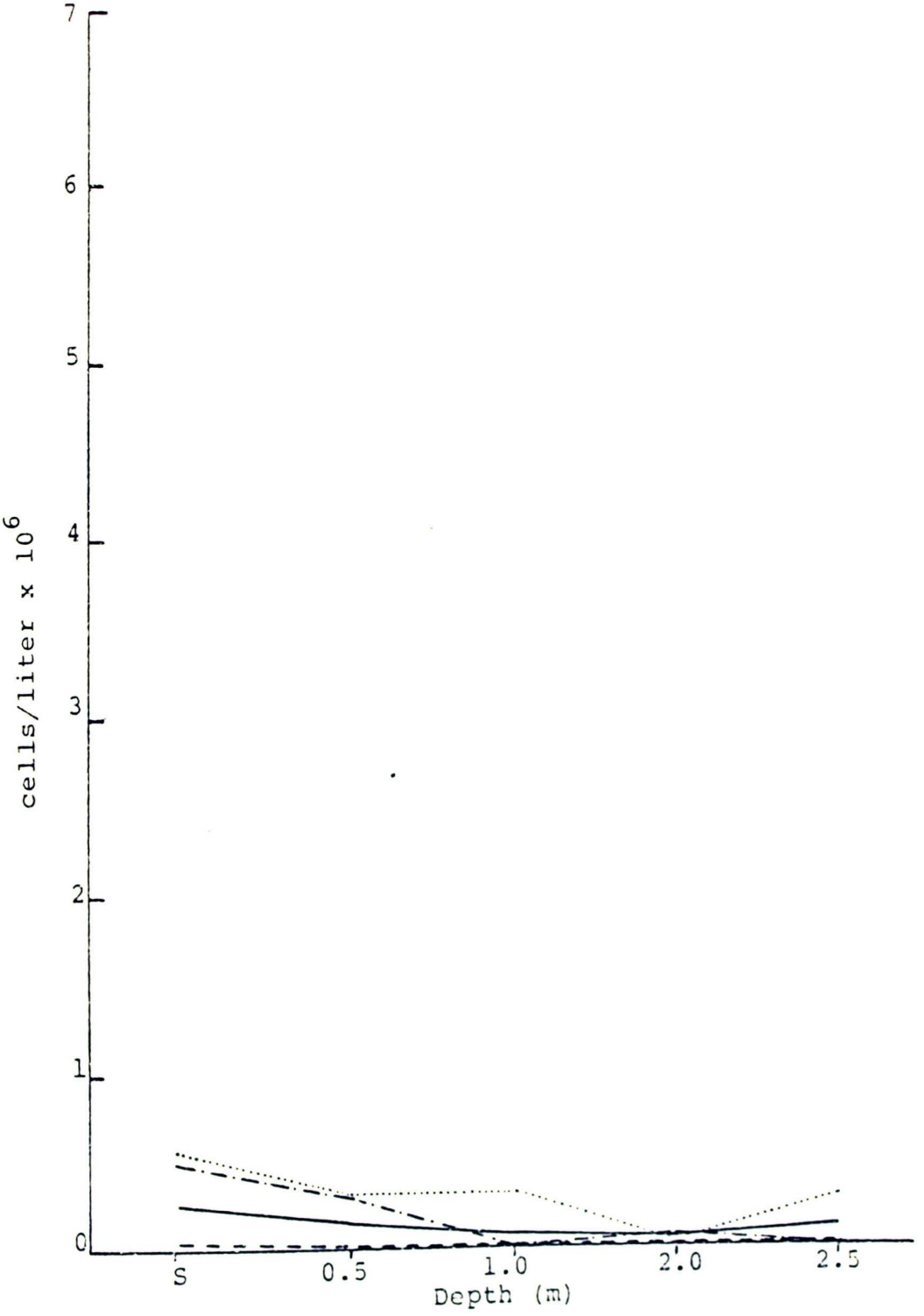

Figure 22. Average concentrations of major algal groups at sampled depths for spring sampling, 1978. Cyanophyta (———), Chlorophyta (– – –), Pennales (· · ·), and Centrales (– · – · –).

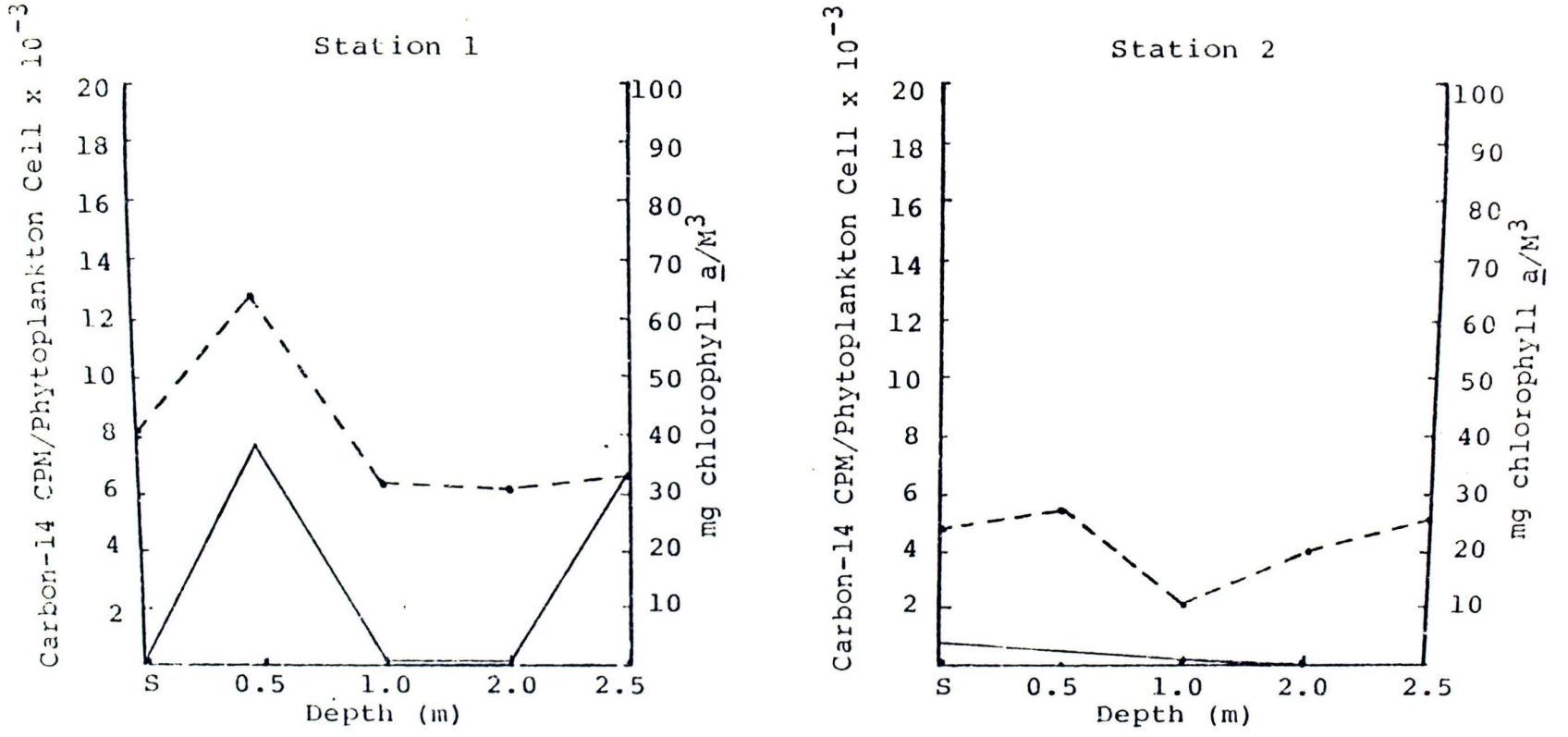

Figure 23. Depth profiles of Carbon-14 primary productivity during one hour incubation and phytoplankton cells per liter (———) ratios plotted with chlorophyll a concentrations (– – –) for station 1 and station 2 for summer sampling, 1977.

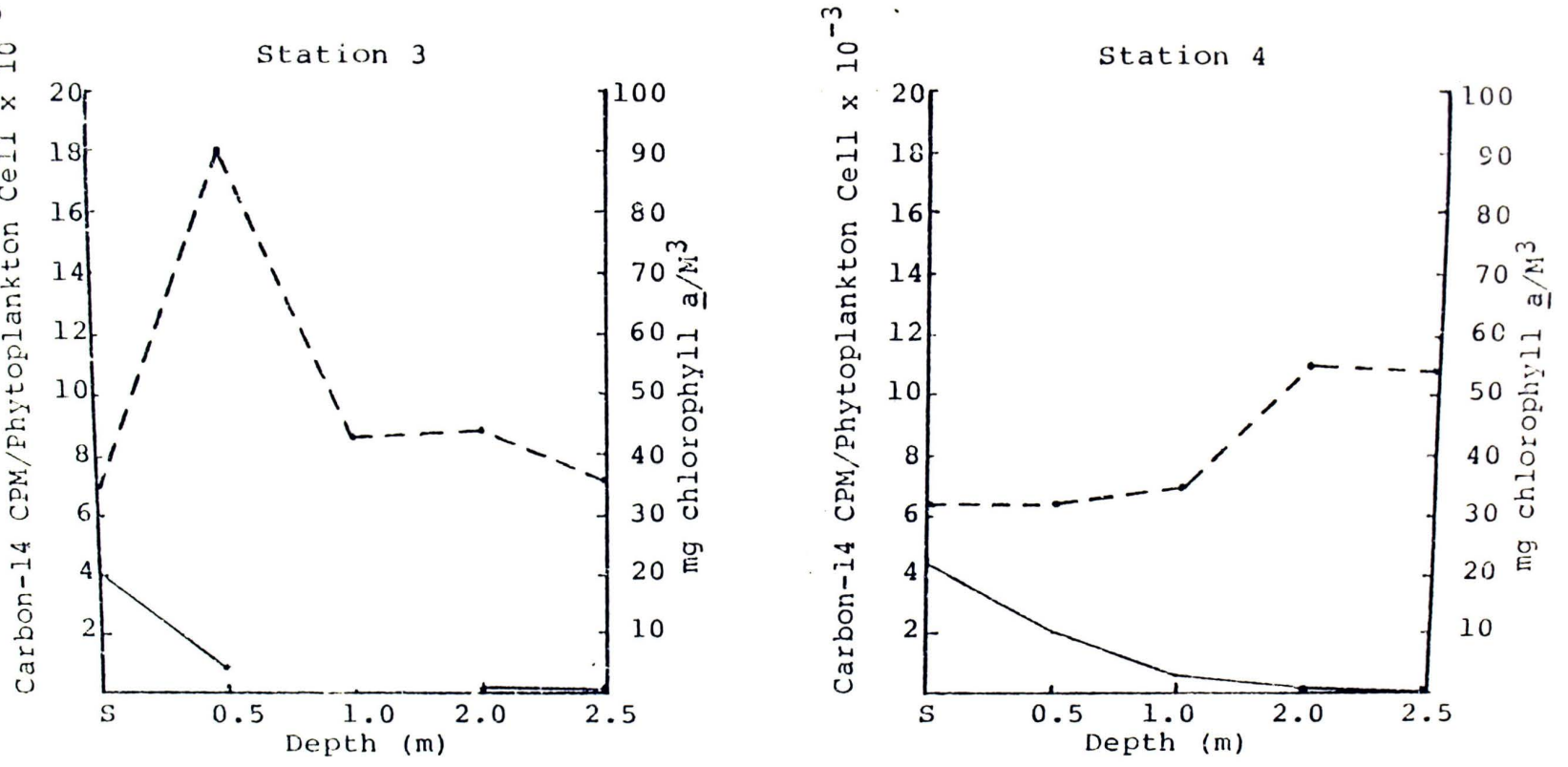

Figure 24. Depth profiles of Carbon-14 primary productivity during one hour incubation and phytoplankton cells per liter (———) ratios plotted with chlorophyll a concentrations (- - - -) for station 3 and station 4 for summer sampling, 1977.

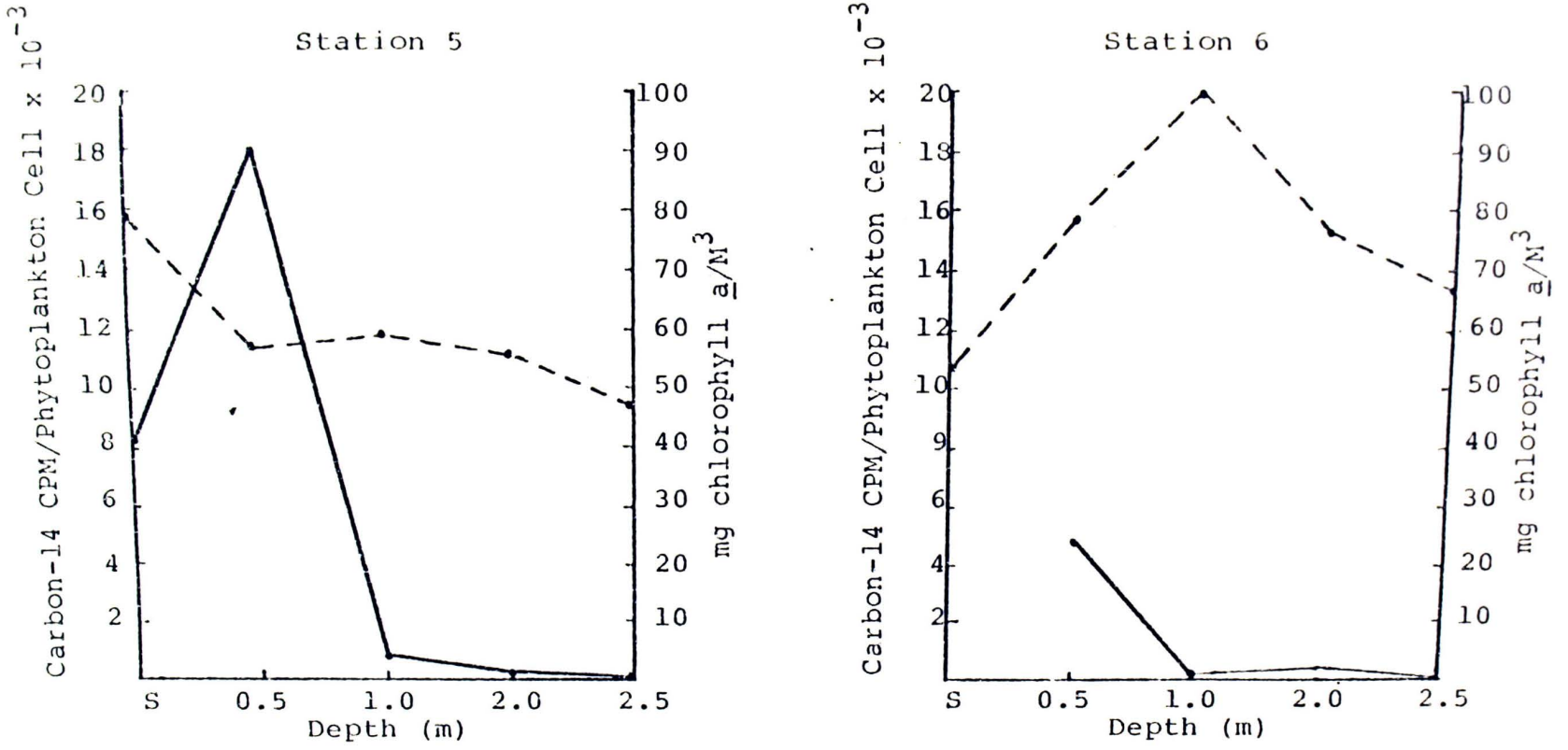

Figure 25. Depth profiles of Carbon-14 primary productivity during one hour incubation and phytoplankton cells per liter (———) ratios plotted with chlorophyll a concentrations (– – –) for station 5 and station 6 for summer sampling, 1977.

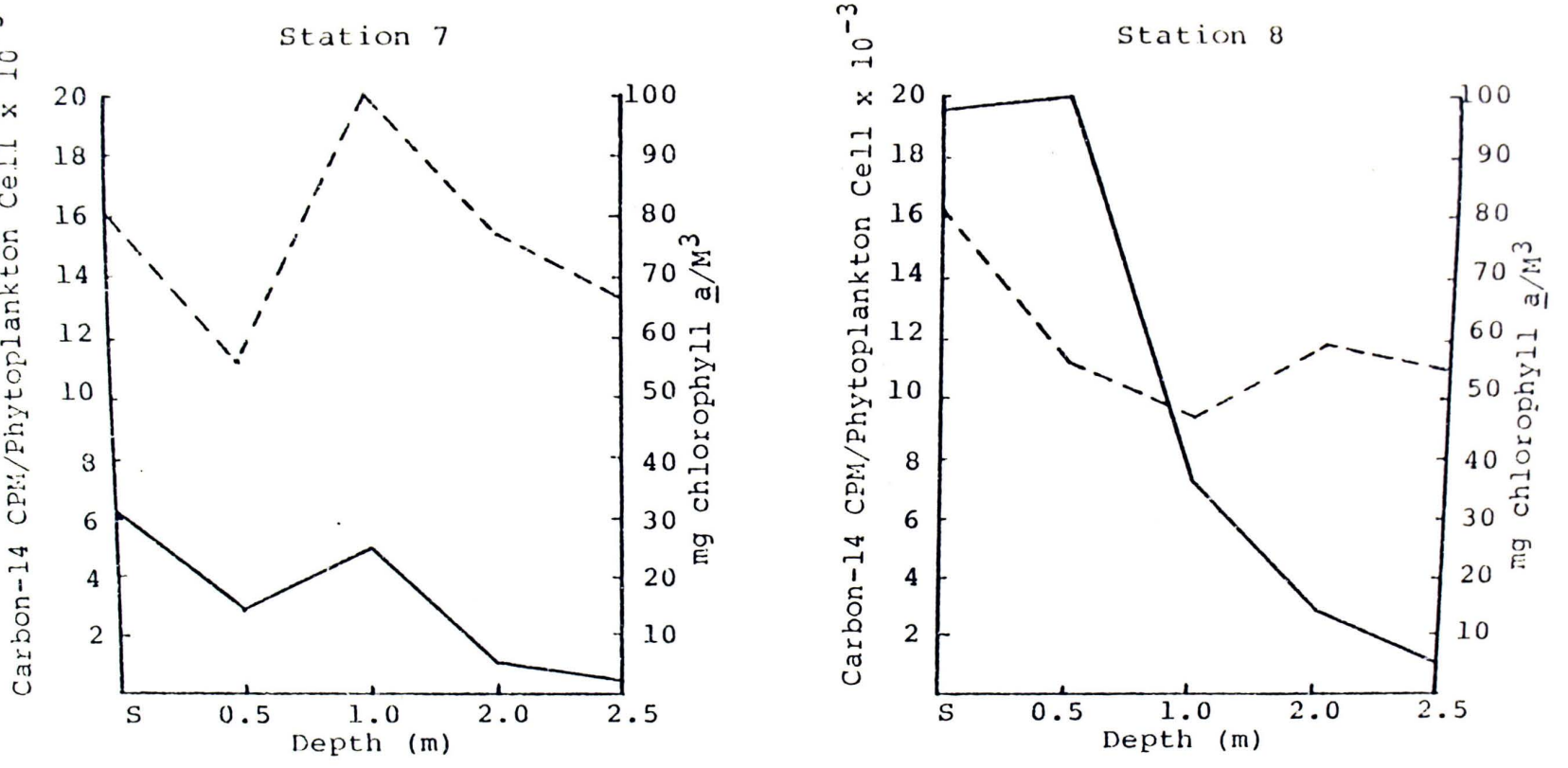

Figure 26. Depth profiles of Carbon-14 primary productivity during one hour incubation and phytoplankton cells per liter (———) ratios plotted with chlorophyll a concentrations (- - - -) for station 7 and station 8 for summer sampling, 1977.

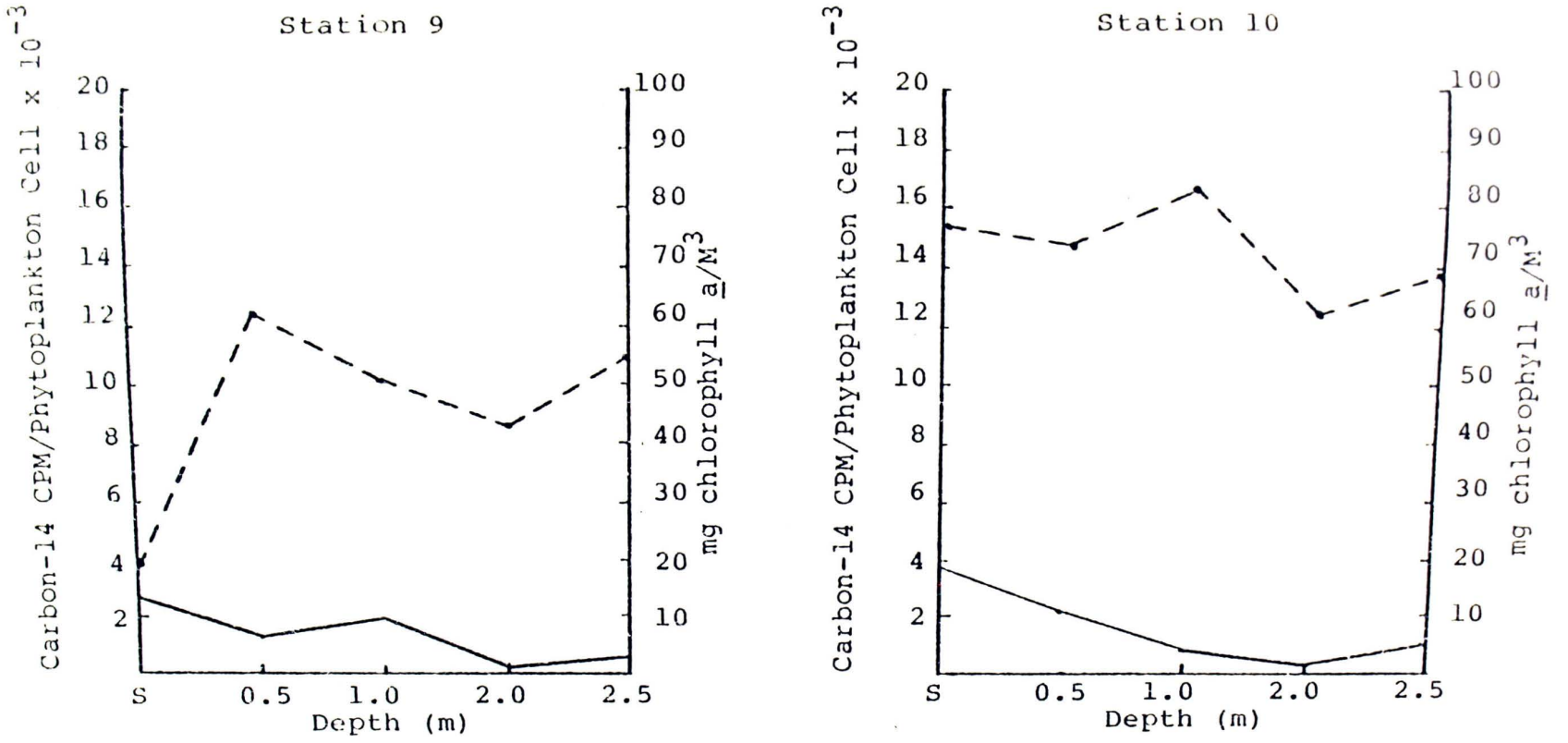

Figure 27. Depth profiles of Carbon-14 primary productivity during one hour incubation and phytoplankton cells per liter (———) ratios plotted with chlorophyll a concentrations (– – – –) for station 9 and station 10 for summer sampling, 1977.

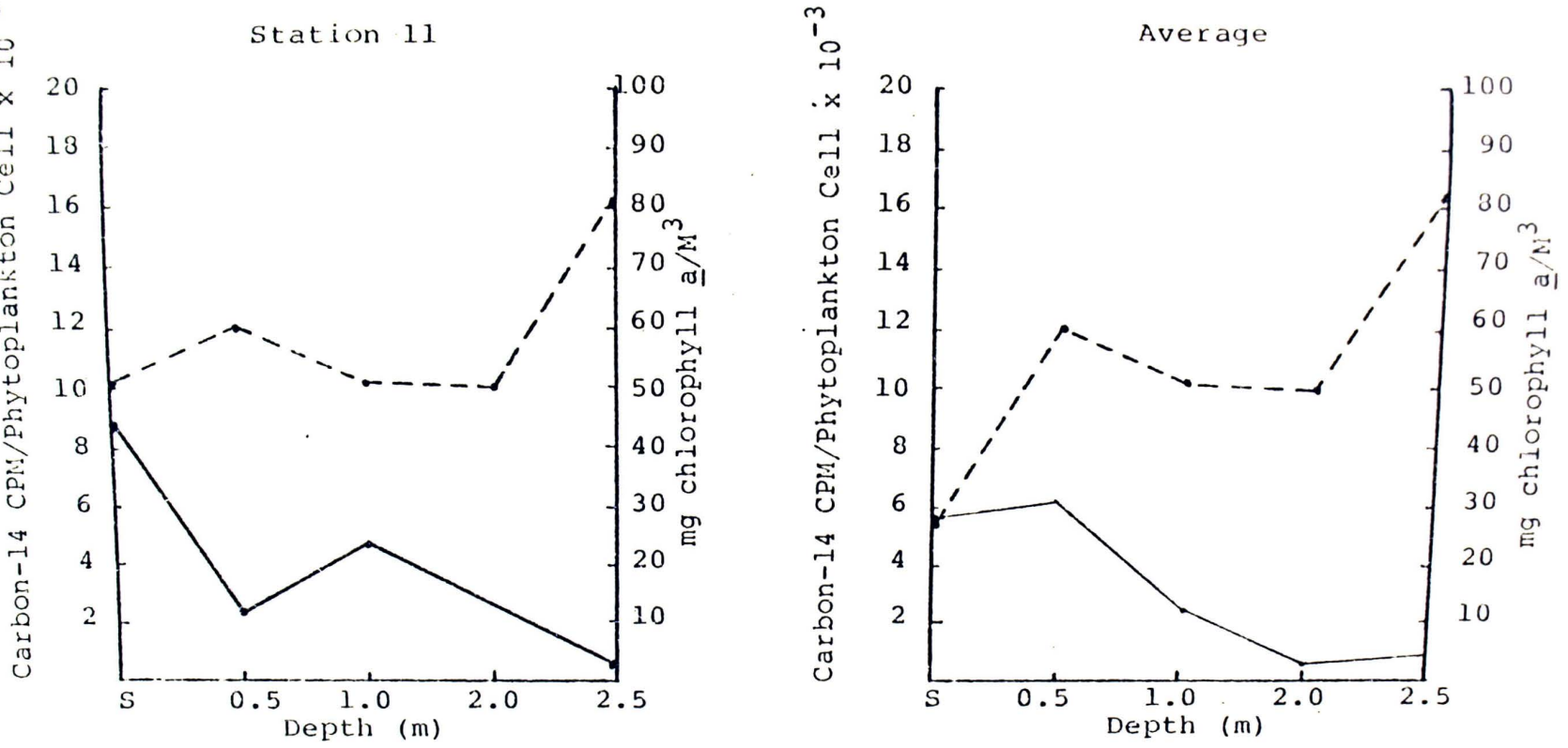

Figure 28. Depth profiles of Carbon-14 primary productivity during one hour incubation and phytoplankton cells per liter (———) ratios plotted with chlorophyll a concentrations (– – – –) for station 11 and average for summer sampling, 1977.

Appendix II, as counts/minute of C-14. Primary productivity increased at most downstream stations and decreased with depth.

Other Tests

Dissolved oxygen concentrations, water temperatures, and percent oxygen saturations are given in Tables VIII, IX, X and XI, Appendix III. Surface temperatures and dissolved oxygen concentrations are compared in Figures 29, 30 and 31 for summer, fall, and spring. The highest dissolved oxygen concentration occurred in winter (15.8 ppm) and lowest (1.2 ppm) during spring. Temperature extremes for the waterways were 30.0° C for summer and 2.5° C for winter. Percent oxygen saturations ranged from 120 percent in winter to 12 percent in the spring. Mean values for dissolved oxygen concentrations, temperatures and percent oxygen saturations were: summer-5.8 ppm, 27.5° C and 75 percent; fall-4.4 ppm, 12.3° C and 42 percent; winter-8.8 ppm, 4.1° C and 69 percent; spring-5.1 ppm, 15.8° C and 55 percent.

Hydrogen ion concentration (pH) averaged a slightly basic value of 7.6 for the summer and slightly acidic values of 6.8 for fall, 6.3 for winter, and 6.4 for spring (Figure 32).

Phosphate (PO_4) concentrations (Figure 33) showed increases at stations 5 through 9. Averages were 0.20, 0.46, 0.08, and 0.16 ppm for summer, fall, winter and

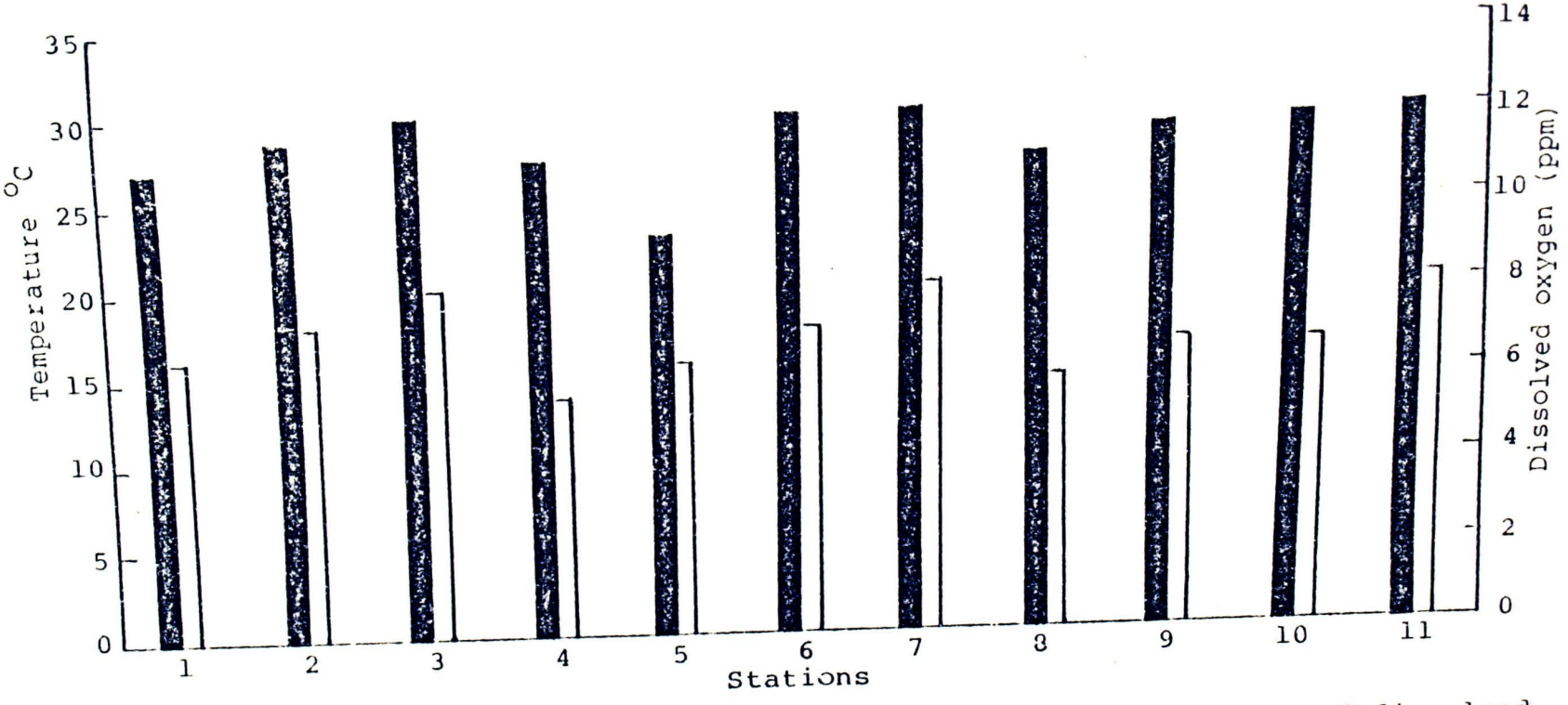

Figure 29. Longitudinal profile of surface temperature (solid bars) and dissolved oxygen (outlined bars) for the Red River, Big West Fork Creek, and Cumberland River for summer, 1977.

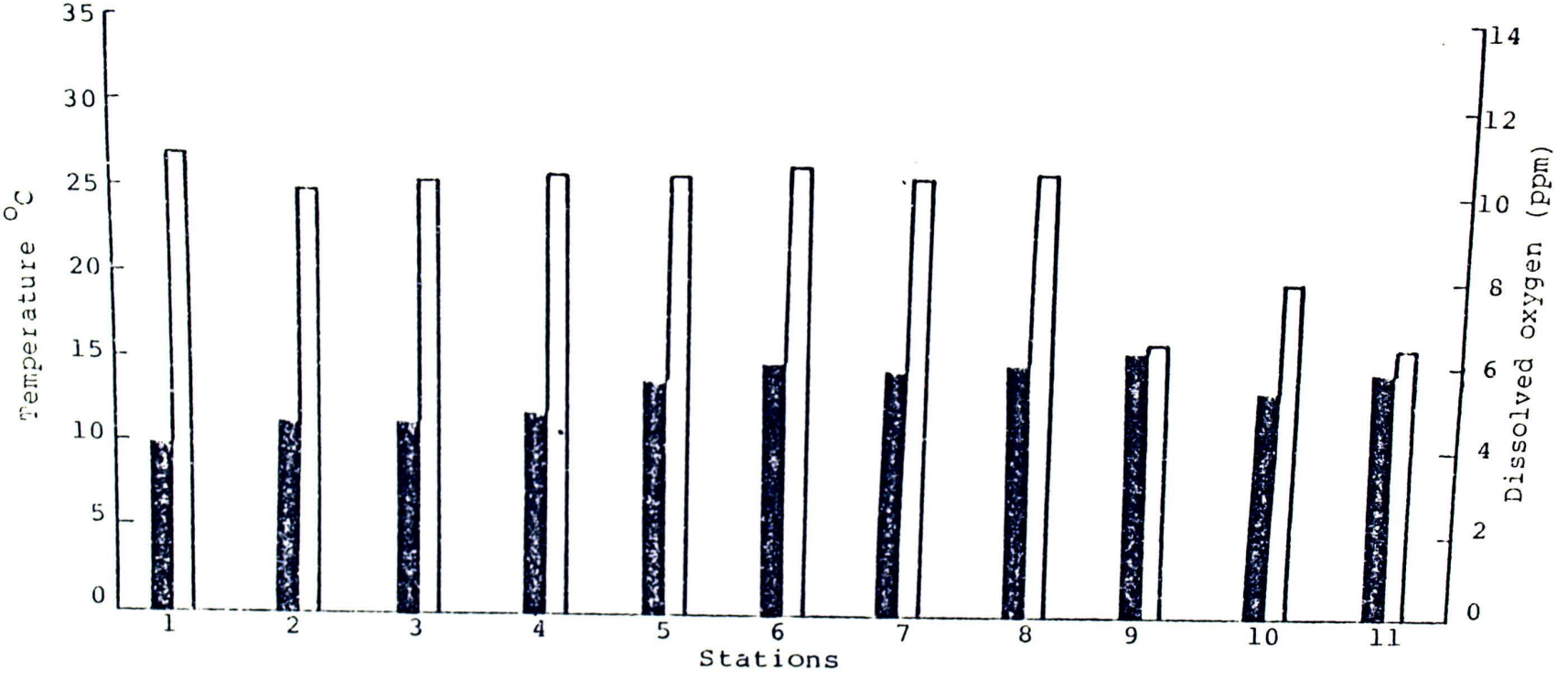

Figure 30. Longitudinal profile of surface temperature (solid bars) and dissolved oxygen (cutlined bars) for the Red River, Big West Fork Creek, and Cumberland River for fall, 1977.

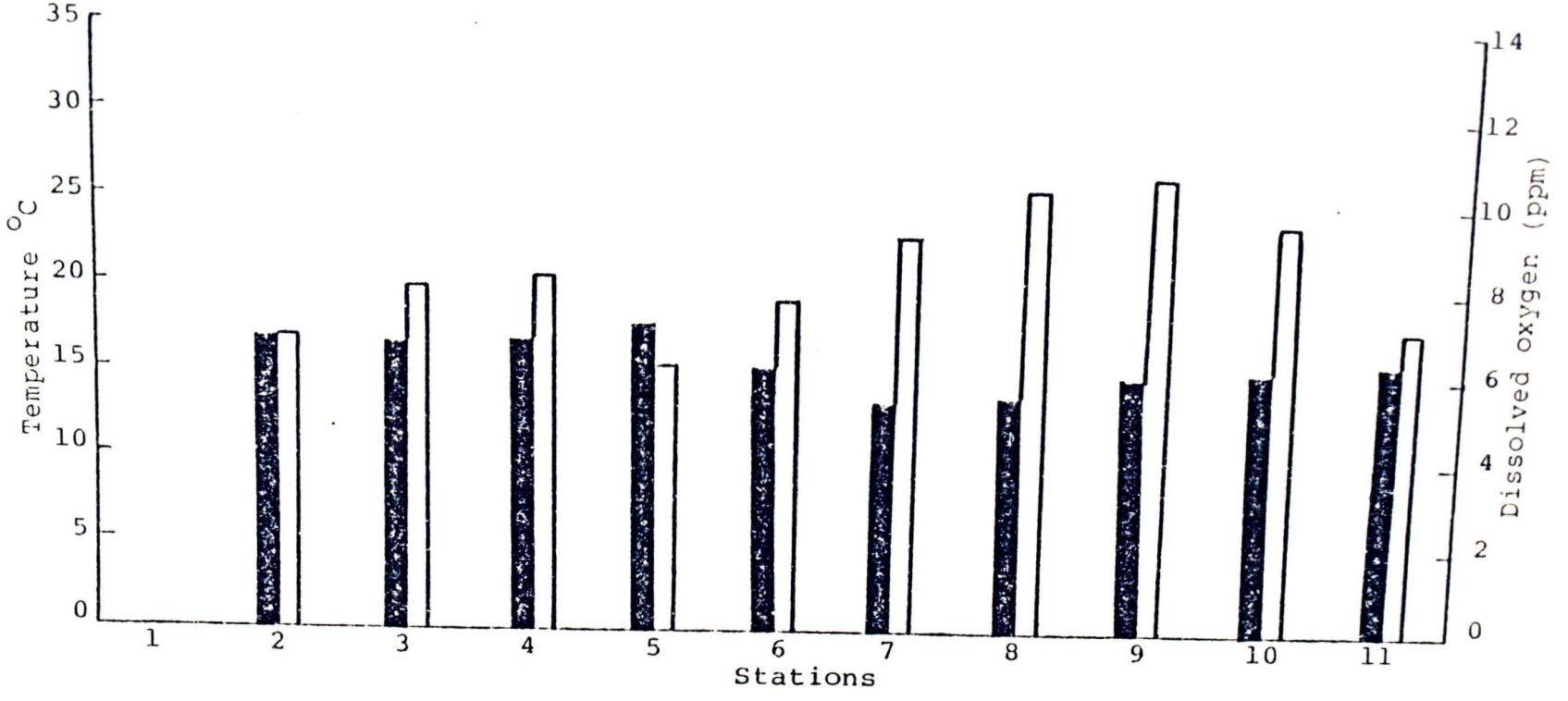

Figure 31. Longitudinal profile of surface temperature (solid bars) and dissolved oxygen (outlined bars) for the Red River, Big West Fork Creek, and Cumberland River for spring, 1978.

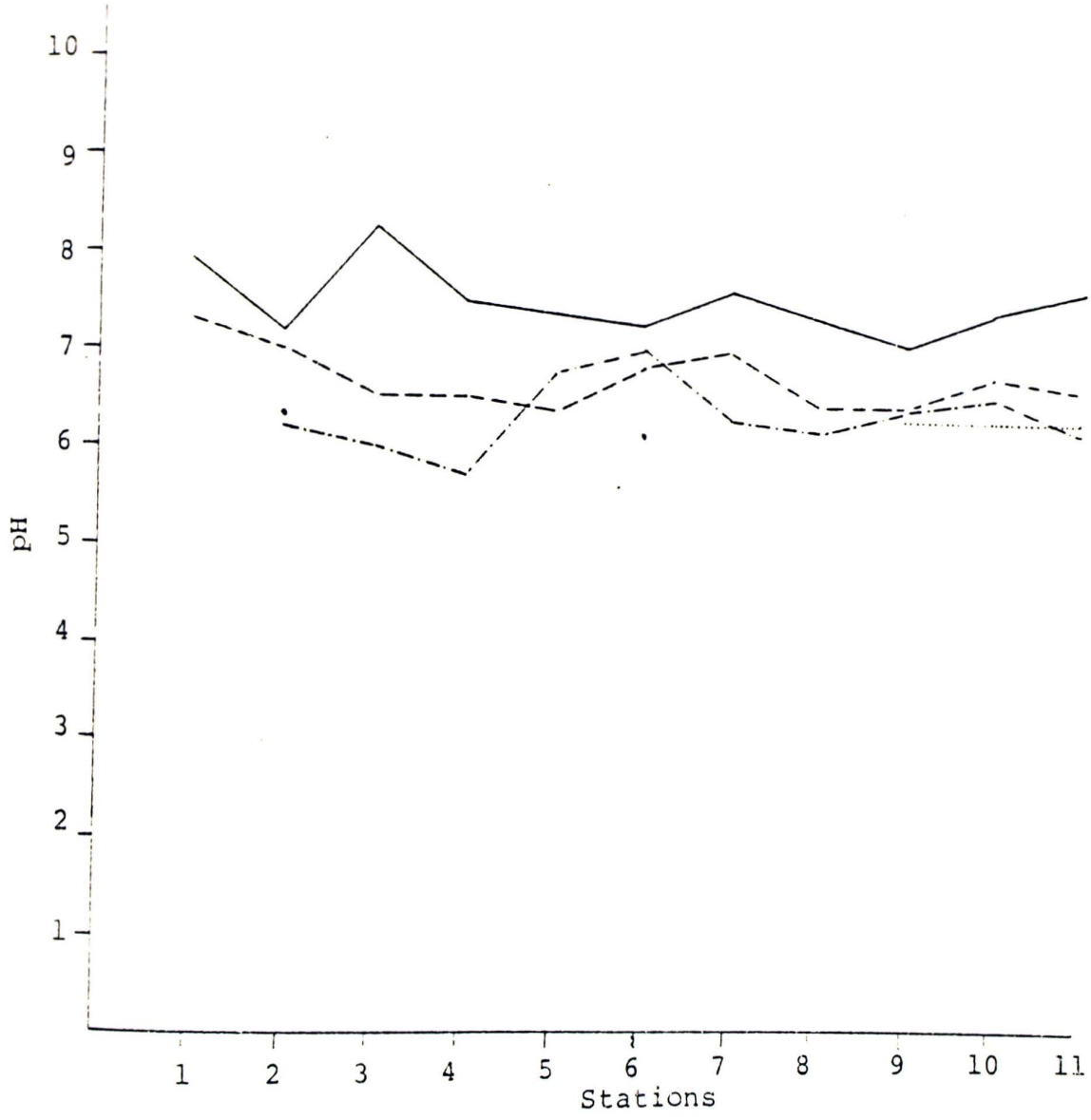

Figure 32. Hydrogen ion concentrations (pH) for summer (———), fall (- - - -), winter (·····), and spring (-·-·-·).

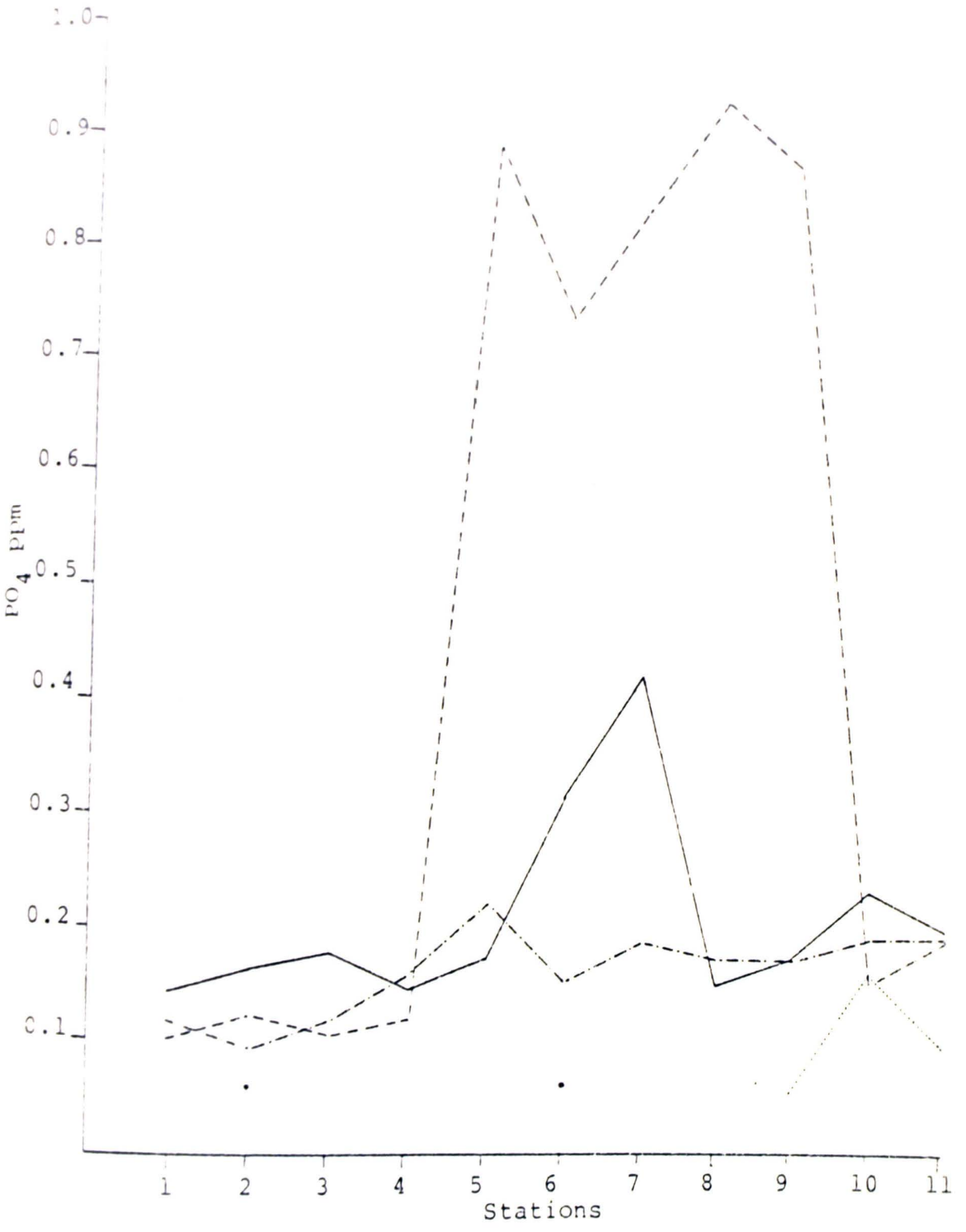

Figure 33. Phosphate (PO_4) concentrations for summer (———), fall (– – – –), winter (· · · · · ·), and spring (– · – · –).

spring, respectively.

Nitrate (NO_3) concentrations (Figure 34) were mostly uniform for the summer, fall, and winter with concentrations of 2.7, 2.5, and 2.9 ppm but increased in the spring to an average of 3.8 ppm.

Total hardness concentrations were generally higher at upstream stations and decreased at downstream stations. The fall concentrations were highest with an average of 163 ppm while summer, winter, and spring revealed means of 137, 148 and 143 ppm (Figure 35).

Transparency (Secchi-disk) readings are given in Figure 36 and reveal unsteady values; none exceed one meter in depth.

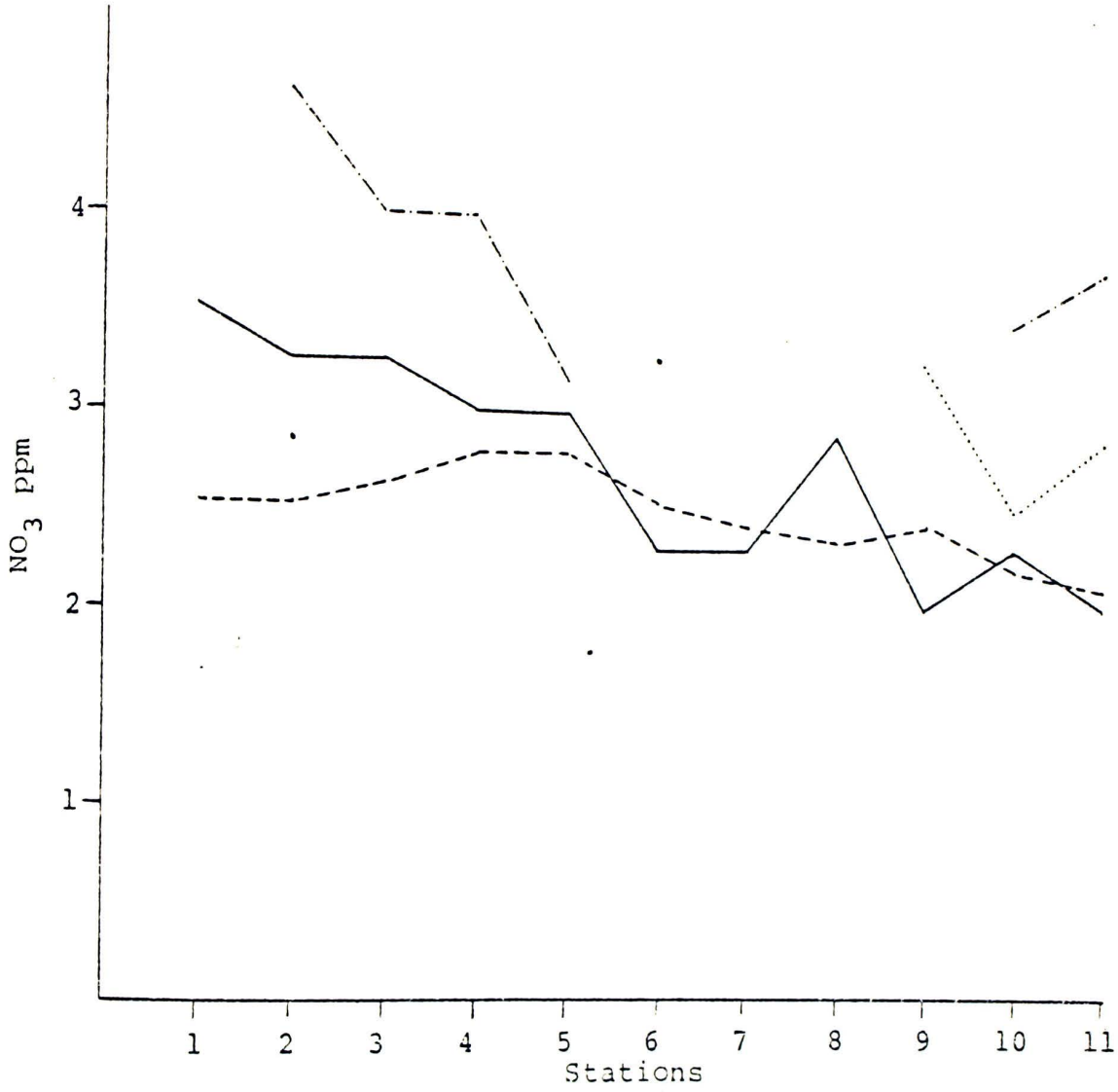

Figure 34. Nitrate concentrations (NO_3) for summer (———), fall (– – – –), winter (·····), and spring (– · – · –).

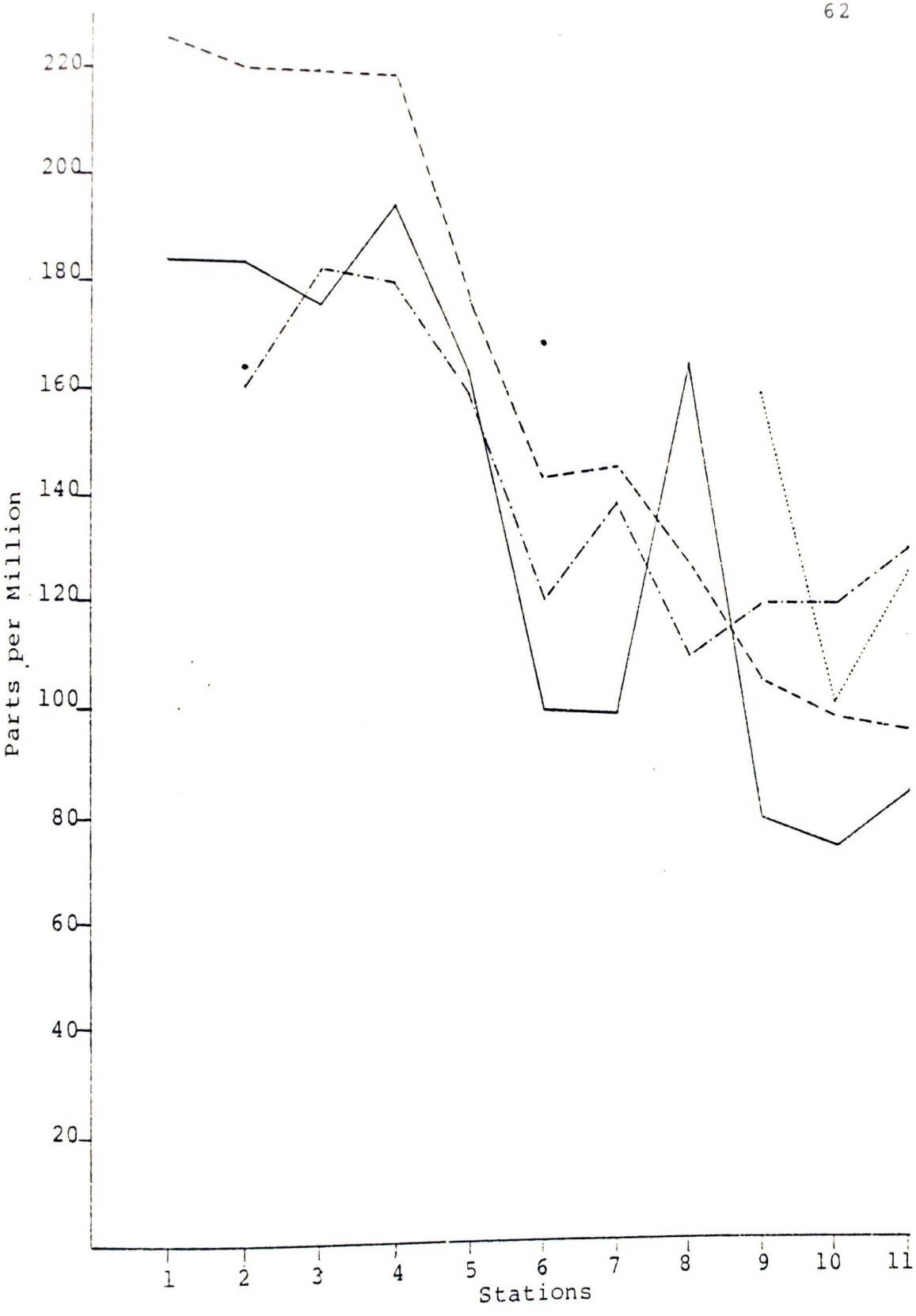

Figure 35. Total hardness concentrations for summer (———), fall (– – – –), winter (·····), and spring (– · – · –).

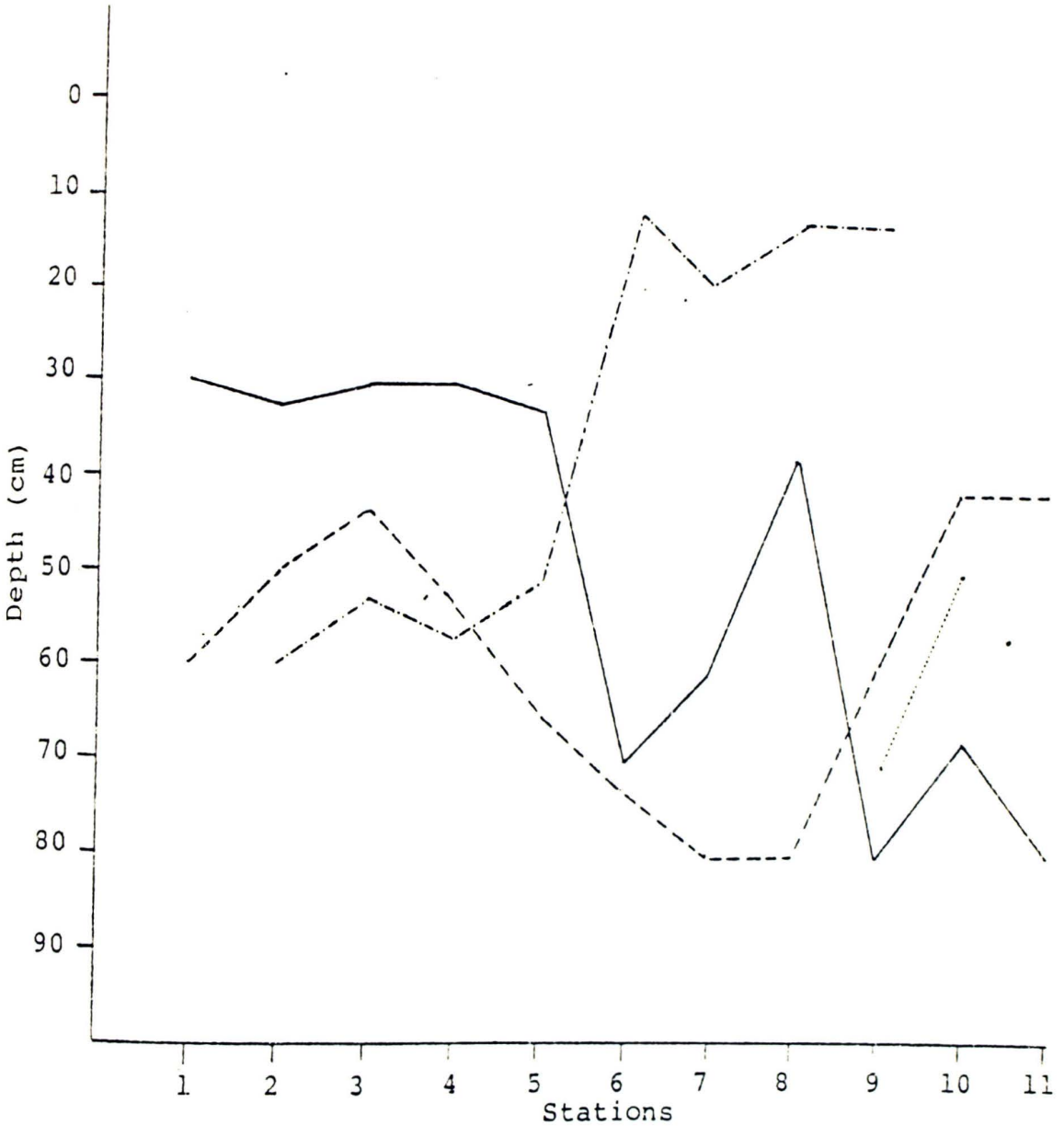

Figure 36. Secchi-disk values for summer (———), fall (– – –), winter (.....), and spring (–·–·–).

CHAPTER IV

DISCUSSION

When assessing the water quality, methods for biological, chemical, and physical measurements must be chosen carefully. In the laboratory as well as in the field, measurements must be as precise as possible with the best equipment available and all must be finished in the time allowed. In this investigation, the biological (algal) parameters received primary attention; chemical and physical parameters were determined as accurately as possible and were conducted primarily to support the biological data.

Study Design

Stations 1, 2, 3 and 4 were in areas where the Red River was unaffected by municipal allochthanous nutrient and pollutant input and were adjacent to forests and cultivated fields. Any allochthanous input was considered as non-point and was mostly agricultural chemicals. These upstream-most stations were in noticeable currents while currents were less apparent at downstream stations due to wider channels and greater depth.

Station 5 did not receive any point source of pollution but probably received nutrients from farmland and from septic tanks. Human population density increased

at this point as the river approached the Clarksville area.

Below station 5, point sources of allochthanous materials increased. One major contributor at this station was thought to be effluent from a meat packing lagoon (oxidation pond) located on the south side of the river (this plant is no longer in operation). Stations 5 through 11 were close to each other in order to detect point sources of input and to measure any resulting changes.

At approximately river mile 0.5 on the Red River, a pipe carrying secondary treated effluent from the Clarksville main sewage treatment plant enters and extends downstream on the river bed to the Cumberland River. Near the center of the Cumberland River, the pipe turns downstream and releases effluent at river mile 125.3. Unfortunately, the pipe appears to be broken near the entrance point; leaking effluent has been shown by sonar (Davis, 1981) and solids float to the surface.

Two additional sewage treatment plants discharge into the river system. The New Providence plant employs the trickling filter method of secondary treatment and discharges into Little West Fork Creek at river mile 2.9. Effluent from the Edgoten plant enters Little West Fork Creek at river mile 7.5. This is the smallest of the three facilities and from such evidence as floating sewage solids, it is assumed that at times the sewage receives negligible treatment.

The facilities have compound effects upon the waterways. The primary effect is that they fertilize the streams and add high concentrations of bacteria. The fertilization causes an increase in plant life while bacterial concentrations decrease dissolved oxygen concentrations.

Phytoplankton - Summer

Phytoplankton is a mixture of both normally free-floating forms and attached forms which have broken from their substrate. These broken-off forms are termed "tychoplankton" by Williams (1964). In calm-flowing systems, the amount of tychoplankton may be nominal whereas in headwaters and after heavy precipitation the amount may be considerable. Bottom disturbances may result in benthic algae breaking from the substrate and floating to the surface; this is especially true for some blue-green algae where gas vacuoles facilitate floating (Hutchinson, 1967).

The observed seasonal succession of phytoplankton does not conform to the typical fluctuations of numbers and divisional dominance. As shown in Figure 4, the greatest standing crop (standing stock) occurred during the summer. According to Fogg (1975), in the north temperate zone the typical summer flora should be lower in population size and at times, more comparable with that of winter.

The size of the summer crop may be attributed to two primary factors: warm temperatures (which select for blue-green algae) and high nutrient concentrations. Actually, the nutrient concentrations may be high throughout all seasons but when temperatures are higher, bacterial metabolism increases and the "unlocking" of essential nutrients from human by-products and naturally introduced organics such as forest litter is completed at a faster rate.

The blue-green algae were the major constituent of the summer flora (Figure 4), representing 75 percent of the total standing crop and dominating at every station (Figure 9). This percentage may be higher since the "others" category is made up of unknown cells and probably includes some blue-green algae.

The checklist shows only one representative of the blue-green Order Chroococcales. This is atypical for systems where sewage pollution is high (Stanier, et al., 1971). Since the algal identifications were made at a low power, proper identifications of some of the nannoplanktonic species were questionable; therefore they were grouped into classes of higher taxonomic rank.

Organic pollution usually results in an abundance of blue-greens due to the high concentrations of phosphates, nitrates and chelators. Their metabolites control species succession in phytoplankton blooms (Vance, 1965). Also, since bacteria accompany organic pollution, blue-green

algae and bacteria may have mutualistic associations (Whitton, 1973). Once blue-green algae have the proper nutrient requirements, they are advantaged further by freedom from zooplankton grazing, their ability to float, thus keeping them well within the photic zone (Bierman, 1976), and because they can use carbon dioxide more efficiently at lower concentrations than green algae (Shapiro, 1973).

The summer flora exhibited very high concentrations of mostly filamentous taxa of Cyanophyta. The most abundant was a taxonomically difficult species identified as Phormidium angustissimum West et West (G. W. Prescott, personal communication). Phormidium angustissimum is a very small alga and often confused with bacteria. The highest concentrations were found at depths of 0.5 m and at the surface. At stations 1 through 5, P. angustissimum occurred infrequently in the samples, averaging only 1,677,860 cells per liter at each station. However, at downstream stations 6 through 11, its concentrations increased to an average of 3,642,348 cells per liter. Following P. angustissimum, the blue-green genera Anabaena, Lyngbya, Oscillatoria and Nostoc ranked next in order of abundance.

The summer Cyanophycean flora was composed of the following taxa with their percentage of cell counts within the Division: Phormidium angustissimum 55.8, Anabaena sp. 17.3, Lyngbya sp. 8.4, Oscillatoria sp. 7.8, Nostoc sp.

5.8, Aphanizomenon flos-aquae 3.5, Merismopedia tenuissima 1.0, Merismopedia sp. 0.15, Anabaenopsis circinalis 0.09, Rivularia sp. 0.05, and Spirulina sp. 0.04.

The Division Chrysophyta, Order Centrales, was the second most dominant group and was represented by two genera. The five species of Melosira identified ranked in order of most to least abundant were: M. granulata, M. ambigua, M. varians, M. herzogii, and M. distans. Cyclotella glomerata was the most abundant species of that genus, while C. bodanica was found rarely in a few upstream samples. Cyclotella glomerata has been cited as one of the common diatom taxa occurring at water pollution surveillance stations in the United States (Weber, 1971).

Major Chlorophyta taxa included Ankistrodesmus convolutus, A. falcatus, Chlamydomonas sp., Chlorella sp., Eudorina sp. and Scenedesmus quadricauda. Non-filamentous Chlorophyta were common while filamentous taxa were rare (Figure 13). Chlamydomonas, Scenedesmus, Chlorella, Ankistrodesmus, and Eudorina rank 3, 4, 5, 10 and 33 respectively on Palmer's (1969) list of 60 most pollution tolerant genera. From the list of 80 species most tolerant to organic pollution, S. quadricauda ranks fourth while Ankistrodesmus falcatus ranks eighth. Overall, coccoid members dominated the Chlorophyta flora at six stations while flagellates exhibited dominance at three and filamentous forms at one (Figure 13).

At stations 4, 7 and 8, Platydorina caudata was found, always below the surface. Prescott (1970, 1978) noted that P. caudata is very rare and has been collected in only eight states. It was reported from Tennessee by Forest (1954) and Lackey (1942). Allen (1920) and Olson (1938) correlated the occurrence of the species with large amounts of organic pollution and Harris (1969) noted that it thrives at temperatures between 15° C and 40° C, can survive anaerobically in the presence of a proper carbon source, and grows well in the presence of $NaNO_3$ and urea. Harris (1970) also reported that an autoinhibitory substance is produced. Platydorina caudata was only found during summer and in water temperatures ranging from 27.1° C to 30.0° C.

The genus Phacus was the major constituent of the summer Euglenophyta. This Division was of minor importance overall. Phacus ranks 11 on the Palmer (1969) list of genera tolerating organic pollution.

Summer longitudinal diversity in the Red River was greatest at downstream stations (Table II). Station 10 on the Cumberland River yielded the most taxa with 48. Typically, diversity decreases and numbers per species increase in very polluted zones (Cairns, Lanza, and Parker, 1972).

Another parameter for estimating the standing crop of phytoplankton is the concentration of chlorophyll a. This technique is widely employed but there are often problems

associated with methods and interpretation. The primary goal of the test is to give an indication of the amount of algae in a sample but it has also been used to measure primary production (Vollenweider, 1974), and as an index of potential productivity (Prescott, 1962).

The total size of the summer phytoplankton standing crop along with chlorophyll a concentrations at each station is shown in Figure 5. Station 9 had the greatest standing crop, but the chlorophyll a concentration did not differ greatly from that found at other stations. The average cell counts found at stations 2, 3, 4 and 5 were much smaller than those found at stations 6, 8 and 9. There was also an increase in algal numbers and chlorophyll a concentration at station 6. As mentioned earlier, the effluent lagoon which lies between stations 5 and 6 may be the primary reason for the phytoplankton pulse exhibited there.

Station 9, located at the widest, deepest, and slowest moving point of the Red River, had the largest standing crop during summer. This may be due to several factors: (1) nutrient increases due to bacterial decomposition of discharge from the effluent lagoon, sewage treatment plants located upstream on the Big West Fork Creek, and the main Clarksville sewage treatment plant, (2) the presence of impounded water from the Cumberland River, and (3) the change in river morphology allowing for a more stable phytoplankton population and shifting to a more lentic

situation. This semi-lotic water allows for the settling out of detrital substances and hence greater light penetration (Figure 36). Station 8, located upstream from the sewage treatment plant release and just downstream from the confluence of the Big West Fork Creek, had lower standing crops, possibly due to less available nutrients at that point and turbulence attributed to the tributary discharge.

Phytoplankton - Fall

The fall flora revealed both differences with and similarities to the summer flora. Quantitatively, it was five times smaller and exhibited a qualitative dominance shift to the Chrysophycean Order Centrales (Figure 4). This Order included 75.9 percent of the standing crop and was represented by 12 species. The most abundant was Melosira italica, followed by M. ambigua, M. distans, M. granulata and M. varians. Other Centrales occurred infrequently and at low concentration.

The Division Chlorophyta was composed of 23 taxa and increased from 5.6 percent of the summer flora to 12.7 percent of the fall. Scenedesmus quadricauda was most abundant with Chlamydomonas sp., Ankistrodesmus convolutus, Gloeocystis sp., and Chlorella sp. occurring frequently and in moderate concentrations. Other Chlorophyta occurred infrequently.

Following the Chlorophyta, five taxa of Cyanophyta comprised 7.9 percent of the standing crop. Phormidium

angustissimum dominated; others included Lyngbya sp., Oscillatoria sp., Anabaena sp. and Merismopedia sp.

The Chrysophycean Order Pennales attained highest diversity in the fall with 25 taxa. However the pennate numbers were much smaller and constituted 2.3 percent of the flora. The genus Navicula was the most diverse with seven species. Synedra acus was the most abundant single pennate species with Synedra ulna occurring at slightly lower concentrations than S. acus. The pennate genus Nitzschia, represented by three taxa, was also an important component.

The Division Euglenophyta was represented by two taxa, Euglena sp. and Phacus sp., and was minimal in the fall standing crop.

Longitudinally, the fall flora exhibited the best display of zonation (Figure 6). Cell counts and chlorophyll a concentrations showed low concentrations at the upstream stations but begin to increase at station 5. Station 9 had the highest cell count concentration whereas station 8 yielded slightly higher chlorophyll a concentrations. The Cumberland River stations were nearly the same with slightly lower concentrations of both parameters at the upstream station 10.

A longitudinal analysis of the major groups (Figure 10) revealed that the Order Centrales was the reason for the increase beginning with station 4. This clear Centrales reaction was accompanied by massive phosphate concentrations

which showed slight increases at station 4, large concentrations at 5 through 9, and low concentrations at 10 and 11. Total hardness showed definite decreases as the phytoplankton flora increased (Figure 6). The Divisions Chlorophyta and Cyanophyta exhibited pulses at station 6 and both peaked at station 9 (Figure 10). Coccoid members of the Chlorophyta were dominant at most stations and were largely responsible for the Chlorophyta pulses (Figure 14).

The fall flora averaged 20 taxa per station and showed lowest diversity at stations 1 through 4 and greatest diversity at stations 5 through 11 (Table II).

Phytoplankton - Winter

Winter sampling yielded incomplete collections due to bad weather and equipment breakdowns. Stations 1, 2, 4, 6 and 7 were collected at the surface only, while stations 3, 5 and 8 were not collected. Stations 9 and 10 were sampled completely while station 11 was collected at surface and 0.5 m.

Quantitatively, the winter flora was smaller than the fall (Figure 4). The Order Centrales remained dominant but decreased to approximately 52 percent while the Order Pennales constituted 22 percent. Ranking next in abundance were the Divisions Cyanophyta with 10 percent, Chlorophyta with nine percent and Euglenophyta with 0.3 percent.

The winter flora averaged 11 taxa per station, the lowest diversity of any season. Winter diversity was lowest

at stations 1, 2 and 4 and much higher at stations 6, 7, 9, 10 and 11 (Table II).

Nine taxa made up the winter-dominating Order Centrales. Again, Melosira was most numerous and was represented by M. ambigua, M. herzogii, M. granulata and M. varians, in order of decreasing abundance. Coscinodiscus Rothii, Coscinodiscus sp., Cyclotella bodanica, Cyclotella sp. and Stephanodiscus sp. occurred infrequently.

The Chrysophycean Order Pennales was the largest taxonomic group and included 37 taxa. The most numerous pennate genus was Navicula with seven taxa; N. peregrina was most abundant. Synedra was represented by four species; from most to least abundant was S. ulna, S. acus, S. actinastroides and S. rumpens. Nitzschia gracilis and N. acicularis were prominent and Opephora occurred frequently.

The Division Cyanophyta was represented by three taxa; Lyngbya was most abundant but Phormidium angustissimum and Spirulina occurred rarely.

Of the 11 Chlorophyceae taxa identified, Chlamydomonas sp., Franceia ovalis and forms of Chlorella sp. dominated. The Euglenophyta was represented by Euglena and Trachelemonas in very low concentrations.

Longitudinal analysis (Figure 7) showed low concentrations of cells and chlorophyll a concentrations at upstream stations 1, 2, 4 and 6 with a large pulse at the Big West Fork Creek station 7. This was largely due to an increase in Melosira ambigua and was accompanied by

increases of Cyanophyta and Chlorophyta (Figure 11). Coccoid species dominated the Chlorophyta. Station 9 remained as the greatest in standing crop for both algal cells and chlorophyll a (Figure 7). Both Cumberland River stations exhibited moderate populations with an increase in algal cells and decrease in chlorophyll a concentrations at the downstream station 11.

Phytoplankton - Spring

Spring sampling included complete collections at all stations except station 1. Phytoplankton dominance shifted from the Order Centrales of the previous fall and winter to the Chrysophycean Order Pennales.

Pennate diatoms occupied 50 percent of the standing crop (Figure 4). This also was the most diverse group of the entire study with 46 taxa. An average of 33 taxa were identified at each station. An average of one million cells/l made the spring flora lowest in seasonal standing crop.

The most abundant genus was Navicula with N. peregrina dominating, followed by N. salinarum, N. cuspidata and N. radiosa. Nitzschia ranked second in abundance with N. gracilis, N. holsatica, N. acicularis and N. tryblionella. Species of Achnanthes, Cymbella, Opephora, Gomphonema and Fragilaria occurred frequently.

The Order Centrales ranked second in abundance and occupied 26 percent of the standing crop. The centric

diatom genus Melosira was the most abundant single genus and was composed of, in order of abundance, M. herzogii, M. ambigua, M. varians, M. granulata and Melosira sp.

The Division Cyanophyta yielded 18 percent of the spring flora with Phormidium angustissimum, Aphanizomenon flos-aquae, Lyngbya sp., Oscillatoria sp., Anabaena sp. and Nostoc sp. occurring in most to least abundance.

The Division Chlorophyta represented four percent of the standing crop and increased in diversity to 15 taxa. Dominating the small Chlorophycean crop was Scenedesmus with S. bijuga and S. dimorphus in greatest to least abundance.

Longitudinally, stations 2 through 9 revealed similar phytoplankton and chlorophyll a concentrations (Figure 8). Station 10 had a very large standing crop but station 11 decreased in both cell counts and chlorophyll a concentrations. The large crop at station 10 was due primarily to Centric diatoms and increases of Pennate diatoms and Cyanophyta species. The spring Chlorophycean flora was dominated by coccoid forms except at station 10 where filamentous forms dominated. Longitudinal diversity was mostly homogeneous at station 1 through 9 (Table II) with slightly lower diversity at station 11.

Vertical Distribution

Vertical arrangement is primarily a result of reproduction in the photic zone and the subsequent sinking of

dead and dying cells. A slow reproduction rate in the photic zone with a greater sinking speed allows for a more homogeneous concentration of cells throughout the water column.

Turbulence is the most important factor affecting sinking speeds. Water lacking turbulence has greater sinking rates than does turbulent waters (Gessner, 1948). In thermally stratified waters the epilimnion is turbulent due to its contact with winds and radiation. The hypolimnion has much less turbulence due to its separation from the epilimnion via the metalimnion (thermocline). It has been shown by Gessner (1948) that algal cells sink ten times faster in the hypolimnetic waters. Streams lacking thermal stratification could possibly be very homogeneous or heterogeneous with higher concentrations in certain areas.

Analysis of the vertical distribution of both cell counts and chlorophyll a concentrations revealed that for summer, fall and winter (Figures 15, 16 and 17) , greater concentrations occurred at 0.5 m than at the surface. The spring distribution revealed greater concentrations at the surface (Figure 18), probably as a result of higher reproductive rates there.

Vertical distributions during each season followed closely the dominant and subdominant groups shown in Figure 4. The summer flora was dominated at all depths by

the Cyanophyta (Figure 19); other groups were uniform throughout but at lower concentrations. The fall flora was dominated by the Centrales (Figure 20). The vertical arrangement for winter (Figure 21) was much like fall; Centrales dominated but other groups were also important at 2.0 m and 2.5 m. The spring vertical profile (Figure 22) revealed uniform concentrations of all groups except at 1.0 m where the Pennales were in larger concentrations.

Primary Production

Streams are one of the most productive biological habitats; this is especially true for stream zones recovering from organic waste deposits (Odum, 1956). Problems are often encountered in measuring primary production in streams. For example, benthic algal communities exhibit temporal and spatial heterogeneity (Wetzel, 1975), whereas phytoplankton communities have diurnal pulses (Blum, 1956) and are subject to periodic grazing by vertically migrating larval insects (Hynes, 1970).

In this study area, water levels are primarily due to the Barkley hydroelectric dam. At times of high generating activity, the water level may drop considerably within a 24 hour period; conversely, during times of low generation, water levels increase accordingly. Although no quantitative data were available, water level fluctuations were observed during consecutive sampling days. With these water level fluctuations and the reduced light

transparency primarily due to large phytoplankton standing crops and suspended solids, production by benthic algae was minimal; this low production was also observed by Blum in Wisconsin (1956).

Primary production rates were not calculated to net photosynthesis per day (mg C/M^2/day) due to problems with field equipment, primarily alkalinity testing and incident radiation detection. This discrepancy disallows the comparison of results with other findings but the comparison of the stations and depth measurements to each other are very useful.

The study area exhibited a longitudinal zonation of productivity. Stations 1 through 4 had lower carbon assimilation and stations 5 through 11 had much higher rates (Table VII). Surface and 0.5 m measurements (Table VII) lie within the photic zone and their peaks at downstream stations were much higher than samples from the upstream zone. Depths of 1.0, 2.0, and 2.5 m had similar longitudinal fluctuations as surface and 0.5 m values but were much reduced in counts per minute. The surface waters were the most productive overall, probably due to available sunlight (Table VII). Analysis of vertical profiles of carbon uptake reveals greater productivity at the surface from all stations and decreasing carbon assimilation through the photic zone. Wetzel (1975) suggests that this general decrease of carbon assimilation through the photic zone is primarily due to turbidity but maintains

that this is also characteristic of a hypereutrophic situation.

Ratios of Carbon-14 uptake and phytoplankton cell counts at stations 1 and 2 were very low (Figure 23) whereas stations 3 through 11 (Figures 24, 25, 26, 27 and 28) revealed higher ratios near the surface, indicating greater Carbon-14 uptake per cell.

Temperature

Summer air temperatures were warmest, averaging 29.9° C. Surface waters during this same period were also warmest, averaging 28.8° C. The fall season showed a decrease in air temperature to an average of 16.4° C with a corresponding surface water decrease to an average of 13.5° C. Winter sampling revealed the lowest temperature for air, 1.5° C and for surface water, 4.2° C. The spring average air temperature was 14.2° C and surface water averaged 15.7° C.

Vertical temperatures showed no evidence of complete thermal stratification (Tables VIII, IX, X and XI) for summer, fall and spring. Although some stations exhibited differences in temperature from surface to bottom, distinct zones did not exist. The temperature and discharge data show that the Big West Fork Creek, Red River and Cumberland River have some characteristics of reservoirs but the degree of circulation shows that they should be considered streams.

Longitudinal profiles of surface temperatures indicate homogeneity from successive Red River stations and typically different temperatures for the Big West Fork Creek and Cumberland River (Figures 29, 30 and 31).

Dissolved Oxygen

The primary sources of oxygen in waters are the atmosphere and chlorophyll bearing plants. Atmospheric oxygenation is primarily accomplished by diffusion and is accelerated by surface water movements (Welch, 1952). Welch also points out that atmospheric diffusion is a very slow process. The amount of atmospheric oxygen entering the water surface depends on atmospheric pressure, water temperature, and the concentration of dissolved solids in the water (Reid, 1961).

Oxygen can be produced in the littoral region by aquatic angiosperms and periphyton or in the limnetic zone by phytoplankton. Aquatic angiosperms were not observed in the study area and benthic algal communities were not well developed. In the limnetic zone, factors important for oxygen production by phytoplankton are the concentration of plants and the quantity and duration of light.

Vertical profiles of dissolved oxygen followed closely that of temperature (Tables VIII, IX, X and XI). At some stations dissolved oxygen concentrations were greater at or near the surface due to interaction with the atmosphere, higher concentrations of phytoplankton (Figures 15, 16, 17

and 18) and greater metabolic rates (Table VII).

Other Tests

Nitrogen and phosphorus concentrations are major factors in controlling the growth of algae due to their usual scarcity in relation to other essential micronutrients (Shapiro, 1970). River concentrations are mainly of allochthanous origin and very little is saved for the next year because they are transported downstream.

During summer, phosphate concentrations (Figure 33) and phytoplankton standing crops (Figure 5) did not always increase and decrease correspondingly. Station 6 did show increases in phosphate, chlorophyll a concentrations and phytoplankton cell counts but at station 7, where an increase in phosphate concentration existed, cell counts dropped and chlorophyll a concentrations increased. Stations 9, 10 and 11 exhibited highest cell counts however phosphate concentrations were comparatively low. Large algal standing crops use much more phosphorus and the concentration of phosphorus and algal standing crops should be inversely proportional.

Nitrate concentrations for winter (Figure 34) revealed an inverse relationship to phosphate (Figure 33) with a decrease from station 9 to 10 and an increase at station 11. Incomplete nitrate data for spring (Figure 34) shows a decrease from station 2 through 5 and an increase from station 10 to 11.

Phosphate concentrations for fall exhibited a very large increase at stations 5 through 9 (Figure 33). Nitrate concentrations (Figure 34) only showed a slight decrease in concentration through the same interval of river. In comparing these results to the total phytoplankton crop (Figure 6), it appears that phosphate could have been a limiting factor for upstream stations 1 through 4, causing the decrease in algal cells and chlorophyll a concentrations. If this was the case, it also appears that the algae never attained sufficient population size to cause a decrease in phosphate and an inverse relationship between the chemical and biological parameters. Winter phosphate concentrations (Figure 33) correspondingly increased from station 9 to 10 as did phytoplankton standing crops (Figure 7). Downstream, station 11 exhibited a lower phosphate concentration along with lower chlorophyll a concentrations while cellular concentrations increased. Spring phosphate concentrations (Figure 33) and pH (Figure 32) were similar at most stations.

Total hardness values were lower at station 9 than at any other point for summer sampling (Figures 34 and 35). This low hardness level may be associated with the decrease in current at that point and the settling out of suspended solids. Lower hardness concentrations throughout for fall may also be due to decreased currents. Winter total hardness concentrations (Figure 35) followed the same pattern as nitrate concentrations with a decrease at stations 9

to 10 and an increase at station 11. Hardness concentrations exhibited a general decrease through the system during spring with an increase from station 8 to 11.

Low light penetration was probably due to large phytoplankton standing crops and suspended solids. Summer sampling exhibited an increase in visibility at downstream stations; this may have been due to the settling out of suspended solids. Similar reasons may account for fluctuations of Secchi-disk visibility for fall. Light penetration for winter (Figure 36) was lowest at Cumberland River station 10, probably due to the greater phytoplankton standing crop found there. Low light intensities, small phytoplankton populations, and speculative lower photosynthetic activity may have resulted in slightly acidic pH values during winter (Figure 32). Light penetration for spring was poor at downstream stations 6 through 9 (Figure 36).

CHAPTER V

SUMMARY

Algal studies were conducted quarterly at 11 stations on the Red River, Big West Fork Creek, and Cumberland River, Montgomery County, Tennessee during 1977 and 1978. In addition, certain chemical and physical parameters were surveyed. The studies showed that the algal flora consisted of 149 taxa which were in greatest abundance during summer and decreased through fall, winter and spring. Centric diatoms (Order Centrales) were dominant in fall and winter whereas pennate diatoms (Order Pennales) dominated in spring. Quantitative parameters involved cell counts and chlorophyll a concentration. These results indicated larger standing crops at downstream stations with Phormidium angustissimum, Melosira italica, Melosira ambigua and Navicula peregrina dominating for summer, fall, winter and spring respectively. The phytoplankton was most productive at the surface of downstream stations although algal standing crops were usually most concentrated at a depth of 0.5 m.

The input of nutrients from agricultural runoff and municipal sewage was identified as factors responsible for high phytoplankton standing crops and productivity. The nutrient additions and decreased current formed a stable

riverine phytoplankton flora at downstream stations.

The absence of thermal stratification made available nutrients from the bottom which would not have been available in a stratified water column. Warm temperatures of summer were especially favorable for growth of blue-green algae.

Chlorophyll a concentrations generally fluctuated with phytoplankton cell counts; however, direct relations between chlorophyll a concentrations and phytoplankton cell counts were not always evident.

Nitrate, phosphate and total hardness concentrations varied and were due to both natural and human-introduced autochthonous and allochthanous sources. At times, these chemical parameters appeared to fluctuate with phytoplankton standing crops and metabolic rates.

Summer pH values were higher at all stations than during the other seasons. This may be correlated with the large phytoplankton standing crops during summer.

Secchi-disk values were very low due to large phytoplankton populations and suspended solids. Low transparency may have been a limiting factor for algal growth.

From a limnological standpoint, these streams are characterized as eutrophic due to the presence of large phytoplankton standing crops, large concentrations of summer blue-green algae, high productivity at the surface, high percent oxygen saturations during daytime, and high

nitrate, phosphate and total hardness concentrations. The chemical and physical data did not always reveal explanations for algal flora structure and function.

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APPENDIX I

Table III. Corrected chlorophyll *a* concentrations in mg/m^3 at each station and depth for summer sampling, 1977.

Depth in Meters	Stations											
	1	2	3	4	5	6	7	8	9	10	11	Avg.
Surface	41	48	69	32	79	54	80	81	19	77	51	57
0.5 m	64	55	90	32	57	79	107	56	62	74	60	67
1.0 m	32	21	43	35	59	103	119	47	51	83	51	59
2.0 m	31	40	44	55	56	77	77	59	43	62	50	54
2.5 m	33	46	36	54	47	67	67	55	55	69	81	55
Avg.	40	42	56	42	60	76	90	60	46	73	59	

Table IV. Corrected chlorophyll a concentrations in mg/m^3 at each station and depth for fall sampling, 1977.

Depth in Meters	Stations											
	1	2	3	4	5	6	7	8	9	10	11	Avg.
Surface	3	6	5	6	52	94	67	63	60	102	60	47
0.5 m	29	5	*	8	75	67	75	76	74	80	65	55
1.0 m	6	6	6	7	8	73	56	67	58	80	86	41
2.0 m	3	13	9	24	26	39	21	59	64	70	97	39
2.5 m	6	24	*	7	11	16	13	*	62	74	106	35
Avg.	10	11	7	10	34	58	46	66	64	81	83	

* No data available

Table V. Corrected chlorophyll a concentrations in mg/m^3 at each station and depth for winter sampling, 1978.

Depth in Meters	Stations											
	1	2	3	4	5	6	7	8	9	10	11	Avg.
Surface	*	26	*	*	*	27	*	*	24	68	42	37
0.5 m	*	*	*	*	*	*	*	*	54	63	*	59
1.0 m	*	*	*	*	*	*	*	*	32	66	*	49
2.0 m	*	*	*	*	*	*	*	*	34	*	*	34
2.5 m	*	*	*	*	*	*	*	*	30	68	*	49
Avg.	*	26	*	*	*	27	*	*	35	66	42	

* No data available

Table VI. Corrected chlorophyll a concentrations in mg/m^3 at each station and depth for spring sampling, 1978.

Depth in Meters	Stations											
	1	2	3	4	5	6	7	8	9	10	11	Avg.
Surface	*	18	16	16	16	*	10	16	11	25	11	15
0.5 m	*	19	18	15	15	27	12	14	15	*	*	17
1.0 m	*	20	15	14	22	19	13	21	16	*	*	18
2.0 m	*	21	18	14	19	16	*	19	16	*	*	18
2.5 m	*	20	17	16	14	16	5	18	13	*	*	15
Avg.	*	20	17	15	17	20	10	18	14	25	11	

* No data available

APPENDIX II

Table VII. Net primary productivity of phytoplankton as Carbon-14 assimilated in disintegrations per minute for three hours incubation.

Depth in Meters	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Surface	1229	891	4644	7789	21508	54922	36647	50002	32631	55983	39798
0.5 m	1147	656	1821	4859	9746	16897	13305	29555	31957	27972	18937
1.0 m	239	255	413	891	1592	5741	7151	15136	19131	13663	9623
2.0 m	1050	54	132	226	211	737	702	2250	5768	8356	4872
2.5 m	383	---	85	172	158	144	277	691	2476	4295	3619

APPENDIX III

Table VIII. Dissolved oxygen concentrations (ppm), water temperatures (^{o}C), and percent oxygen saturations at each station and depth for summer sampling.

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
1	6.6 26.8 84 %	6.3 26.8 79 %	6.3 26.7 79 %	6.3 26.7 79 %							
2	7.2 29.2 96 %	6.2 27.1 79 %	5.4 27.0 69 %	5.7 27.0 73 %							
3	8.1 30.0 108 %	6.9 27.6 87 %	6.0 27.0 77 %	5.6 27.0 71 %	5.3 27.0 68 %						
4	5.6 27.5 72 %	5.3 27.1 68 %	5.2 27.1 67 %	5.5 27.1 70 %	5.4 27.1 69 %	5.2 27.0 66 %					
5	6.3 28.0 81 %	5.5 26.7 70 %	5.4 26.5 69 %	5.3 26.5 67 %	5.2 26.5 66 %	5.2 26.5 66 %					
6	7.2 29.9 96 %	6.8 28.6 88 %	5.3 27.9 68 %	5.1 26.3 65 %	5.3 26.1 66 %	5.2 26.9 66 %					

Table VIII. (Continued)

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
	8.1	7.7	6.1	5.3	4.6	4.4	4.0				
7	30.0	28.0	26.8	26.0	25.2	25.0	25.0				
	108 %	101 %	77 %	67 %	57 %	55 %	50 %				
	5.9	5.8	5.4	5.4	5.0	4.5	4.2	3.9			
8	27.5	27.2	27.1	27.0	26.8	26.3	26.0	26.0			
	76 %	75 %	69 %	70 %	64 %	57 %	53 %	50 %			
	6.7	5.9	5.9	5.6	5.3	4.6	4.4	4.1			
9	29.0	28.5	28.2	28.0	27.1	27.0	26.9	26.5			
	87 %	78 %	76 %	73 %	67 %	59 %	56 %	52 %			
	6.6	6.5	6.2	6.2	6.3	6.3	6.2	6.2	6.2	6.2	
10	29.1	28.8	28.6	28.6	28.6	28.6	28.6	28.6	28.5	28.5	
	87 %	86 %	81 %	81 %	81 %	82 %	81 %	81 %	81 %	81 %	
	8.1	7.5	6.2	5.7	5.7	5.5	5.4	5.3	5.3	5.2	5.0
11	30.0	28.9	28.7	28.6	28.5	28.5	28.5	28.5	28.5	28.2	28.2
	108 %	99 %	81 %	75 %	75 %	72 %	71 %	69 %	69 %	68 %	65 %

Table IX. Dissolved oxygen concentrations (ppm), water temperatures (^{o}C), and percent oxygen saturations at each station and depth for fall sampling.

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
	10.8	5.1	3.6	3.6							
1	10.5	10.5	10.5	10.5							
	100 %	47 %	33 %	33 %							
	10.0	5.4	4.2	4.4							
2	11.5	11.0	11.0	11.0							
	97 %	52 %	39 %	41 %							
	9.7	4.6	4.4	4.4	3.8						
3	11.5	11.0	11.0	11.0	11.0						
	93 %	43 %	41 %	41 %	35 %						
	8.1	5.2	4.0	4.0	4.2	4.0					
4	12.0	10.9	10.9	10.9	10.8	10.8					
	78 %	49 %	37 %	37 %	39 %	37 %					
	8.4	3.8	4.1	3.9	4.0	4.0					
5	14.0	12.0	11.0	11.0	11.0	11.0					
	85 %	36 %	38 %	36 %	37 %	37 %					
	8.0	3.8	3.6	3.6	3.6	3.6					
6	15.0	13.5	12.0	11.5	11.5	11.5					
	83 %	37 %	35 %	34 %	34 %	34 %					

Table IX. (Continued)

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
	5.6	4.2	3.2	3.4	4.0	3.4	3.4				
7	14.7	13.5	12.2	11.0	11.0	11.0	11.0				
	56 ‰	42 ‰	31 ‰	32 ‰	37 ‰	32 ‰	32 ‰				
	6.8	3.2	3.1	3.6	3.7	3.7	3.6	3.6			
8	15.0	14.0	13.2	11.7	11.2	11.2	11.2	11.2			
	70 ‰	32 ‰	31 ‰	35 ‰	35 ‰	35 ‰	34 ‰	34 ‰			
	6.5	3.2	3.0	3.2	3.4	3.4	3.4	3.4			
9	16.1	15.0	13.9	12.0	11.8	11.5	11.5	11.5			
	69 ‰	33 ‰	30 ‰	30 ‰	32 ‰	32 ‰	32 ‰	32 ‰			
	8.0	2.3	2.1	2.0	2.0	2.0					
10	14.0	15.0	15.0	15.0	15.0	15.0					
	80 ‰	24 ‰	21 ‰	20 ‰	20 ‰	20 ‰					
	6.4	2.2	2.2	2.1	2.0	2.0	2.0	2.0	2.0		
11	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0		
	65 ‰	22 ‰	22 ‰	22 ‰	20 ‰	20 ‰	20 ‰	20 ‰	20 ‰		

Table X. Dissolved oxygen concentrations (ppm), water temperatures (^{o}C), and percent oxygen saturations at each station and depth for winter sampling.*

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
	9.6	8.5	5.1	3.7	3.0						
9	5.9	5.9	5.8	5.8	5.8						
	80 %	71 %	42 %	31 %	25 %						
	15.8	7.2									
10	2.5	2.5									
	120 %	55 %									

* Stations 1-8 and 11 were not sampled due to adverse weather conditions.

Table XI. Dissolved oxygen concentrations (ppm), water temperatures (^{o}C), and percent oxygen saturations at each station and depth for spring sampling.*

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
2	6.9 17.1 69 %	3.7 17.1 40 %	2.8 17.1 30 %	2.5 17.1 27 %	2.4 17.1 25 %						
3	8.0 17.1 86 %	4.6 17.1 49 %	3.6 17.1 39 %	4.0 17.1 43 %	3.0 17.1 32 %	3.4 17.1 36 %	17.1				
4	8.2 17.1 88 %	6.4 17.1 70 %	7.0 17.1 76 %	4.2 17.1 45 %	3.5 17.1 37 %	3.2 17.1 35 %	5.1 17.1 55 %				
5	6.1 18.0 66 %	4.6 18.0 50 %	3.2 17.9 35 %	2.8 17.9 31 %	2.6 17.9 29 %	2.5 17.9 27 %	2.4 17.9 26 %				
6	7.8 15.0 81 %	5.2 15.0 54 %	3.4 15.0 35 %	1.2 15.0 12 %	2.7 15.0 28 %	2.6 15.0 27 %	2.4 15.0 24 %	2.4 15.0 24 %			
7	9.1 13.0 85 %	6.5 13.0 64 %	4.6 13.0 45 %	3.8 13.0 37 %	3.5 13.0 35 %	3.3 13.0 32 %	3.1 13.0 31 %	3.0 13.0 30 %			

Table XI. (Continued)

Station No.	Depth in Meters										
	Surf.	1	2	3	4	5	6	7	8	9	10
8	10.2 14.0 103 %	7.2 14.0 73 %	4.9 14.0 50 %	3.8 14.0 38 %	3.3 14.0 33 %	3.2 14.0 32 %	3.1 14.0 31 %	3.1 14.0 31 %	3.1 14.0 31 %		
9	10.5 15.0 110 %	6.6 15.0 67 %	5.1 15.0 53 %	4.2 15.0 43 %	3.9 15.0 40 %	3.5 15.0 35 %	3.4 15.0 35 %	3.3 15.0 33 %	3.3 15.0 33 %	3.3 15.0 33 %	
10	9.6 15.8 100 %										
11	7.2 15.6 96 %										

APPENDIX IV

Table XII. Total phytoplankton cell counts at each depth and station for summer sampling. Values indicate cell concentrations as cells/liter.

Depth	Stations 1	2	3	4	5	6
Surf	10988900.0	1215240.0	1134240.0	1744920.0	2563160.0	*
0.5m	146520.0	*	1942500.0	2246240.0	540930.0	3499650.0
1.0m	1278720.0	1101120.0	*	1367520.0	1833720.0	3705000.0
2.0m	5377240.0	537240.0	2579840.0	3019200.0	1217640.0	1802640.0
2.5m	57720.0	1562000.0	1265400.0	1217300.0	1776000.0	3467880.0
Total Mean	17859100.0 3571820.0	4415600.0 1103900.0	6921980.0 1730495.0	9595180.0 1919036.0	7931450.0 1586290.0	12475170.0 3118793.0

Depth	7	8	9	10	11	Total Mean
Surf	5943850.0	2546480.0	11909920.0	14420780.0	4521770.0	56999260.0 5699926.0
0.5m	1632870.0	1430130.0	25353020.0	12709840.0	8065860.0	60567560.0 6056756.0
1.0m	1401120.0	2073880.0	9799020.0	17120510.0	2011320.0	41691930.0 4169193.0
2.0m	644380.0	789810.0	14509660.0	25730760.0	*	51367410.0 5136741.0
2.5m	570570.0	661640.0	4868370.0	4290390.0	6499350.0	26236620.0 2385147.0
Total Mean	13192790.0 2638558.0	7500940.0 1500188.0	66439990.0 13287998.0	74272280.0 14854456.0	21098300.0 5274575.0	236862780.0 4689553.0

*No data available

Table XIII. Total phytoplankton cell counts at each depth and station for fall sampling. Values indicate cell concentrations as cells/liter.

Depth	Stations 1	2	3	4	5	6
Surf	144430.0	333300.0	33330.0	66660.0	899910.0	1099890.0
0.5m	88880.0	22220.0	22220.0	14820.0	1344310.0	377740.0
1.0m	44440.0	88880.0	99990.0	444400.0	355520.0	5555000.0
2.0m	33330.0	122210.0	33330.0	211090.0	155540.0	281580.0
2.5m	*	55550.0	33330.0	33330.0	214890.0	377740.0
Total Mean	311080.0 62216.0	622160.0 124432.0	222200.0 44440.0	770300.0 154060.0	2970270.0 594034.0	7691950.0 1538390.0

Depth	7	8	9	10	11	Total Mean
Surf	3466320.0	2288660.0	2310880.0	2788610.0	2110900.0	15542890.0 1412990.0
0.5m	3299670.0	2421980.0	2177560.0	3666300.0	2733060.0	16168760.0 1469887.0
1.0m	2333100.0	2099790.0	3488540.0	811030.0	1799820.0	17120510.0 1556410.0
2.0m	955460.0	2222000.0	2666400.0	1599840.0	1833150.0	10113930.0 919448.0
2.5m	388850.0	999900.0	1466520.0	2177560.0	2644180.0	8391850.0 762895.0
Total	10443400.0 2088680.0	10032330.0 2006466.0	12109900.0 2421980.0	11043340.0 2208668.0	11121110.0 2224222.0	67337940.0 6121630.0

*No data available

Table XIV. Total phytoplankton cell counts at each depth and station for winter sampling. Values indicate cell concentrations as cells/liter.

	Stations					
Depth	1	2	3	4	5	6
Surf	244420.0	277750.0	*	155540.0	*	311080.0
0.5m	*	*	*	*	*	*
1.0m	*	*	*	*	*	*
2.0m	*	*	*	*	*	*
2.5m	*	*	*	*	*	*
Total	244420.0	277750.0		155540.0		311080.0
Mean	244420.0	277750.0		155540.0		311080.0

Depth	7	8	9	10	11	Total / Mean
Surf	6310480.0	*	466620.0	3599640.0	711040.0	12076570.0 / 1509571.0
0.5m	*	*	666600.0	1299870.0	2821940.0	4788410.0 / 1596137.0
1.0m	*	*	377740.0	1666500.0	*	2044240.0 / 1022120.0
2.0m	*	*	366630.0	377740.0	*	744370.0 / 372185.0
2.5m	*	*	422180.0	999900.0	*	1422080.0 / 711040.0
Total	6310480.0		2299770.0	7943650.0	3532980.0	21075670.0
Mean	6310480.0		459954.0	1588730.0	1766490.0	4215134.0

*No data available

Table XV. Total phytoplankton cell counts at each depth and station for spring sampling. Values indicate cell concentrations as cells/liter.

Depth	Stations 1	2	3	4	5	6
Surf	*	1699830.0	799920.0	477730.0	388850.0	833250.0
0.5m	*	322190.0	377740.0	522170.0	344410.0	622160.0
1.0m	*	533280.0	633270.0	866580.0	411070.0	433290.0
2.0m	*	999900.0	522170.0	333300.0	355520.0	488840.0
2.5m	*	411070.0	688820.0	344410.0	511060.0	811030.0
Total Mean		3966270.0 793254.0	3021920.0 604384.0	2544190.0 508838.0	2010910.0 402182.0	3188570.0 637714.0

Depth	7	8	9	10	11	Total Mean
Surf	699930.0	777700.0	388850.0	6377140.0	1877590.0	14320790.0 1432079.0
0.5m	388850.0	477730.0	755480.0	1577620.0	2921930.0	8310280.0 831028.0
1.0m	433290.0	611050.0	766590.0	*	*	4688420.0 586035.0
2.0m	433290.0	1133220.0	655490.0	*	*	4921730.0 615216.0
2.5m	344410.0	555500.0	588830.0	*	*	4255130.0 531891.0
Total Mean	2299770.0 459954.0	3555200.0 711040.0	3155240.0 631048.0	7954760.0 3977380.0	4799520.0 2399760.0	36496350.0 11125554.0

*No data available