PRIMARY PRODUCTION AND SEASONAL SUCCESSION OF THE PHYTOPLANKTON COMPONENT OF CRESCENT POND, DELTA MARSH, MANITOBA.

BY

Dennis James Brown

Submitted to the

Faculty of Graduate Studies

at the University of Manitoba

in partial fulfilment of the requirements

for the degree of MASTER OF SCIENCE

Department of Botany

September, 1972.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I wish to express my gratitude and appreciation to all those persons who have contributed to the preparation of this thesis, with special thanks to:

Dr. G.G.C. Robinson (Thesis Supervisor), Department of Botany, for initial stimulation of interest in Phycology and for his unfailing guidance, assistance and patience in the preparation of this thesis;

Drs. E.R. Waygood (Department Head- Botany), F.J. Ward (Department of Zoology) and J.M. Walker (Director, University of Manitoba Field Station, Delta Marsh Manitoba), for their aid and encouragement throughout the study;

my student colleagues for their many helpful comments and suggestions;

my wife Linda, for her spiritual aid during thesis research and preparation of this script.

List of Abbreviations used in this thesis:

C	Carbon
cm	Centimeter
cpm	Counts Per Minute
DB	Dark Bottle
DDDMF	Double Distilled and Deionized, Millipore Filtered Water
dpm	Disintegrations Per Minute
DST	Daylight Saving Time
hr	Hour
LB	Light Bottle
m	Meter
uci	Microcurie
ug	Microgram
mg	Milligram
ml	Milliliter
NEN	New England Nuclear Corporation
O_2	Oxygen
rad	Radiation (sunlight)
l	Liter

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Considerable work has been done on the macrophytes of the freshwater marsh ecosystem (Walker 1965, 1962), but the contribution of the phytoplankton component to the entire marsh community is essentially unknown, even though a large portion of the marsh is under water. The selection of methodology for primary production cannot be accomplished without prior examination and comparison of methods. Therefore the oxygen evolution and carbon-14 methods were compared to determine the most suitable method for use in the marsh ecosystem.

As well, primary production was measured to determine variations inherent between the two methods as they pertain to the aquatic marsh ecosystem.

Quantitative and qualitative fluctuations in the phytoplankton community of Crescent Pond were measured to determine the ecological succession as well as relating the plankton crop to seasonal fluctuations in primary production.

Environmental and chemical parameters were measured to determine the extent of influence on the phytoplankton community (Hutchinson 1967).

During the thesis research, it was found that some commercially produced ampoules contained particulate organic matter (Platt and Irwin 1968). An extensive series of quality comparisons were performed on three lot numbers of commercially prepared ampoules and a laboratory produced ampoule, to determine which ampoule was the most suitable for routine measurement of primary productivity.

The project commenced in May 1969 with preliminary investigations into the algal flora and primary productivity of selected areas of Delta

Marsh, with Cadham Bay as the primary sample area. An intensive quantitative and qualitative program was begun on Crescent Pond during May 1970 and continued through October 1970.

LITERATURE REVIEW

Relatively few papers have been published on freshwater algae populations or primary production in mid-western Canada. Bailey (1920, 1925) examined the diatom flora of some lakes in Saskatchewan and Alberta, while Lowe (1924) was concerned with the algae flora of southern Manitoba. Kuehne (1941) examined the phytoplankton of southern and central Saskatchewan. Rawson (1953, 1955, 1956 1960) has examined various aspects of productivity, algal populations and limnology of Saskatchewan lakes. Bozniak and Kennedy (1968) investigated periodicity and ecology of phytoplankton in two Alberta lakes and compared their trophic status.

A.) PHYTOPLANKTON SUCCESSION

Several theories have been proposed by a number of investigators to explain seasonal succession of phytoplankton. Hutchinson (1967), Fogg (1965) and Lund (1965) have analyzed these theories which include antibiosis, accessory organics and vitamins, parasitism, grazing, inorganic nutrient concentrations and environmental variables.

Akehurst (1931) initiated a theory of antibiosis and growth inhibitors as the explanation of seasonal succession of the phytoplankton algae. He postulated that only two algal groups were present, the oil group and the starch group, which invariably alternate under natural conditions. A complex interaction between the oil and starch groups inhibited and/or stimulated other algal species of the same group or from the alternate group. Jorgensen (1956) found an inverse correlation between the presence of planktonic and epiphytic diatoms, as well as the retardation of numbers of planktonic diatoms by green algae. He found certain species produced substances which were inhibitory to some species and stimulatory to others. He theorized that the spring planktonic diatom increase was restricted by silica

concentrations and the onset of epiphytic diatom growth was delayed by an inhibitory substance. With the decline of planktonic diatoms, the epiphytic diatoms multiply rapidly, utilizing the silica absorbed from the substrate which was unavailable to the planktonic species. The growth restriction of the planktonic forms are held in check by an inhibitory substance from the epiphytic diatoms. Hartman (1960) has written an excellent review of the antibiosis-inhibitory theory and listed the algal genera and species known to be involved in this type of reaction. Vance (1965) cited an example of Cyanophyte algae creating a seasonal succession in ponds. An inhibitory effect, with regard to succession, has also been suggested by Bozniak and Kennedy (1968).

Many species have been found to require dissolved organic compounds or vitamins, the production and excretion of which may result in the stimulation of other algal species possessing a requirement for them (Eyster 1968; Fogg 1952, 1958, 1965; Saunders 1957). The release of the above organic compounds may proceed from either living or decomposing cells and are capable of creating algal succession (Krogh 1931; Pearsall 1932; Fogg 1952; Fogg and Westlake 1955; Saunders 1957). Most recent and extensive research on vitamin requirements of algae have been performed in the laboratory utilizing marine diatoms (Carlucci and Bowes 1970a, 1970b).

Fungi from the orders Chytridales, Logenidales and Saprolegniales have taxa capable of parasitizing a variety of algal species (Canter 1949). More recently, Daft, Begg and Stewart (1970) have reviewed the literature and produced evidence for virus epidemics which are pathogenic to certain blue-green algae. It is possible that certain blue-green algae may be limited in number due to viral infections. Canter and Lund (1951) gave evidence for Oscillatoria , as well as several genera of diatoms being

attacked by a fungus. They stated that the parasitism of one algal genus may favour the development of other species as long as other conditions were favourable for growth. Canter and Lund (1953) found parasitic Chytrids of Stephanodiscus and Synedra, both of which are present in Crescent Pond. Ulothrix, Oedogonium, Spirogyra and Cladophora glomerata, allof which were present in Crescent Pond, have been affected by parasitism (Barr and Hickman 1967a, 1967b). The literature suggests the parasitism and viral infection of phytoplankton is widespread, but whether it is solely responsible for the ecological succession of algal species has not been proven conclusively.

Zooplankton grazing upon the phytoplankton component has been postulated as an explanation for the seasonal succession of algae. Anderson (1958) and Anderson et al (1955) found a direct correlation between zooplankton abundance and seasonal succession of the phytoplankton.

Two main theories of zooplankton-phytoplankton relationships have been postulated; a grazing theory by Harvey et al (1935) and a theory of animal exclusion by Hardy (1936). Both theories postulate low zooplankton and high phytoplankton and high zooplankton-low phytoplankton relationships. Harvey's (1935) interpretation of this phenomenon was that it was the result of grazing, wheras Hardy (1936) maintained that dense phytoplankton may exclude zooplankton by the production of unfavourable conditions resulting from excretory products.

Environmental variables, particularly water temperature and its dependency upon incident solar radiation, was postulated as a cause of succession in algal species (Lund 1965; McCombie 1953). Riley (1940) believed an environmental-nutrient control of the phytoplankton created the succession. A correlation between nitrate concentrations and water

temperature was found by Stern (1968). Bellis and McLarty (1967) concluded that Cladophora glomerata was primarily dependent upon meteorological conditions.

A large portion of the phytoplankton literature has dwelled upon the seasonal succession in relation to dissolved nutrient concentrations. Goldman (1965) and Eyster (1968) have reviewed the role of micro-nutrients and their potential effect on the ecology of the algae. A voluminous amount of literature has dwelled on the nitrate and phosphate influence on phytoplankton limitation and succession produced by these two inorganic nutrients. Stewart (1968) reviewed nitrogen-algae relationships and Kuhl (1968) reviewed phosphorus-green algae relations.

Hutchinson (1967) suggested the seasonal succession was inter-dependent on all the above theories and that the seasonal succession of the algae is towards a unispecific community, but rarely acheives it due to one or a combination of factors. As early as Griffiths (1923), a multi-factor approach to phytoplankton succession was postulated, although biological factors were excluded. Many authors have preferred the inter-related approach as a plausible explanation of seasonal succession (Hutchinson 1967; Saunders 1957; Pennak 1946; Chandler and Weeks 1945). Hrbacek (1964), examing Aphanizomenon, utilized an integrated approach while Hammer (1964) proposed an integrated approach in which one factor was consistently predominant in controlling the successional pattern. Hutchinson (1967) lists the following as interrelated factors in the interpretation of the seasonal succession of the algae:

Partially independent physical factors

Temperature

Light

Turbulence

Interdependent biochemical factors

Inorganic nutrients

Accessory organic materials, vitamins

Antibiotics

Biological factors

Parasitism

Predation

Competition

B.) PRIMARY PRODUCTIVITY

Saijo and Ichimura (1962) credit Lohmann (1908) with the first attempt at production estimates, utilizing changes in standing crop. Atkins (1922, 1923, 1924) attempted production measurements by changes in the carbon dioxide concentrations. Gaarder and Gran (1927) initiated the concept of production/by monitoring the oxygen evolved during the photosynthetic process. Steeman-Nielsen (1951, 1952) developed the carbon-14 uptake method for the determination of primary production in the sea.

Goldman (1962) reviewed the history of freshwater productivity relating to carbon-14 , and credits Kuznetov (1955), Nygaard (1955), and Sorokin (1955, 1956) with the first publications. A review of carbon-14 productivity measurement has been produced by Steemann-Nielsen (1964), while Vollenweider (1969) edited a review publication pretaining to all primary production methodology. Strickland (1960), Vinberg (1960) and Saijo and Ichimura (ibid) have produced historical reviews of primary productivity assessment methods.

Ryther and Vaccaro (1954) compared the oxygen evolution and carbon-14 methods of primary production and found the methods comparable only in experiments of 6 to 24 hour duration and moderate phytoplankton population. In 1952, Steemann-Nielsen determined the oxygen method gave a 33% greater yield than the carbon-14 method. Ryther (1956) wrote,

> " uptake of carbon dioxide is equivalent mole for mole, to the production of organic carbon, and hence represents one of the most direct approaches to the measurement of primary productivity."

Steemann-Nielsen (1958) originally maintained that carbon-14 evaluations measure net production and not gross production. This was later modified (Steemann-Nielsen and Hansen 1959) to say that only long term incubations yield a value which estimates net production. Strickland (1960) and Strickland and Parsons (1968) concurred with this latter conclusion that the carbon-14 technique gave values between gross and net production, although it tends toward net primary production.

In 1961 McAllister stated that the carbon-14 method measured net production while the oxygen method measured gross production, and therefore, a comparison of the two methods would produce higher oxygen production at all but optimum light intensity. Where extracellular excretion was insignificant, Bunt (1965) found the carbon-14 method gave a measure of net photosynthesis. Margalef (1965) believed that production was a genuine function of community structure in the biological sense.

Vinberg (1960) found an excellent comparison between the carbon-14 and oxygen methods, although the high sensitivity of the carbon-14 method was an advantage. According to Strickland (1960) the carbon-14 method is 50 to 100 times as sensitive as the oxygen technique. Doty et al (1965) have reviewed the errors inherent in primary productivity studies

conducted other than in situ.

Vinberg (1960) included a review on photosynthesis in ponds. He found sharp fluctuations in photosynthesis were characteristic of low productivity ponds and in general, warm periods yielded an increase in photosynthesis which was only partially dependent upon increased phytoplankton. Vinberg (ibid) found that Vinetskaya's (1956) work on shallow ponds showed oxygen production during the summer was primarily due to macrophytes and not the phytoplankton component.

A portion of the literature pertaining to the primary production method has dealt with the light and dark bottle technique and its anomalies. Ryther (1956) stated that a shortcoming of the bottle method was the assumption that equivalent rates of respiration occur in both the light and dark bottles. Dugdale and Wallace (1960) speculated that a time lag between filling and lowering the bottles, or a photochemical oxidation of humic material, may be responsible for a substantial oxygen loss. Gessner and Pannier (1958) attributed this low dark bottle respiration rate to the lack of locally high oxygen tensions within the light bottles. Strickland (1960) stated that a few small air bubbles in bottles in the carbon-14 method had no adverse effect, but may substantially alter the results of the oxygen method.

Vinberg (1960) concluded that the effect of bottle size on the production of oxygen was almost negligible, and that the results of the bottle method were independent of the initial oxygen concentration. He concluded, through an extensive literature survey, that under ordinary conditions the results of the bottle method corresponded to the pattern of the same process in situ.

Using the data of Zobell and Anderson (1936) as well as Heukelekian and Heller (1940), Vinberg (1960) found a direct relationship between surface area and numbers of bacteria which necessitates the routine acid washings of primary productivity glassware.

The liquid scintillation method for counting carbon-14 uptake resulting from algal photosynthesis was first published by Schindler (1966) although Jitts and Scott (1961) used scintillation counting to determine the absolute activity of carbon-14 stock solutions with a precision of ± 2%. Wolfe and Schelske (1967) determined liquid scintillation to be an accurate and efficient substitute for geiger-mueller counting. Liquid scintillation counting reduces the substantial storage and desiccation loss of carbon-14 (Wallen and Geen 1968; Ward and Nakanishi 1971), which may be as high as 50% within 24 hours. Lind and Campbell (1969) modified the method by desiccating the filters before addition to the fluor. Pugh (1970) investigated internal and external standardization procedures of liquid scintillation and concluded that the channels ratio method provided the most suitable means of determining counting efficiencies. Wang and Willis (1965) have completely outlined the background to the channels ratio method.

Many correction factors have been applied to the carbon-14 method to compensate for inherent errors within the method. Norman and Brown (1952) calculated a 15% differential between carbon-14 and carbon-12 uptake. Steemann-Nielsen (1955, 1958) utilized a 1.05 correction factor for the differential uptake. Ryther (1956), Goldman (1960) and Goldman et al (1969) used a 1.06 correction factor for isotope uptake. More recent studies, Strickland and Parsons (1968), Barnett and Hirota (1967) and Strickland (1960) have used a 1.05 correction factor.

Vinberg (1960) stated that the accuracy of the carbon-14 method was not greater than $\pm$ 10% - 15% and therefore, a correction was necessary to determine the real production value. Wetzel (1964) theorized that the LB - DB count eliminated nonphotosynthetic carbon fixation and absorption. Cassie (1962) discussed the statistical variation within the sampling method, related to phytoplankton population.

The length of bottle incubation has varied greatly, and is dependent upon the area of study and the population levels. Goldman (1960, 1962) utilized a four hour incubation. Vollenweider and Nauwerck (1961) compared different incubation times and found a 3 to 6 hour incubation to be maximal in efficiency. The above authors concluded that after 8 hours results became invalid. Rhode (1958) found that accurate results were attained only after a 24 hour incubation or after a 1/2 day experiment, which was doubled to determine the days production.

According to Kalff (1969) an optimum light intensity for maximum photosynthesis (I_{max}) exists in natural populations of phytoplankton, although a similarity in I_{max} values did not neccessarily indicate a similarity in species composition or abundance. The I_{max} did not alter significantly over a season for equivalent portions of the day, although the species composition and abundance of phytoplankton changed markedly (Kalff 1967). Kalff (1969) determined that organisms had the ability to alter the I_{max} when available light decreases. This supports the theory of Yentsch and Lee (1966), that surface phytoplankton behave as sun plankton during the day and shade plankton during low light intensities.

Steemann-Nielsen (1952) showed a linear increase in photosynthesis with light intensity existed up to a saturationpoint, where further light of higher intensity resulted in photosynthetic inhibition. Ryther (1956)

found an empirical relationship between surface radiation and the relative rate of photosynthesis, while Lorenzen (1963) determined that seasonal changes in day length was the most significant factor modifying potential photosynthesis.

Doty and Oguri (1957) and Newhouse et al (1967) concluded a bimodal daily periodicity in photosynthesis was evident with respect to phytoplankton. Using carbon dioxide differentials, Verduin (1957) found maximal rates between 700 and 1000 hours and reported negative production values between 1000 and 1600 hours. Jackson and McFadden (1954) as well as Odum (1957) found pronounced reductions in afternoon photosynthesis. Doty and Oguri (1957), as well as Ohle (1958, 1961), found a maximum rate production in the morning, while Vinberg (1960) showed a noon peak in the production of oxygen.

The diurnal curve of photosynthesis is an important factor in the extrapolation of primary production to a daily rate. Rhode (1958) has avoided this by 24 hour or 1/2 day incubations. Efford (1967) determined that a 1000 to 1400 hour incubation period gave an estimation of daily production. Vollenweider and Nauwerck (1961) determined that incubations should not exceed 4 to 6 hours. Vollenweider (1965) has calculated that the most suitable method for extrapolation to the day rate of photosynthesis was to divide the light period into 5 equal portions and incubate during the second period or third period (if nutrient depletion during the day was negligible). Incubations during both second and third periods were found to have a $\pm$ 10% error (Vollenweider ibid).

With respect to the carbon-14 method of primary production, Steemann-Nielsen (1952) suggested a 20 minute fuming of filters over concentrated

HCl was necessary. Rhode et al (1958) found acidification made no significant difference on the final results. Goldman (1962, 1963) and Strickland (1960) recommended dilute acid rinses of uniform volumes to remove inorganic carbon-14 retained on filters. McAllister (1961) and Paasche (1961) successfully used 1 to 2 minute fuming periods for the removal of inorganic carbon-14 from filters. Steemann-Nielsen (1955) suggested a 15/minute to 20 acidification, while Wetzel (1965) suggested a 10 minute fuming acidification for desiccated filters.

Goldman and Mason (1962) found that iron was capable of increasing activity on filters, possibly due to co-precipitation involving adsorption, occlusion or post precipitation of the carbon-14 and colloidial iron. Acidification lengths of 15 minutes was not able to remove greater than 6% of the activity. They suggested that similar effects may result from other nutrients, pH shifts, temperature and redox potential changes, and recommended both light and dark bottle prefiltered controls.

Carbon-14 is assimilated via non-photosynthetic uptake and may create a substantial error if both light and dark bottles are not incubated simultaneously for each depth. Steemann-Nielsen (1960) determined that after a four hour incubation, dark fixation was only 1% to 3% of the light bottle uptake and was of minor importance in short-term experiments.

Brown et al (1949) calculated this non-photosynthetic assimilation to be 1% in algal cultures not subject to nutrient depletion. Steemann-Nielsen and Kholy (1956) found that under nitrogen deficient conditions, dark assimilation reached 37% of that in illuminated cultures. This was not found in experiments with phosphate deficient cultures. Goldman (1962) reviewed the possible reasons for dark uptake of carbon-14 and cites

chemosynthesis (Kuznetov 1955), adsorption to other plant material (Kramer 1957) and the Wood-Werkman reaction (Steemann-Nielsen 1960a) as the major causal factors. The Wood-Werkman reaction is responsible for the direct carboxylation of pyruvic acid in the dark.

Steemann-Nielsen (1960a) and Gerletti (1969) have shown that the rate of dark fixation slows down with an increase in the incubation period. Elster (1965) determined that the dark uptake of carbon-14 was attributable to adsorption of the isotope on the filter or to heterotrophic bacterial uptake. Gerletti (ibid) found that an increase in temperature resulted in an increase in dark uptake and that dark uptake had a linear relationship between the amount filtered and radioactivity. Kalff (1969) found that the dark uptake may be as high as 25% of the light bottle uptake when experiments were begun after the onset of strong light inhibition.

Taylor and Collins (1948) found that bacterial growth in bottles was dependent upon the unit area of the wall, and that growth was stimulated by soluble chemical substances in the glass. The use of Pyrex glassware eliminated this error. Ryther and Vaccaro (1955) determined that bacteria in glass bottles were protected from the bactericidal effects of sunlight and therefore were capable of a rapid multiplication with a corresponding reduction in the dissolved oxygen or an increase in the carbon-14 uptake. Therefore an error in both methods was evident. Steemann-Nielsen (1958) showed that in waters with a high bacterial content, dark uptake may be substantial. Pratt and Berkson (1959) using 48 hour incubations, found a substantial bacterial respiration at approximately $20^{o}C$, which tends to alter the measurement of net photosynthesis in light and dark bottle experiments. They determined that bacterial populations in the light bottle

were responsible for accelerated growth of phytoplankton due to rapid nutrient turnover. Vinberg (1960) found no apparent differences in the bacterial population increase between the light and dark bottles with incubations up to 24 hours.

The carbon-14 method of primary production underestimates total photosynthesis to the extent of the loss of carbon-14 by extracellular excretion and filter rupture. It was determined by Fogg (1958), that excretion of photosynthetic products by natural populations was proportional to the increase in depth. A greater excretion was evident in oligotrophic lakes when compared to eutrophic lakes. Lasker and Holmes (1957) and Guillard and Wangersky (1958) found maximum excretion to be taking place in senescent cultures. Losses greater than 50% of assimilated carbon-14 have been found by Nalewajko and Marin (1969). Anderson and Zeutschel (1970) evaluated in situ excretion loss and found agreement with previous investigators (Nalewajko and Marin ibid), that the release was greatest in oligotrophic waters.

Guillard and Wangersky (1958) as well as Fogg and Nalewajko (1964) found that some algal cells may rupture and lose labelled organic carbon to the filtrate under high vacuum pressure.

Allen (1962) stated that Holmes (1961) found a substantial portion of labelled phytoplankton passed through a filter of pore size 0.45 micron, and suggested cell fragmentation was occurring. Fogg and Watt (1965) determined that high concentrations of dissolved organic substances in surface dark bottles increased when photosynthesis was inhibited by high light intensity. Glycollate release from natural phytoplankton should occur with low concentrations of actively growing cells, when subjected to high

light intensity and carbon dioxide deficiency.

Arthur and Rigler (1967) determined the calculated rates of carbon-14 uptake were underestimated unless the values were corrected for carbon-14 loss during filtration. Schindler and Holmgren (1971) used the corrected values in the Experimental Lakes Area of Northwestern Ontario, and determined the error to be 1.2 to 6.1 times the uncorrected filter activities.

DESCRIPTION OF THE SAMPLING AREA

I. Delta Marsh

Delta Marsh is located in the province of Manitoba on the southern extremity of Lake Manitoba (Figure 1) and covers greater than 15,000 hectares. It consists primarily of a series of shallow inter-connected bodies of water, varying greatly in extent. A few isolated 'potholes' exist within the marsh complex, one of which is Crescent Pond the area under study.

Only four surface connections are present between the marsh and Lake Manitoba (Cram Creek, Deep Creek, Delta Channel, Clandeboye Channel). The direction of water flow is dependent upon precipitation and wind direction (Walker 1965).

The marsh overlies Jurassic and earlier age bedrock of the Sundance and Gypsum Springs Formations, both of which are alkaline in nature. The Sundance Formation is composed of glauconitic sandstone, gypsum, shale and limestone while the Gypsum Springs Formation is of gypsum and red shale (Manitoba Department of Mines and Natural Resources 1968).

During the Pleistocene the entire area was invaded by a series of ice sheets which deposited glacial drifts over the bedrock. A glacial lake, Lake Agassiz, developed over the entire area and during its presence lacustrine deposits of clays, silts, sands and gravels were laid down.

The marsh soil, for the most part, is poorly drained consisting of thin muck and peat deposits (Walker 1965). A variable depth of peat is found, but over most of the area it is approximately 30 centimeters.

The temperature range is 70^{o}F, with mean monthly temperatures being below 32^{o}F from November to March and exceeding 50^{o}F from May to September.

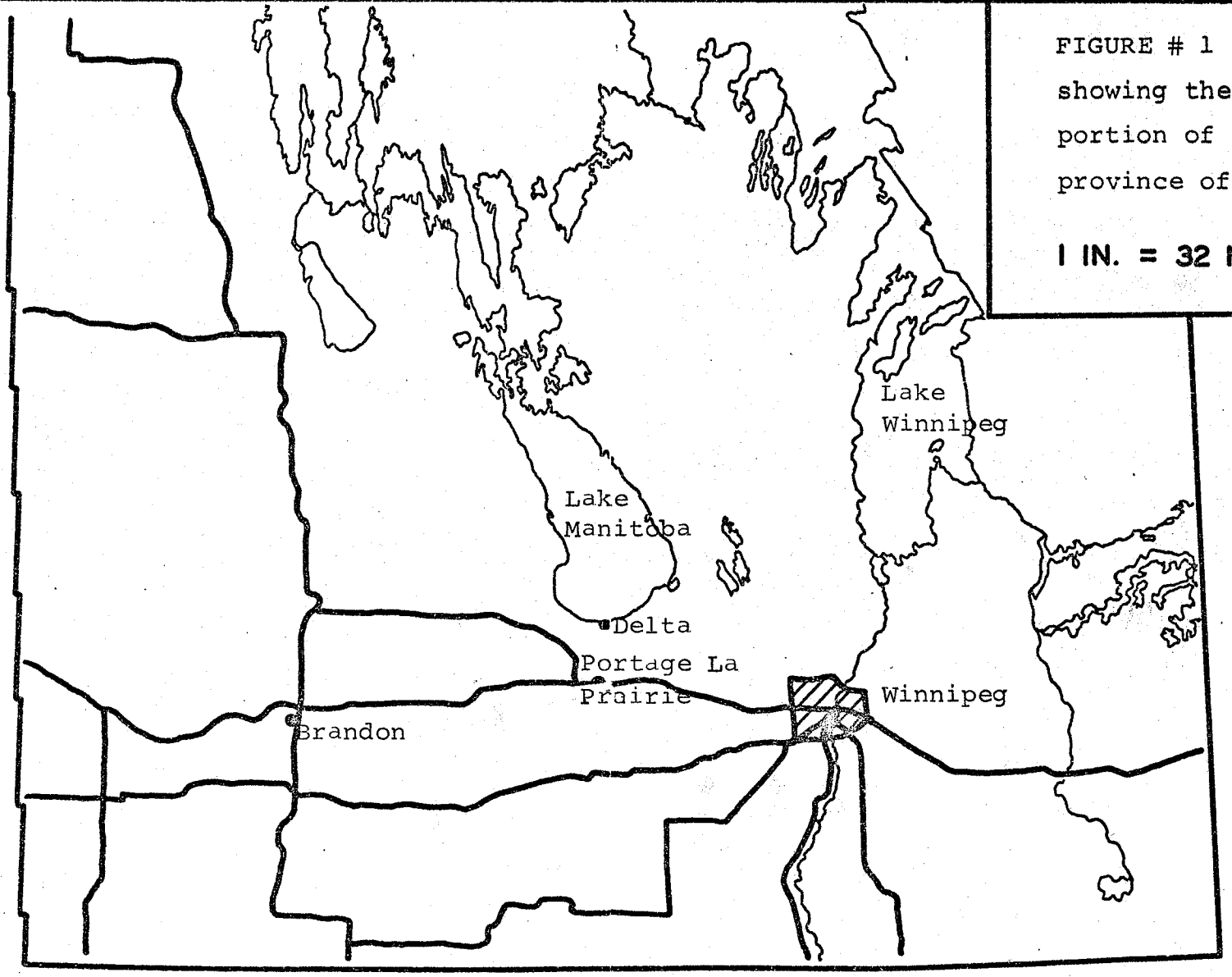


FIGURE # 1 - Map showing the southern portion of the province of Manitoba.

1 IN. = 32 MILES

Mean annual precipitation for the region is 18.5 inches with approximately 80% falling as rain between April and October (Manitoba Department of Mines and Natural Resources 1968).

Evapotranspiration loss for the year has been calculated as 27.2 inches per year (Dillon 1966). A mean moisture deficit of 9.6 inches per annum and 11.4 inches per growing season have also been calculated (Dillon 1966). Replenishment of water to the marsh is primarily by Spring runoff from Winter precipitation.

II. Crescent Pond

Crescent Pond lies in the west Delta Marsh region and is located approximately one mile west of the University of Manitoba Field Station (Figure 2). The pond has no permanent surface connection with any other body of water, although, when substantial amounts of melt water or precipitation occur, an outlet to Forsters Bay is formed (Wright 1971). Meltwater, runoff, precipitation and ground water are all sources for Crescent Pond. During periods of heavy precipitation substantial amounts of water may temporarily build up within the marsh. Hutchinson (1957) indicated that seasonal fluctuation in water levels may be of significance to the biota.

Crescent Pond had a maximum area of 8.6 hectares in the spring of 1970 and dropped to a minimum of 6.7 hectares by late autumn.

TABLE 1.

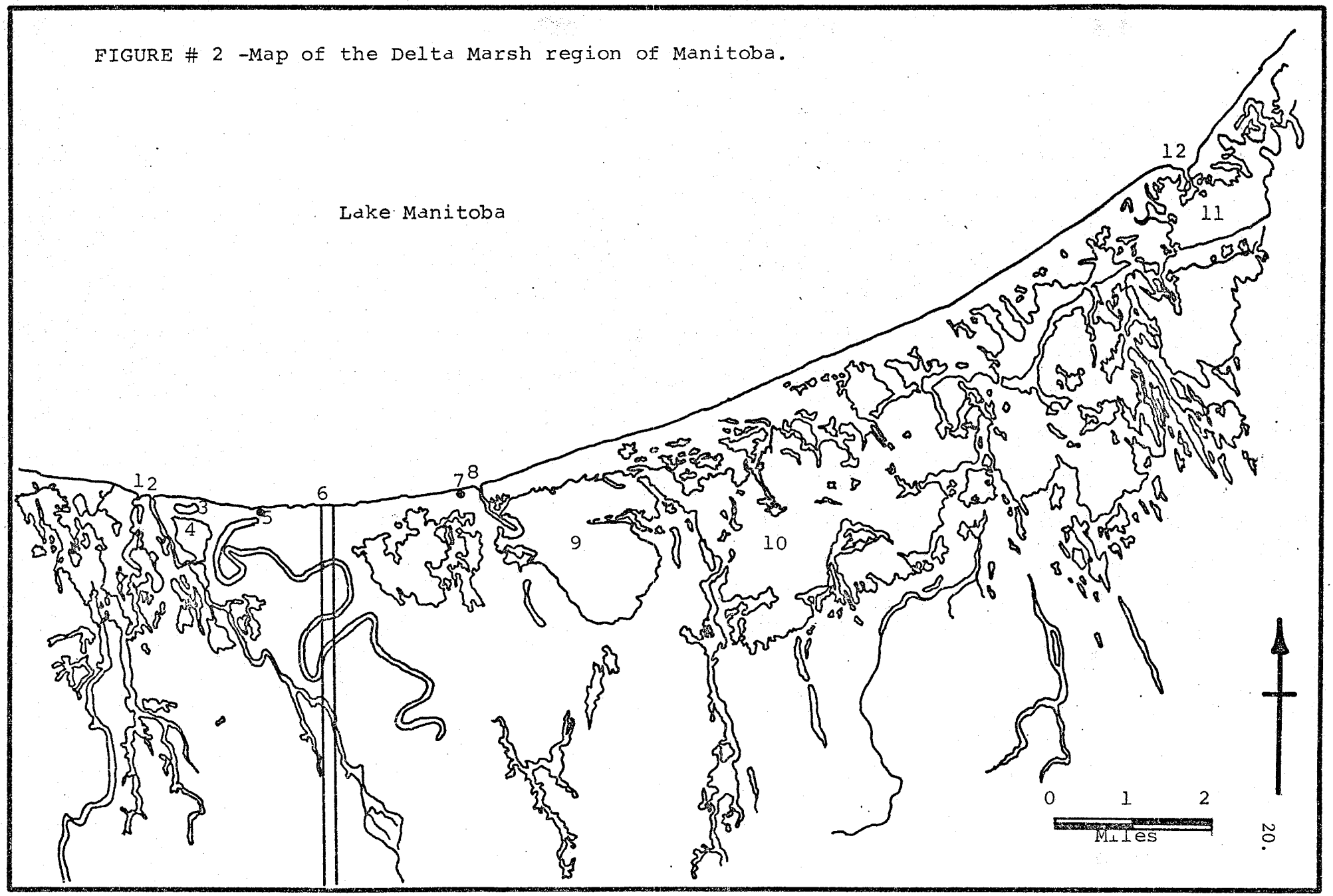
Surface area calculated as of May 1970

Total Surface Area	8.6 hectares
Area 0-50 cm. contour	3.2 hectares
Area 51-100 cm. contour	4.1 hectares
Area greater than 100 cm. contour	1.2 hectares

To Face Figure 2 :

1. Deep Creek
2. Cram Creek
3. Crescent Pond
4. Forsters Bay
5. University of Manitoba Field Station
6. Diversion Ditch
7. Delta Beach
8. Delta Channel
9. Cadham Bay
10. Simpson Bay
11. Clandeboye Bay
12. Clandeboye Channel

FIGURE # 2 -Map of the Delta Marsh region of Manitoba.



The pond had a maximum length of 584 meters and a maximum width of 152 meters. Maximum depth in spring was 123 cm. declining to 94 cm. by late Autumn (Figure 3). Primary causes for the seasonal decline in water level were surface evaporation and transpiration from emergent vegetation. A secondary cause was ground water movement.

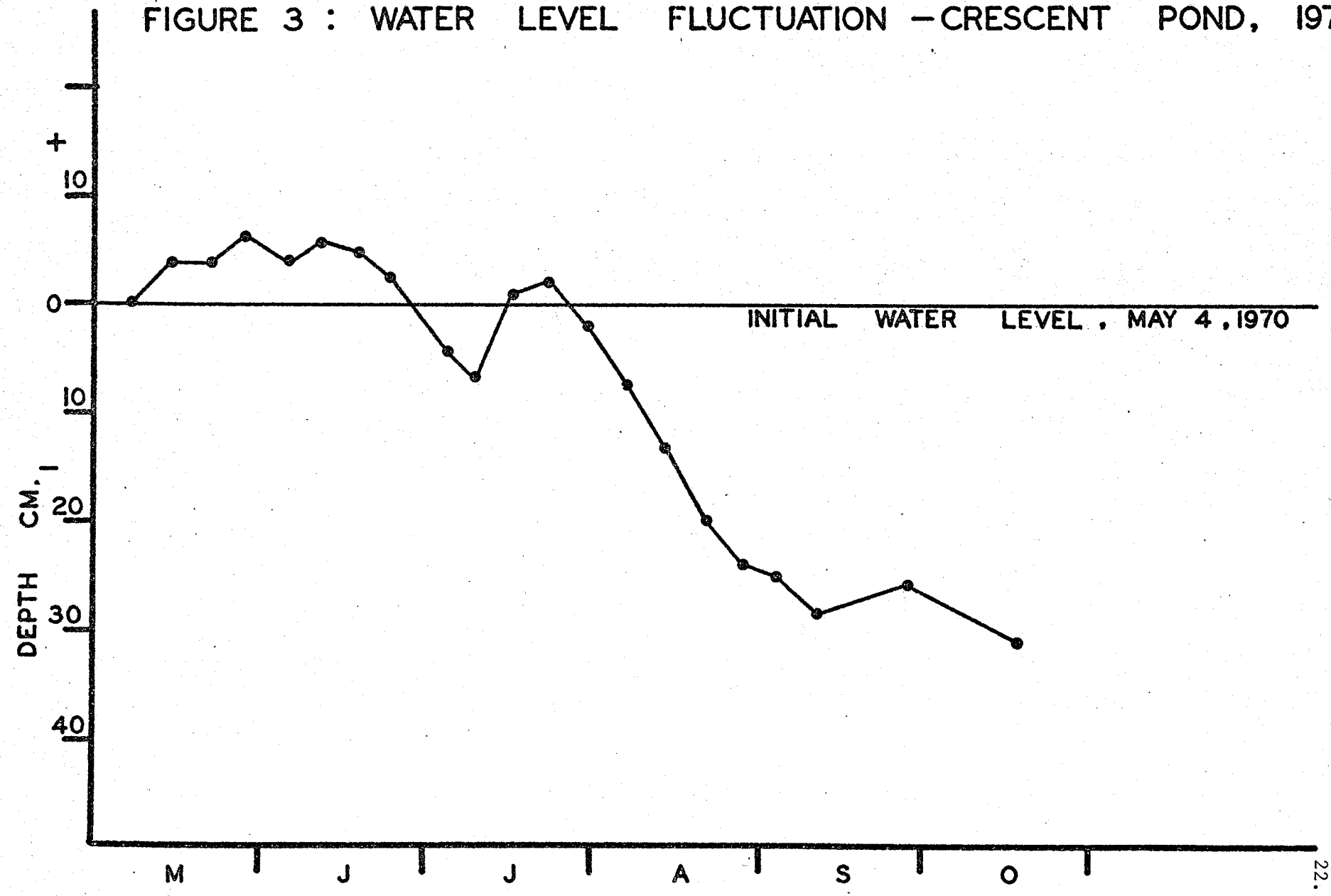
The surrounding vegetation was predominantly Typha latifolia with several areas of Phragmites communis. Typha latifolia grew as an emergent aquatic macrophyte in shallow areas, to a depth of 40 centimeters. The submerged portions of the stems become blanketed in epiphytic algae. Phragmites communis was located on higher ground and formed an interrupted border around the Typha latifolia .

Submerged aquatic vegetation consisted predominantly of Potamogeton pectinatus, Potamogeton friessi, Lemna minor and Myriophyllum spp. The P. pectinatus, P. friessi and Myriophyllum spp. formed an extensive submergent network upon which a variety of unicellular and filamentous epiphytic algae were attached.

During July and August approximately 25% of Crescent Pond was inundated by Cladophora glomerata. This filamentous alga formed large floating mats from the sediment to the surface and were shifted very little by wind action. Irregular shaped thalli of Enteromorpha sp. were located in the shallower areas of the pond. Nostoc verrucosum covered the benthic sediments entirely, at depths greater than 80 centimeters while being only of minor importance at lesser depths and where Cladophora glomerata was absent.

Crescent Pond and its immediate area provided food and shelter for a variety of mammals including: Odocoileus virginianus borealis (White-tailed deer), Procyon lotor (Racoon), Vulpes fulva (Red Fox), Ondatra zibithecus

FIGURE 3 : WATER LEVEL FLUCTUATION – CRESCENT POND, 1970.



(Muskrat), Mephitis mephitis hudsonica (Skunk) and a number of species of small rodents.

A large number of waterfowl utilized the pond as a breeding habitat and a niche for the young to develop. Grazing of young amphibians on epiphytic and filamentous algae may account for a significant portion of their diet (Dickman 1968).

Numerous genera of aquatic invertebrates were present in varying quantities throughout the year. Large numbers of planktonic crustaceans were observed to be present during the entire study period. Aquatic insect larvae were present within the pond, particularly the benthic sediments. Several genera were observed to have ingested a variety of algal species, particularly diatoms and filamentous algae associated with the mud-water interface.

METHODS :

A simple stratified random sampling method was adopted in the choice of three sampling stations which were to be examined on a regular weekly basis. One station was chosen from each of the three depth contours (0-50 centimeters; 51-100 centimeters; greater than 100 centimeters) (Figure 4). A numbered grid was superimposed upon the contour map of Crescent Pond to divide it into sections of 100 square meters. From this map stations were chosen utilizing a table of random numbers (Richmond 1964). When other stations were sampled within the pond, the same method was used to choose the appropriate stations within the given contour.

The three primary stations were marked with polystyrene fishing bouys. These were permanently attached to wooden 1" x 2" posts which were driven firmly into the sediments. All samples were collected within a two meter radius of the station marker.

I. DETERMINATION OF ENVIRONMENTAL PARAMETERS

A. PHYSICAL

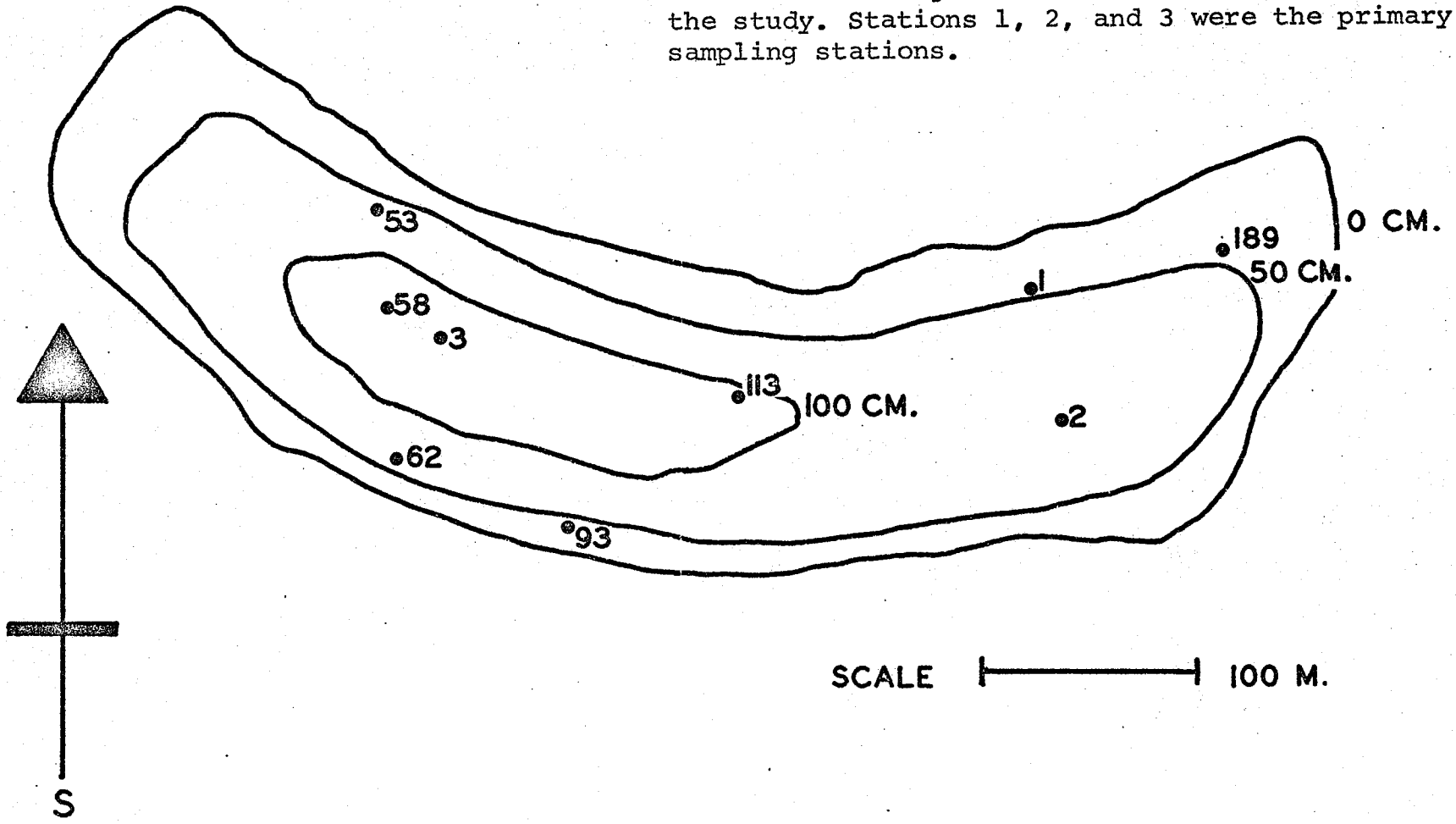
Temperature of surface and bottom waters were recorded twice weekly at each sampling station with a clinical centigrade thermometer. Surface temperatures were measured in situ, and those of bottom waters were measured directly from a van Dorn sampler. All temperatures were taken at 10:00 AM DST $\pm$ 15 minutes, at all stations and on all dates.

Fluctuations in the water level of Crescent Pond were measured weekly by means of a centimeter rule fastened to a post at the eastern end of the pond.

Incident solar radiation was measured with a Belfort Recording Pyrheliometer. Recording charts were replaced weekly and incident radiation

FIGURE 4: CRESCENT POND CONTOUR MAP

The numbers designate stations utilized during the study. Stations 1, 2, and 3 were the primary sampling stations.



plotted on a daily basis for utilization with primary productivity data.

B. CHEMICAL

Carbon dioxide, alkalinity and pH determinations were made weekly. A two liter water sample from each station and each depth was collected in the field and brought to the laboratory where it was screened to remove zooplankton and the filamentous algae. The carbon dioxide, alkalinity and pH measurements were then performed immediately. Water samples were collected at 10:00 AM $\pm$ 15 minutes on each sampling date.

Garrels and Christ (1965) stated the necessity of immediate pH measure in order to reduce errors. All pH determinations were made with a Radiometer PHM 29b meter and a GK 2311c Radiometer electrode.

Carbon dioxide concentrations were determined by the titrimetric method for free carbon dioxide as outlined in the American Public Health Association (1965).

Dissolved oxygen samples were taken twice weekly with a one liter van Dorn sample bottle. Collections were made both at the surface and at 5 centimeters above the sediments. All water samples for dissolved oxygen were collected in duplicate. The water was run gently into a 300 ml pyrex BOD bottle through a length of rubber tubing. Water was allowed to overflow for a short time period to equilibrate any oxygen differential due to agitation during filling. The azide modification of the idiometric method for dissolved oxygen was utilized (American Public Health Association 1965). Manganous sulphate monohydrate was used to prepare the manganese sulphate solution, while sodium hydroxide and sodium iodide were used to prepare the alkali-iodide- azide reagent. The starch solution was prepared from an analytical grade of soluble starch. Sodium thiosulphate stock

solution was preserved by the addition of one gram of sodium hydroxide per liter. Manganous sulphate and alkali-iodide-azide reagents were added in the field. The BOD bottles were agitated and placed in a light tight box until removal at the laboratory where two milliliters of concentrated sulphuric acid was immediately added. All titrations were done with a 10 milliliter pyrex burette graduated in 0.05 ml units.

C. BIOLOGICAL

Plankton Sampling Techniques

Samples were collected weekly at the three stations, at the surface and immediately above the sediments. Two one liter samples were collected with a van Dorn sampler, andplaced in a 2.25 liter polyethelene container. These were transported to the laboratory where the zooplankton were removed by passing the two liters through a polyethelene filter funnel. The zooplankton and filamentous algae which were caught on the 150 micron filter screen were removed by backwashing and preserved in one ounce bottles containing 5 mls of a 37% formalin solution. A 300 ml portion of the filtered sample was placed immediately in a refrigerator for phytoplankton counts.

Phytoplankton Ennumeration

From preliminary observations of the phytoplankton of Delta Marsh, it was evident that the most suitable method of concentration was the centrifugation method as recommended by Ballantine (1953).

Ennumeration was conducted utilizing a Wild Phase Contrast Binocular Microscope with a Model 20D Hammond transformer light source and a magnification of 200x . Forty milliliters of sample was centrifuged in an

IEC Model CL Clinical centrifuge for a minimum of twenty minutes and a maximum of thirty minutes at 6000 rpm's. The supernatant was carefully decanted off and discarded while the remaining residue was resuspended by agitation. From this resuspended residue a one ml subsample was placed in a Sedgewick-Rafter counting cell and the remainder measured for future calculations. Fifty-two fields were examined at random and the phytoplankton ennumerated as genera, or as species where identification was possible at 200x .

The following formula was derived in order to calculate the number of cells per liter:

$$\frac{\frac{2092^{*}}{\text{Number of fields ennumerated}}}{\text{Number mls resuspended residue}} \times 1000 \times \text{Number of cells} \times \frac{\text{Number mls concentrated sample}}{\text{Number mls resuspended residue}}$$

* Represents the total number of fields in a Sedgewick-Rafter counting cell

Filamentous algae were ennumerated from the concentrated and preserved portion from each two liter sample. The filamentous algae portion was made up to 40 mls from which two 1 ml aliquots were removed and the organisms ennumerated. Chlorophycean filaments were large enough to be readily identified and ennumerated at 100x . The Cyanophycean filaments were identifiable at 100x but cell counts were not possible, so a rapid method was developed to calculate the number of cells for each prominant genus of filamentous Cyanophycean encountered.

Using a calibrated ocular at 400x , a number of filaments of Lyngbya bergeii were examined and the number of cells per 150 microns or 50 units on the grid eyepiece were recorded.

EXAMPLE: Cells of Lyngbya bergeii per 150 microns,

45 cells

50 cells

43 cells

47 cells Sum: 482 cells

52 cells Mean: 48.2 cells/ 150 microns

43 cells

53 cells

44 cells

51 cells

54 cells

The confidence interval for the above was calculated to be $\pm$ 6.4%.

In order to facilitate counting under 100x, the length of the filament was recorded in microns for each of two 1 ml aliquots and summed. The number of cells per liter was then calculated according to the following formula:

$$\frac{150}{48.2} \text{ X Sum of lengths (Microns) X } 20^{*}$$

* Represents the sample dilution factor

A similar calibration and ennumeration technique were employed for Oscillatoria spp. and Aphanizomenon flos-aquae .

D. DETERMINATION OF PRIMARY PRODUCTIVITY

Commercially Prepared Carbon-14 Ampoules

Carbon-14 ampoules prepared specifically for primary productivity experiments were purchased from New England Nuclear Corporation. They consisted of $NaHC^{14}O_3$ packaged in autoclaved sealed glass ampoules containing

1.0 mls glass distilled sterile aqueous solution at a pH of 9.5 (NES-086S). The radioactivity of each ampoule was listed as being 5 uci/unit, and the specific activity was 1.0 uci/ug.

All field productivity experiments utilizing carbon-14 were performed with the above ampoules. However, a laboratory comparison of several lot numbers of New England Nuclear ampoules, as well as laboratory produced ampoules made from Amersham-Searle stock solutions was carried out.

New England Nuclear ampoules were comprised of the following lot numbers:

lot number 555-195 (1970)
lot number 555-195 (1967)
lot number 560-031 (1970)

Standardization of Isotope

Commercially prepared 5 uci ampoules were purchased from New England Nuclear and examined to determine their total activity as well as the variation between ampoules. The results showed the total activity to be 9.833×10^6 dpm per ampoule.

Laboratory produced 5 uci ampoules of carbon-14 sodium bicarbonate solution, were inspected to determine the total activity and the variation between ampoules. The results showed the total activity to be 8.656×10^6 dpm per ampoule. The total activity of the laboratory produced ampoules was somewhat less than the NEN 555-195 , but had no significant effect on the experiments where comparisons were undertaken.

Laboratory Preparation of Carbon-14 Ampoules

In preparation of carbon-14 ampoules for a comparison with the commercially prepared New England Nuclear ampoules, several liters of double distilled and deionized water was adjusted to a pH of 9.8 with NaOH.

The water was then filtered twice through a 0.10 micron millipore filter. Two commercially prepared capsules of 14C-$NaHCO_3$ (Amersham-Searle CFA.3, batch #83; strength- 0.5 millicuries) were added to 198 mls of the DDDMF water. This produced a final activity of 5 uci/ml .

One ml aliquots of this radioactive solution were removed with a one ml TOMAC disposable syringe and dispensed into one ml Wheaton NS-51 glass ampoules. The ampoules were immediately sealed with a flame and placed in a tray containing methylene blue solution before autoclaving in order to detect any ampoules which were not properly sealed (Strickland 1960; Strickland and Parsons 1968). Ampoules were autoclaved for twenty minutes at 15 pounds pressure at a temperature of 270°F . Following autoclaving, a check for faultily sealed ampoules was carried out and the blue stained ampoules were discarded. The properly sealed ampoules were stored upright in a styrofoam container until needed.

Primary Productivity Suspension Apparatus

This apparatus was constructed of 1" X 2" wooden posts with holes drilled every 10 cm along its length. Aluminum rods supporting six stainless steel swivel snap hooks were placed through the holes at the required depths. The rods were held in place by half inch rubber washers (Figure 5). This type of apparatus eliminated self shading, allowed for seasonal variation in water depth and selection of a number of depths required for special experiments.

Primary Productivity Bottles

Light bottles for carbon-14 experiments were 125 ml pyrex bottles with ground glass stoppers. The light bottles for the oxygen evolution method were 300 ml BOD bottles (Wheaton Corporation) fitted with ground

To Face Figure 5 :

Figure 5A : A diagram illustrating the arrangement of bottles on the primary productivity suspension apparatus. The large bottles represent BOD bottles for the oxygen evolution method while the smaller represent the carbon-14 bottles.

Figure 5B : A full scale diagram representing the construction of the primary productivity suspension apparatus.

Legend:

1.) 1" X 2" wooden post

2.) 3/8" aluminum rod

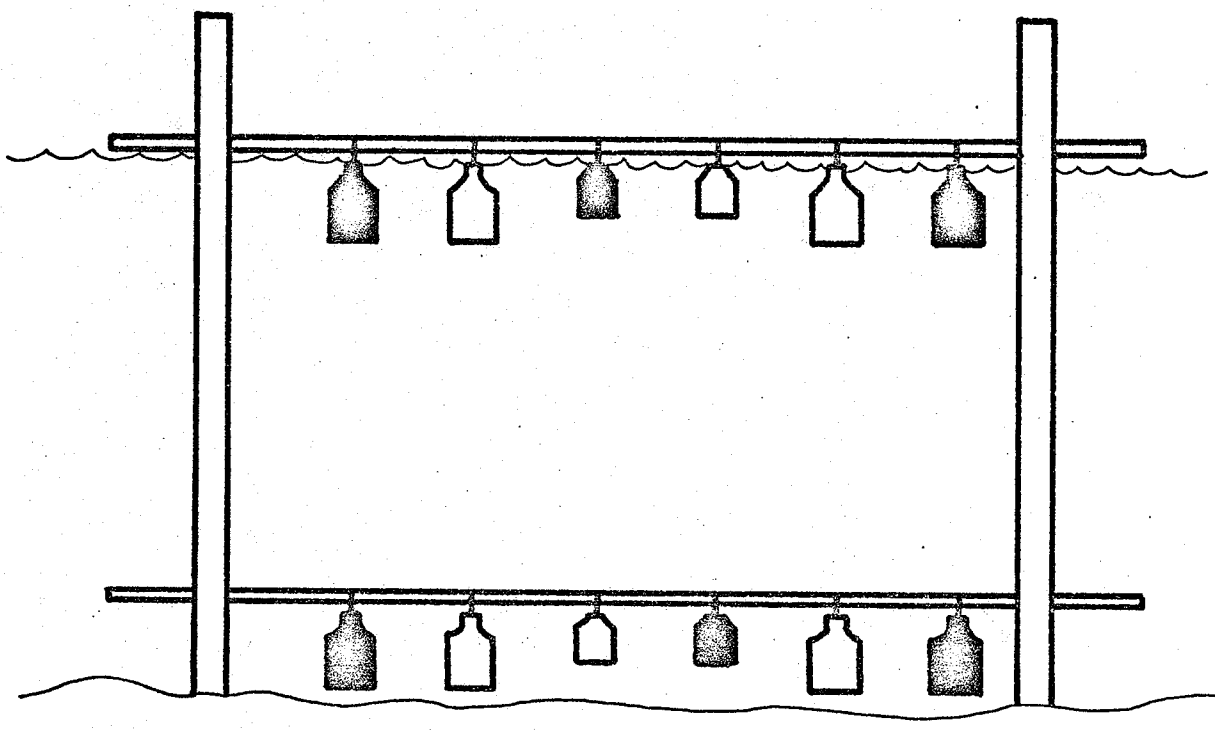
3.) 1/2" rubber washer

4.) 3/8" rubber washer

5.) stainless steel swivel hooks

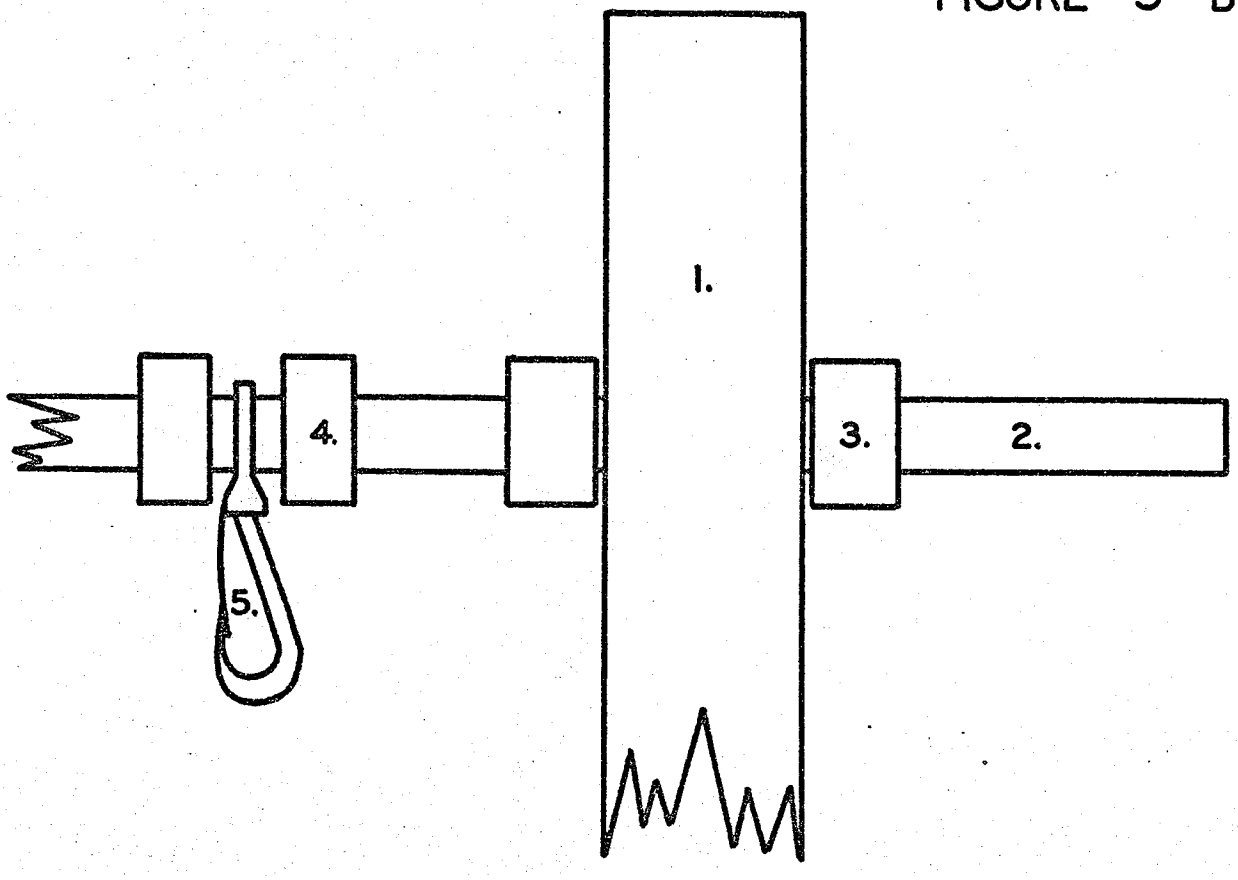
PRIMARY PRODUCTIVITY SUSPENSION APPARATUS

FIGURE 5 A



PRIMARY PRODUCTIVITY SUSPENSION APPARATUS

FIGURE 5 B



glass stoppers. On both types of bottles a plastic coated copper wire was attached to the neck for suspension at the required depths.

Dark bottles for the carbon-14 and oxygen evolution methods were as above with one major modification, two coats of opaque flat black paint and two layers of waterproof (plastic) black tape were applied. As part of routine procedure each darkbottle was rendered light proof by covering the neck with a double layer of aluminum foil.

Carbon-14 Primary Productivity (Field) :

Each water sample was collected using a clear plexiglass one liter van Dorn sampler. Surface samples at all stations were taken by holding the sampler in a horizontal position and operating the closure mechanism manually. At station one, the sample at the bottom was collected using the sampler horizontally with a manual closure. Depth samples at stations two and three were collected vertically using a brass messenger.

One light bottle and one dark bottle were filled from each sampler of water and were immediately placed into a light-tight wooden carrying case. While filling each bottle, the zooplankton were removed by filtering through a removable 150 micron screen imbedded in a polyethelene funnel. The filled bottles were then placed in a light-tight case until all the bottles from that station were ready for the addition of the carbon-14.

Productivity bottles were removed individually from the carrying case and the contents of one ampoule of carbon-14 were added using a 5 ml TOMAC disposable syringe. The ampoule and syringe were both rinsed twice with water from the productivity bottle to ensure transfer of all traces of radioactivity (Strickland and Parsons 1968). The glass stopper was placed in the neck and aluminum foil was placed on the dark bottles. Individual bottles were

returned to the case until all productivity bottles for the station were suitably prepared. They were then fastened to the productivity suspension apparatus and the entire apparatus placed in the water. Bottles were incubated for a four hour period, after which they were returned to the laboratory in a light-tight case. Time delay between removal and return rarely exceeded fifteen minutes.

Upon return to the laboratory the bottles were vigorously shaken and suitable subsamples were removed. Subsample size was 50 ml until August 23, 1970, after which 25 ml was used to facilitate filtration. The subsamples were filtered seperately through a 0.45 micron Metricel filter in a one inch Gelman filter apparatus. When the sample was completely filtered, 15-20 ml of filtered Crescent Pond water was used to rinse the beaker, filter apparatus and filter.

After rinsing, the filter was removed with stainless steel forceps and fumed for 25-30 seconds over fuming hydrochloric acid to remove all extracellular inorganic carbon-14 retained on the filter. The fumed filter was placed in a scintillation vial containing 10 ml of Bray's fluor (Bray 1960).

Wetzel (1965) although using a desiccated filter, suggested a ten minute acidification time to remove inorganic carbon-14; Paasche (1961) and McAllister (1961) have shown an exposure of one to two minutes was adequate, and in this study it was found that 30 seconds was adequate.

Scintillation vials were stored at room temperature until they were taken to the University of Manitoba to be counted in a Picker Nuclear Liquimat 220 scintillation counter. Schindler (1966) stated that for reasons of high counting effeciency, low standard deviation, individually determined sample efficiencies and a reduced filter manipulation, the liquid scintillation method was most desirable where primary productivity was low or variable.

Liquid Scintillation Counting Procedures :

The specific activity of each sample vial was determined by the channels ratio method. With each group of samples counted, three blanks containing a wet filter paper and 10 ml of Bray's fluor were used to determine the background activity. A set of picric acid quenched standards were counted to construct a quench curve with which the counting efficiency of each sample was determined (Ward and Nakanishi 1971; Wang and Willis 1965) .

Only two differences existed between the counting method of Pugh (1970) and the method utilized during this study; Pugh (Ibid) used a manual channel ratio method while a Picker Nuclear Liquimat 220 computes the ratio automatically. As well, a different fluor was utilized in this study.

Calculation of Carbon-14 Primary Productivity :

Dpm were calculated directly by determining the efficiency of counting from a quench curve and extrapolation to 100% . Primary productivity was calculated using the formula given by Strickland and Parsons (1968), except that dpm values rather than cpm were used.

In order to convert this primary productivity data into the standard form of mg carbon fixed/ m^2/ day (Strickland 1960), the following conversions were made:

a.) mg Carbon / $meter^2$/ 4 hour period =

$$\text{mg Carbon/ meter}^3\text{/4 hour period} \times \frac{\text{station depth in cm}}{100}$$

b.) mg Carbon/ $meter^2$/ day =

$$\text{mg Carbon/meter}^2\text{/ 4 hour} \times \frac{\text{total daily radiation}}{\text{radiation during 4 hr incubation}}$$

Oxygen Evolution Primary Productivity (Field) :

Water samples were collected in a manner identical to that described in the carbon-14 methodology. The BOD bottles (light bottle, dark bottle and initial dissolved oxygen bottle) were filled from each of two individual water samples. The bottles were filled by the method previously described for dissolved oxygen determinations. Light and dark bottles were incubated in situ for a period of four hours and then processed for dissolved oxygen. Titrations yielded oxygen values in mg / 1 of dissolved oxygen.

Calculation of Oxygen Evolution Primary Productivity :

The formula of Strickland (1960) was utilized in the calculation of primary productivity by the oxygen evolution method, using a PQ of 1.2 (Strickland ibid; Strickland and Parsons 1968).

In order to convert these data into the standard form of mg carbon fixed/ meter^2/ day (Strickland ibid), the following conversions were made:

a.) mg Carbon / meter^2/ 4 hour period =

$$\text{mg Carbon / meter}^3\text{/ 4 hour period} \times \frac{\text{station depth in cm}}{100}$$

b.) mg Carbon / meter^2 / day =

$$\text{mg Carbon / meter}^2\text{/ 4 hour} \times \frac{\text{total daily radiation}}{\text{radiation during 4 hr incubation}}$$

Ancillary Carbon-14 Experimentation (Field) :

Within each of the three contours (0-50 cm, 51-100 cm, and greater than 100 cm) , three stations were sampled simultaneously to determine the extent of variation which existed within that specific contour and between contours (Figure 1). Two stations were chosen at random from each contour by a random number table (Richmond 1964). The third station was comprised

of the stationary sampling point within that contour. Procedures for sampling, incubation, filtration and calculation were identical to those for other field experiments utilizing carbon-14.

Depth curves of photosynthesis were constructed for Crescent Pond at station 3. The bars on the productivity suspension apparatus were placed either 15 cm or 10 cm apart depending on the experiment. One light and one dark bottle were attached to each of the bars. Procedures for sampling, incubation, filtration and calculation were identical to those for other field experiments utilizing carbon-14.

Diurnal curves of photosynthesis were prepared by running a series of overlapping four hour primary productivity tests. A set of light and dark bottles were added every two hours and removed after four hours. This procedure was repeated for a period of twenty hours. Sampling, incubation, filtration and calculation procedures were identical to those described for previous carbon-14 field experiments.

In order to determine the optimum, minimum and maximum length of incubation time for carbon-14 experiments, a test was carried out at station 2 immediately above the sediment. Six light bottles and six dark bottles were filled in pairs and incubated as previously described. One pair of light and dark bottles were removed every two hours and processed as in other field experiments.

To determine the appropriate volume of incubated water to be filtered, seven light and two dark bottles were incubated at station 2 (60 cm depth) for a period of 4 hours. Aliquots of 5 mls, 10 mls, 15 mls, 20 mls, 25 mls and 30 mls were removed from one light bottle and filtered according to previously described methods. The second light bottle had aliquots of 35 mls, 40 mls and 45 mls removed while the third provided subsamples of 50 mls,

and 60 mls. The 70 mls, 80 mls, 90 mls, and 100 mls subsamples were removed individually from the remaining light bottles. The dark bottle aliquots of 10 mls, 20 mls, 30 mls and 40 mls came from one bottle while the 50 ml sample was removed from the second dark bottle. All samples were processed as in other field experiments.

In order to determine if loss of carbon-14 labelled cellular material was occuring through the Metricel filters, an experiment was designed to refilter the aliquots. Twenty-five ml aliquots from a light and a dark bottle were filtered and the filtrate was collected seperately. The filtrate from the light bottle was filtered three times with a new filter being used for each filtration. Each filter and apparatus was rinsed with 15-20 mls of distilled water. Dark bottle filtrate was refiltered five times. Filters were processed and counted in an identical manner as other carbon-14 field experiments.

The filtrate was also examined for labelled extracellular soluble material by an acidification-lyophyllization technique. Filtrate was collected and acidified to a pH of 3.0 with 0.01N sulphuric acid. The acidified sample was placed in a 200 ml beaker and immediately frozen. Frozen samples were transported to the University of Manitoba where they were lyophyllized to dryness. The lyophyllized samples were resuspended in one ml of deionized distilled water and two 1/2 ml aliquots were removed and placed in seperate scintillation vials for counting.

Specific Activity of Carbon-14 Ampoules

The total radioactivity of carbon-14 ampoules was calculated for use in the primary productivity formulation. Three ampoules were chosen at random from a sample of 100 NEN 555-195 (1970) and five ampoules were

chosen from a sample of 175 laboratory produced ampoules. From each ampoule three one lambda aliquots were removed by micropipette and added individually to scintillation vials, each containing 10 mls of Bray's fluor. These samples were counted in the manner described in the primary productivity counting procedures for carbon-14. The mean DPM was determined for each lot and multiplied by 1000 to provide the total radioactivity of each ampoule.

Ancillary Carbon-14 Experimentation (Laboratory) :

In order to account for high discrepancies between replicates and high apparent rate of dark uptake of carbon-14, a series of experiments were designed in an attempt to determine the problem and rectify the error for further carbon-14 primary productivity studies.

Acid cleaned and DDDMF water rinsed 125 ml bottles were filled with DDDMF water. To each of these bottles, the contents of one ampoule of carbon-14 was added using a 5 ml TOMAC sterile disposable syringe. Ampoules and syringe were rinsed twice with water from the bottle. It was shaken vigourously to distribute the carbon-14 evenly. Two 50 ml aliquots were removed and filtered through a 0.45 micron Metricel GN-6 filter in a Gelman filter apparatus. Filters and apparatus were rinsed with 15-20 mls of DDDMF water and the filters fumed for one minute over concentrated hydrochloric acid and placed in scintillation vials containing 10 mls of Bray's fluor. Scintillation counting procedure was identical to that previously described for carbon-14 field methods.

An experiment was conducted to determine the length of acidification required for the removal of inorganic carbon-14 from filters. All glassware was cleaned in concentrated hydrochloric acid and rinsed several times in DDDMF water before use. Double distilled deionized water was filtered

through a 0.10 micron millipore filter prior to its utilization in the experiments.

125 ml pyrex bottles were filled with DDDMF water and an ampoule of carbon-14 was added with a 5 ml sterile disposable syringe. Both the ampoule and the syringe were rinsed three times to remove all traces of the radioactive carbon remaining after the transfer. The pyrex bottle was shaken vigourously to produce a homogeneous solution and then 25 ml aliquots were removed, filtered and rinsed with 15-20 mls of DDDMF water to remove excess inorganic carbon-14 retained on the filter.

Acidification over concentrated hydrochloric acid was done for varying lengths of time (0, 10, 20, 30, 45, 60, 120 and 180 seconds) to determine the effect. The 0, 10, 20, and 30second aliquots were all taken from one bottle while the 45, 60, 120 and 180 second aliquots were removed from another bottle.

Ancillary Oxygen Evolution Experimentation (Field) :

Within each of the three contours, three stations were sampled simultaneously to determine the extent of variation existing within that contour and between contours. The methodology followed and the random stations utilized were identical to those described for equivalent carbon-14 experimentation and the basic oxygen primary productivity methods.

Ancillary experiments to determine incubation time, diurnal photosynthesis curve and vertical profile of productivity were conducted with the oxygen method. Details of the method have been described previously.

RESULTS AND DISCUSSION :

I. ENVIRONMENTAL PARAMETERS :

A.) PHYSICAL

Throughout the sampling period of this project,Crescent Pond had no permanent thermal stratification due to its shallow depth. A micro-thermal stratification was often established overnight or during calm periods but was only temporary, being destroyed rapidly by wind and thermal convection currents.

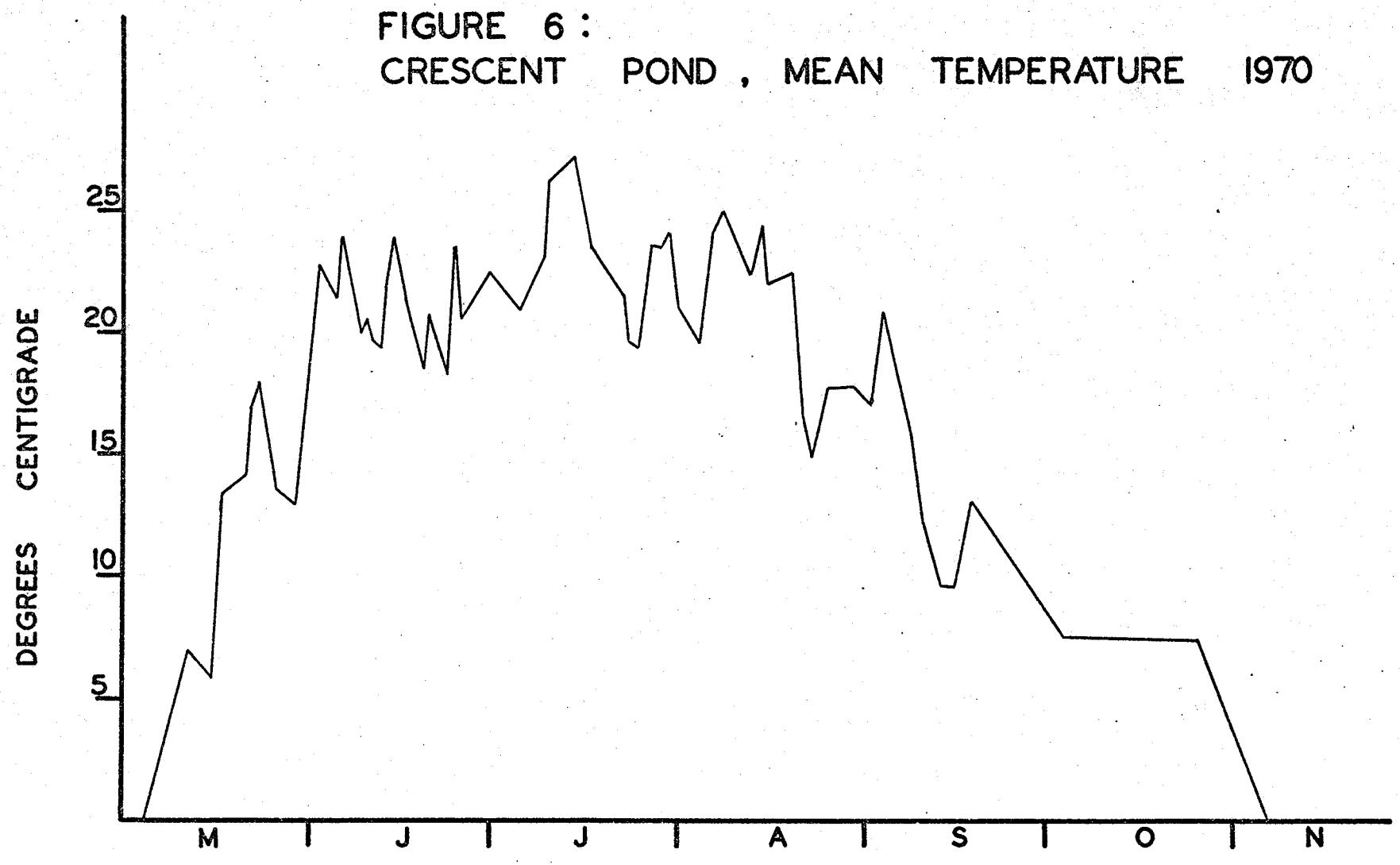
Calculated mean temperature values are presented in Figure 6 to illustrate the overall seasonal trend. The ice cover totally disappeared from Crescent Pond on May 4, 1970 and was followed by a sharp increase in temperature. A gradual temperature decline took place during August through October and continued until the early November freeze occurred.

The daily temperature fluctuations were often pronounced, presumably resulting from the shallow depth and relatively small volume of the pond. The small volume of water was responsible for the rapid loss of latent heat to the surrounding atmosphere, as well as the rapid gain of heat energy from the atmosphere as conditions permitted. According to Hutchinson (1957), Crescent Pond would be a third class lake due to its thermally unstratified condition.

B.) CHEMICAL

The chemical parameters, phenophthalein alkalinity, total alkalinity and carbon dioxide were used to calculate the total carbon content of Crescent Pond which was necessary for the calculation of primary productivity by the carbon-14 uptake method.

FIGURE 6 :
CRESCENT POND , MEAN TEMPERATURE 1970



The pH values for station 1 and station 2 were characterized by similar ranges, in contrast to those from station 3 which were of a consistently higher range. McCombie (1953) suggested that a controling factor of the hydrogen ion concentration may exist with respect to quantity and quality of phytoplankton. At all three stations the pH values were higher at the surface (Table 2). As water levels increased the pH values at all stations decreased for both depths sampled. No vertical changes of pH were evident, as often occurs in deeper bodies of water. The pH in Crescent Pond was regulated by the carbon dioxide-bicarbonate-carbonate buffering system. A relationship between pH and water depth was most noticeable in late May, mid July and late September and was perhaps due to the increased concentration of the buffering ions resulting from evaporation. pH values of greater than 9.0 were encountered, indicating either extreme divergence from equilibrium due to photosynthesis or to the presence of high concentrations of sodium and magnesium carbonates. Between pH 7.0 and 9.0 only the bicarbonate portion of the buffering system is of biological importance (Hutchinson 1957).

Only analytical carbon dioxide was measured, which becomes 0 mg/1 at a pH of 8.30. The total carbon dioxide levels were not measured. The analytical carbon dioxide content fell rapidly with the increase in pH and reached 0 mg/1 by late June at all stations (Table 3). An increase in carbon dioxide was evident on July 15 at all three stations which probably resulted from large amounts of precipitation which lowered the pH and through dilution, enabled analytical carbon dioxide to exist. An increase in pH was responsible for the decline in the concentration of analytical carbon dioxide following that period.

The total alkalinity followed a specific seasonal trend at all stations and depths sampled. Values from the surface water and immediately above the sediments were in close agreement at any given station on each sampling date

TABLE 2 : Selected pH values for Crescent Pond during the summer of 1970 (Stations 1, 2, and 3).

	Station 1		Station 2		Station 3	
Date	Surface	Depth*	Surface	Depth*	Surface	Depth*
June 3	7.90	7.90	7.90	7.90	8.20	8.15
August 31	9.15	9.13	9.18	9.20	9.30	9.30
October 25	8.60	8.60	8.60	8.70	9.00	9.00

* Depth denotes a sample collected immediately above the sediments.

TABLE 3 : Selected analytical carbon dioxide values for Crescent Pond during the summer of 1970 (Stations 1, 2 and 3).

	Station 1		Station 2		Station 3	
Date	Surface	Depth*	Surface	Depth*	Surface	Depth*
June 3	7.0 mg/1	6.5 mg/1	5.0 mg/1	5.0 mg/1	2.0 mg/1	1.0 mg/1
July 1	0	0	0	0	0	0
August 31	0	0	0	0	0	0
October 25	0	0	0	0	0	0

* Depth denotes a sample collected immediately above the sediments.

(Table 4). The seasonal trend in total alkalinity was to an increasing value, from 170 mg/1 to 321 mg/1, with no autumnal increase evident. Several peaks occurred simultaneously at all stations, due possibly to fluctuations in the water level.

The concentration of dissolved oxygen ranged from 1.23 mg/1 to 12.35 mg/1 and was often pronounced among stations and between the two depths sampled. A consistent seasonal trend in the concentration of dissolved oxygen was not evident, although for the most part it was higher at station 3 than at the other two stations.

Dissolved oxygen at the surface of station 1 was generally higher than that immediately above the sediment. This may have resulted from zooplankton respiration associated with large numbers of zooplankton immediately above the sediment, or from the macrophyte vegetation photosynthesizing at a greater rate near the surface. Bacterial action as well as chemical oxidation of organic matter may have contributed to the formation of the oxygen differential.

The higher oxygen concentrations immediately above the sediment at stations 2 and 3 (Table 5), may have resulted from a high rate of photosynthesis by benthic algal forms which predominated at these stations. Hutchinson (1957), attributed low surface dissolved oxygen to the cessation of algal blooms in many cases. However, this was not true in Crescent Pond, for no phytoplankton bloom occurred which corresponded to low oxygen levels.

On June 4 and September 17 oxygen determinations were made at two hour intervals on samples collected from the 60 cm depth at station 2. The resulting diurnal curves (Figure 7) showed a late afternoon recovery of dissolved oxygen. The values for June 4 were considerably lower than those on September 17. In June, rapid oxygen evolution from noon onward was apparent,

TABLE 4 : Selected total alkalinity values for Crescent Pond during the summer of 1970 (Stations 1, 2 and 3).

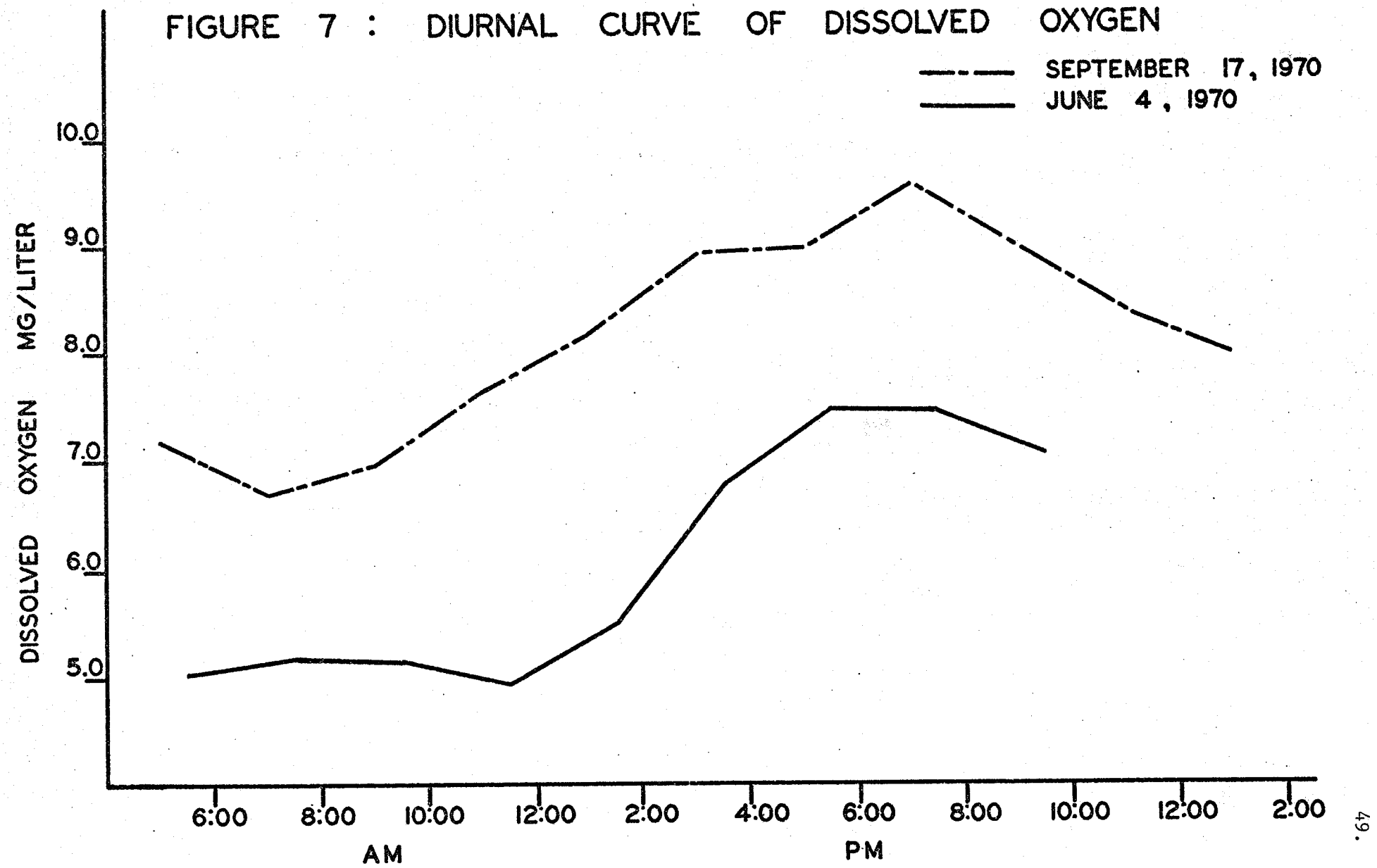
	Station 1		Station 2		Station 3	
Date	Surface	Depth*	Surface	Depth*	Surface	Depth*
June 3	205 mg/1	208 mg/1	261 mg/1	260 mg/1	317 mg/1	317 mg/1
August 31	202	202	258	258	318	321
October 25	213	201	262	262	315	314

* Depth denotes a sample collected immediately above the sediments.

TABLE 5 : Dissolved oxygen concentrations for stations 1, 2 and 3 at the surface and immediately above the sediment. Samples were collected during the summer of 1970.

Date	Station 1		Station 2		Station 3	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
May 21	8.43	8.28	8.38	8.53	8.38	8.43
May 28	8.55	7.80	8.73	9.25	9.20	9.25
June 2	7.45	7.20	8.05	9.25	7.85	7.55
June 11	2.15	1.85	5.00	4.80	4.40	4.40
June 16	1.23	1.58	2.58	4.63	2.53	2.83
June 20	6.00	5.83	6.23	6.90	6.00	5.68
June 23	4.60	2.18	5.08	5.20	5.45	5.53
June 30	2.20	1.78	6.70	6.73	6.95	6.95
July 9	4.55	4.50	5.98	6.25	5.83	6.80
July 14	5.80	5.20	7.50	7.05	4.05	4.95
July 21	8.65	8.60	8.90	8.70	8.55	8.70
July 23	4.23	3.43	3.73	3.55	6.08	6.08
July 28	5.58	3.70	5.65	5.18	7.03	7.43
July 30	3.13	2.98	4.43	4.43	6.83	6.88
Aug. 4	8.05	8.08	8.35	8.35	8.65	8.38
Aug. 6	8.90	5.88	8.38	8.40	8.88	8.78
Aug. 11	3.75	2.23	5.80	3.15	6.78	6.63
Aug. 13	5.10	5.58	5.83	5.83	7.40	7.18
Aug. 18	9.95	7.65	6.33	6.55	8.53	8.83
Aug. 20	5.90	5.00	6.40	6.60	8.23	8.38
Aug. 24	9.93	10.23	5.48	5.65	9.43	9.50
Sept. 1	8.38	6.50	7.78	7.75	9.00	9.15
Sept. 3	5.23	4.53	6.40	6.90	7.93	7.85
Sept. 8	3.95	3.33	2.28	2.40	7.90	7.88
Sept. 10	3.70	3.55	5.35	5.38	8.20	8.00
Sept. 15	5.30	4.10	7.15	7.20	12.30	12.35
Sept. 18	4.15	3.90	4.95	5.15	11.45	11.95
Oct. 4			9.40	9.30	9.53	9.53
Oct. 25			8.85	8.95		

FIGURE 7 : DIURNAL CURVE OF DISSOLVED OXYGEN



while in September a steady state dissolved oxygen recovery was evident.

Diurnal dissolved oxygen fluctuations appear in a variety of habitats (Bartsch 1959), and may be utilized for the measurement of gross primary productivity (Kemmerer and Neuhold 1969; McConnell 1962, 1965; Odum 1957).

The diurnal fluctuations in Crescent Pond may have been associated with zooplankton migration from the surface waters or from photosynthetic inhibition. An association between dissolved oxygen and amount of incident radiation was not evident, although a diurnal curve of photosynthesis indicated that there was oxygen production during the morning. This supported the theory of oxygen utilization by zooplankton. Large temperature fluctuations did not occur at that time and therefore the lower rates of dissolved oxygen production cannot be coupled with fluctuations in the percent saturation of dissolved oxygen resulting from temperature changes. However, from Figure 7, it appeared that the photosynthetic inhibition was not acting on the phytoplankton component, but if present, was inhibiting the aquatic macrophytes and/or benthic algae.

During September, the steady dissolved oxygen production indicated the removal of an environmental inhibition which may have been present earlier. Since cloudless meteorlogical conditions prevailed on both sampling dates, it was assumed that zooplankton respiration was the primary cause of the slow dissolved oxygen recovery on June 4, 1970.

Increases in dissolved oxygen were not attributed to wind or wave action, for the pond was well sheltered and rarely became aggitated.

Algal respiration may account for a significant decline in the dissolved oxygen during dark periods (Hutchinson 1957). This may have occurred to some extent in Crescent Pond, but since the populations of phytoplankton were low, the decrease was probably a result of benthic algae, epiphytic

algae and aquatic macrophytes rather than the phytoplankton.

C.) BIOLOGICAL

From Standard Methods for the Examination of Water, Sewage and Industrial Wastes (American Public Health Association 1965), it was evident that the number of microscope fields counted for phytoplankton was adequate for the concentrations involved. The method used for phytoplankton counting closely followed the recommended procedure outlined by the Biological Methods Panel Committee on Oceanography (1969). Actual tests to determine the validity of this procedure as used on Crescent Pond were not attempted. It is therefore possible that some of the reported variability may be associated with sampling and subsampling errors.

Holmes and Widrig (1956), suggested a minimum of 15 - 30 specimens of any one organism be counted, and in the case of chain forming organisms, the entire sample be counted. In Crescent Pond the counting of 15 - 30 individuals of all encountered specimens would have been an almost impossible task due to the low numbers of phytoplankton present.

The method of centrifugation was similar to that outlined by Ballantine (1953), with the exception that the time was lengthened to ensure maximum recovery of cells. It appeared from the studies of Ballantine (ibid), that length and speed of centrifugation were adequate with regard to the Crescent Pond studies.

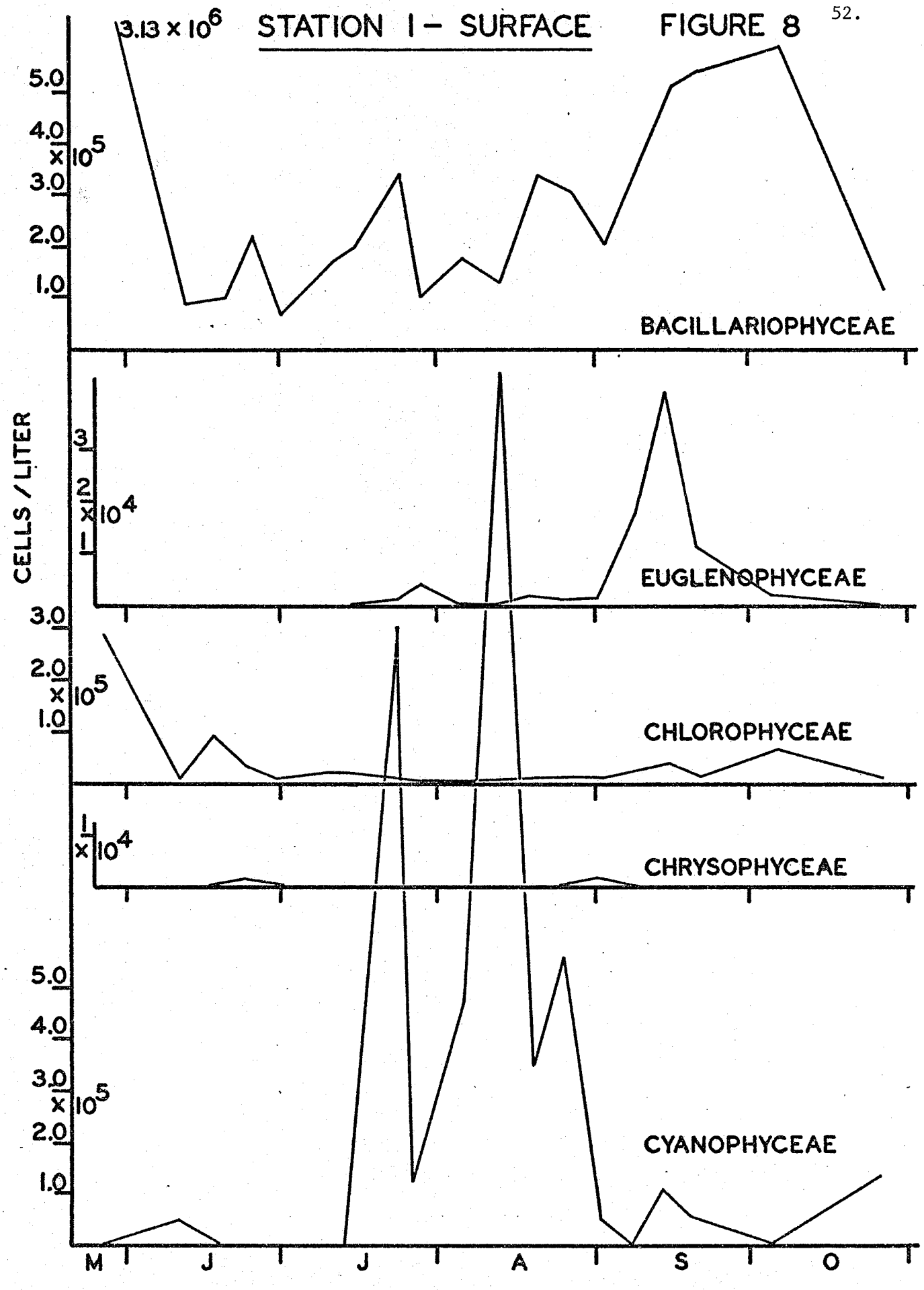
For station 1 (Figures 8 and 9), the total numbers of phytoplankton for the taxa Bacillariophyceae, Cyanophyceae, Euglenophyceae and Chrysophyceae were in agreement between the two depths sampled. The Chlorophyceae was characterized by a greater peak during spring and autumn at the sampling

To Face Figure 8 :

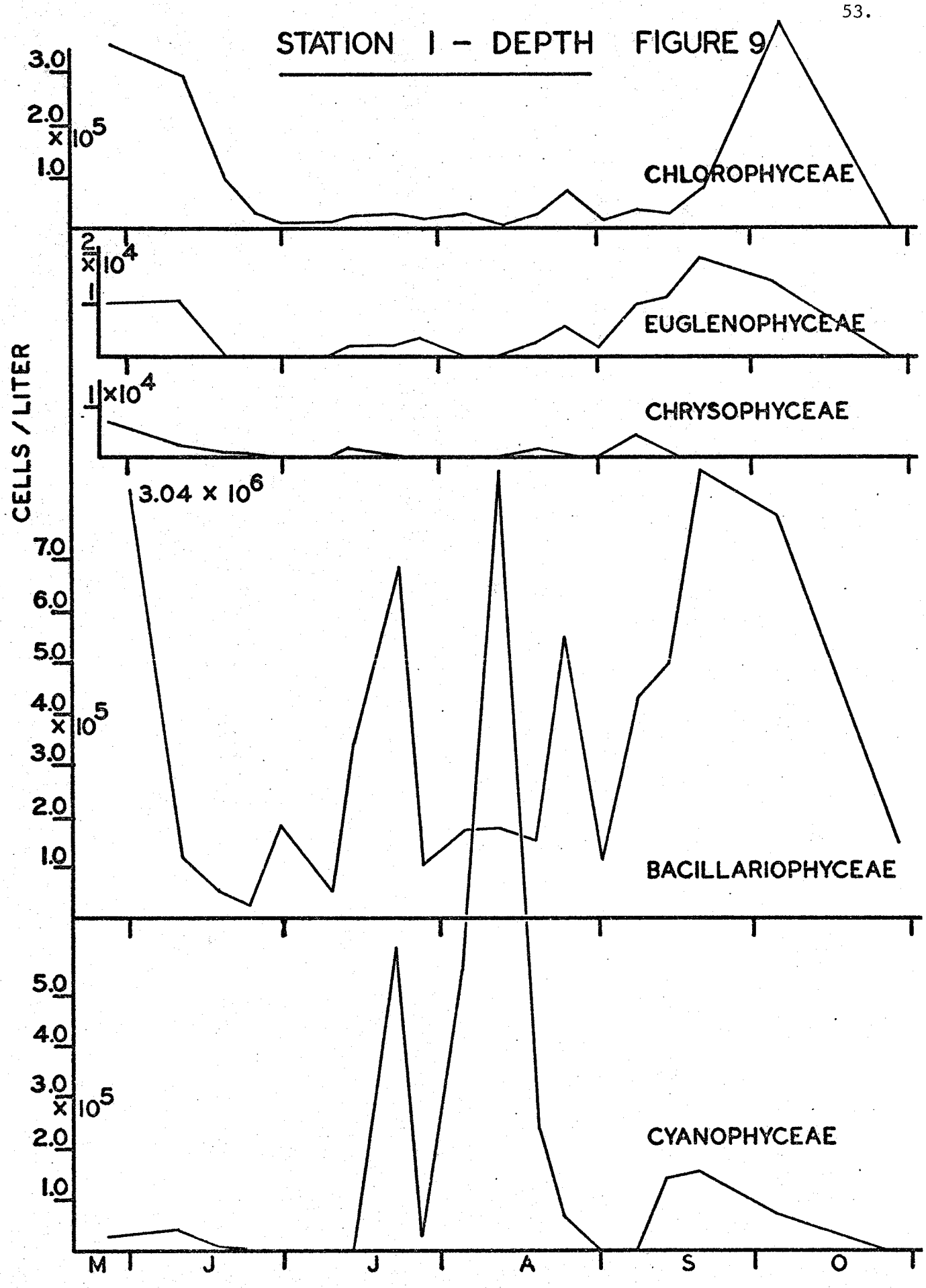
Figure 8: Seasonal changes in phytoplankton numbers (cells / liter), at station 1 - surface during 1970.

To Face Figure 9 :

Figure 9 : Seasonal changes in phytoplankton numbers (cells / liter), at station 1 - immediately above the sediment during 1970.


3.13 x 10^6
STATION 1 – SURFACE
FIGURE 8
5.0
4.0
x 10^5
3.0
2.0
1.0
BACILLARIOPHYCEAE
CELLS / LITER
3
2
1
x 10^4
EUGLENOPHYCEAE
3.0
2.0
1.0
x 10^5
CHLOROPHYCEAE
1
x 10^4
CHRYSOPHYCEAE
5.0
4.0
3.0
x 10^5
2.0
1.0
CYANOPHYCEAE
M
J
J
A
S
O

STATION 1 – DEPTH FIGURE 9



point located immediately above the sediment (Figures 8 and 9).

The spring pulse of Bacillariophyceae was composed predominantly of Navicula spp. and Synedra spp. with a smaller concentration of Stephanodiscus sp. A decline in the diatom population occurred in early June resulting from the decrease in numbers of Navicula spp., Synedra spp., and the total disappearance of Stephanodiscus sp. Small numbers of typically benthic diatoms occurred throughout the season (Navicula, Stauroneis, Synedra), as well as epiphytic diatoms (Cymbella, Gomphonema, Rhoicospenia, Synedra, Acnanthes, Cocconeis). Numerical increases of diatoms during the summer months were attributable to Navicula spp. and Synedra spp. Stephanodiscus sp. reappeared in early August, peaked in early September and declined gradually throughout the autumn. The autumnal peak of Bacillariophyceae was comprised of Navicula spp., Synedra spp. and Stephanodiscus sp.

During summer and autumn the Chlorophyceae at station 1 differed significantly between the surface sample and that collected immediately above the sediment. The spring increase was prolonged at the greater depth by the occurrence of Schroederia setigera, the alga solely responsible for the spring chlorophyte increase. Stichococcus subtilis was well represented on June 10, indicating a possible exotic species which was capable of growth for only a limited period. Samples collected from Lake Manitoba contained S. subtilis in large quantities at this time and may have been transferred to Crescent Pond via waterfowl or insect.

Low numbers of Chlorophyceae existed throughout the summer period. Cladophora glomerata, Oedogonium spp., Rhizoclonium sp. and Spirogyra sp. were present in small numbers during the warm period. Although these were filamentous benthic forms, they appeared to be characterized by a regular appearance within the water column. This may have been due to the activity

of waterfowl. The autumnal pulse consisted primarily of Chaetophora elegans a filamentous cool water alga. This alga was found growing epiphytically upon the aquatic macrophytes and with the decay of the hosts and increase in waterfowl activity, large numbers of cells were carried into the open water. The numerically low and sporadic occurrence of Pediastrum, Scenedesmus, and Ankistrodesmus throughout the year was atypical of the shallow pond environment (Hutchinson 1967; Brown 1969).

Chrysophyceae occurred with irregularity and in low numbers represented by Mallamonas sp. and other small unidentified genera. They were of minor significance in the overall view of algal succession at station 1.

The Cyanophyceae at station 1 commenced with a small spring pulse of Lyngbya bergeii which remained only a short period during the rapid warming of the pond. Two large cyanophyte peaks were evident during the summer period, both represented by Oscillatoria spp. Although not detectable under the magnification utilized for counting, two distinct species of Oscillatoria may have been responsible for the two increases. Aphanizomenon flos-aquae appeared at station 1 at the surface only in late August and early September but was not responsible for any significant increase in numbers. The small increase in blue-green algae in the sample collected above the sediment was due to this species.

Euglenophyceae, although low in numbers during all periods throughout the summer, possessed a small increase during September. Euglena sp. and Phacus sp. were responsible for these increases at both depths sampled.

Dinophyceae, although poorly represented quantitatively after May 26, 1970, were in abundance prior to that period. The dinoflagellate pulse, although not measured quantitatively was examined qualitatively and found to exist of two distinct species of Peridinium.

The numerical count data for station 1 are presented in Appendices 7 and 8 .

Although it was not the intention of this study to determine causitive factors of the phytoplankton succession, some theorizing is possible.

The phytoplankton at station 1 were often comprised of small numbers of typically epiphytic and benthic algae. During the autumnal increase (Figures 8 and 9), many genera which were subdominant in the summer increased, perhaps as a result of the release of epiphytes from decaying filamentous algae and aquatic macrophytes.

Another theory for the autumnal increase in Bacillariophyceae at station 1, is the activity of large numbers of migratory waterfowl, which created a turbulence not generally associated with Crescent Pond. This activity was capable of breaking epiphytes from their hosts as well as stirring the benthic diatoms into the entire water column.

Pearsall (1932) correlated flood conditions with the increase in diatoms and a decline in numbers with oxygen, nitrate, silica and calcium. this theory does not appear to hold true for Crescent Pond, for no association existed between station 1 diatoms and fluctuations in water depth. Patrick (1948) found chemical content plus light and temperature to be initiators of diatom increases, while Ryther (1958) found diatom numbers to be limited by nutrient concentrations. Patrick and Reimer (1966) consider the benthic diatoms to be of greater importance in shallow water areas. Many Navicula spp. belong to the benthic group and may account for the largest proportion of naviculoid diatoms in the pond. Patrick (1948) and Patrick and Reimer (1bid) believe the spring pulse of diatoms to be larger than the autumnal bloom and rarely comprised of the same species in both instances.

Although a spring increase was evident at station 1, the autumnal increase

was perhaps due to benthic and epiphytic forms being carried into the water column. However, if nutrients were available and conditions were unsuitable for the development of benthic and epiphytic forms, an increase in planktonic forms may have occurred. If this had occurred, then the actual autumnal increase in planktonic diatoms was negligible. During both the spring and autumn increases the same species were responsible for the increase and refutes the theory of Patrick and Reimer (1966), as it applies to Crescent Pond.

Hutchinson (1967) states that a reduction in the numbers of Desmidaceae occurs with an increase in pH. The sporadic and numerically rare appearance of the desmid flora in Crescent Pond may be a function of an increase in pH.

The Cyanophyceae at station 1 had a small spring pulse represented by Lyngbya bergeii, which remained only a short period during the rapid warming phase of the water. This species may have been limited by temperature as no other species were at a maximum and competing for nutrients at this time. The two large Cyanophycean increments were evident during the summer period, both resulting from Oscillatoria sp. Since temperature remained relatively constant during this period, a nutrient limiting factor or an antibiosis-stimulating theory may be applied. However, if the Oscillatoria increases represent one species, the most probable explanation was a wind-current factor carrying the algae to other portions of Crescent Pond. This theory is supported by the increase in Oscillatoria at the open water stations during the period of low numbers at station 1. Merismopedia and Spirulina occurred occasionally during the cooler months.

Aphanizomenon flos-aquae developed at an atypical time of the year for that genus. It is generally associated with warm temperatures, high

orthophosphate concentrations (Hammer 1964) and high pH (Prescott 1951). This may indicate the release of an inhibitory substance from the Oscillatoria, capable of retarding growth of the Aphanizomenon flos-aquae. This may also have resulted from sampling errors.

For station 2 (Figures 10 and 11) the Bacillariophyceae lacked the characteristic autumnal peak, although a mid summer peak did occur. The magnitude of the spring pulse at the surface was greater than that immediately above the sediment. Navicula spp. and Stephanodiscus spp. were again primarily responsible for the increase in the numbers of diatoms at both depths. Similar diatom communities existed at both stations 1 and 2, although a higher incidence of chain forming diatoms occured in the sample collected immediately above the sediment at station 2. These consisted of Fragilaria sp. and Tabellaria sp. which characterize the littoral zone of lakes and ponds (Hutchinson 1967). The midsummer increase was due primarily to an increase of Navicula sp. and was present only at station 2. The lack of an autumnal increase in Bacillariophyceae was atypical (Hutchinson ibid; Patrick and Reimer 1966; Patrick 1948).

The number of Chlorophyceae in the surface water at station 2 were greater in the spring and autumn, than in the water immediately above the sediment. Schroederia setigera was responsible for the spring increase in cell numbers of green algae. Scenedesmus, Ankistrodesmus, Pediastrum and Chlamydomonas were all represented during the spring but occurred only sporadically and in low numbers throughout the remainder of the year. Schroederia setigera was the dominant green alga until early July. An increase at the surface during October was due to the presence of Chaetophora elegans. Filamentous algae were present in low numbers coupled with sporadic occurrence (Cladophora, Oedogonium, Rhizoclonium, and Enteromorpha).

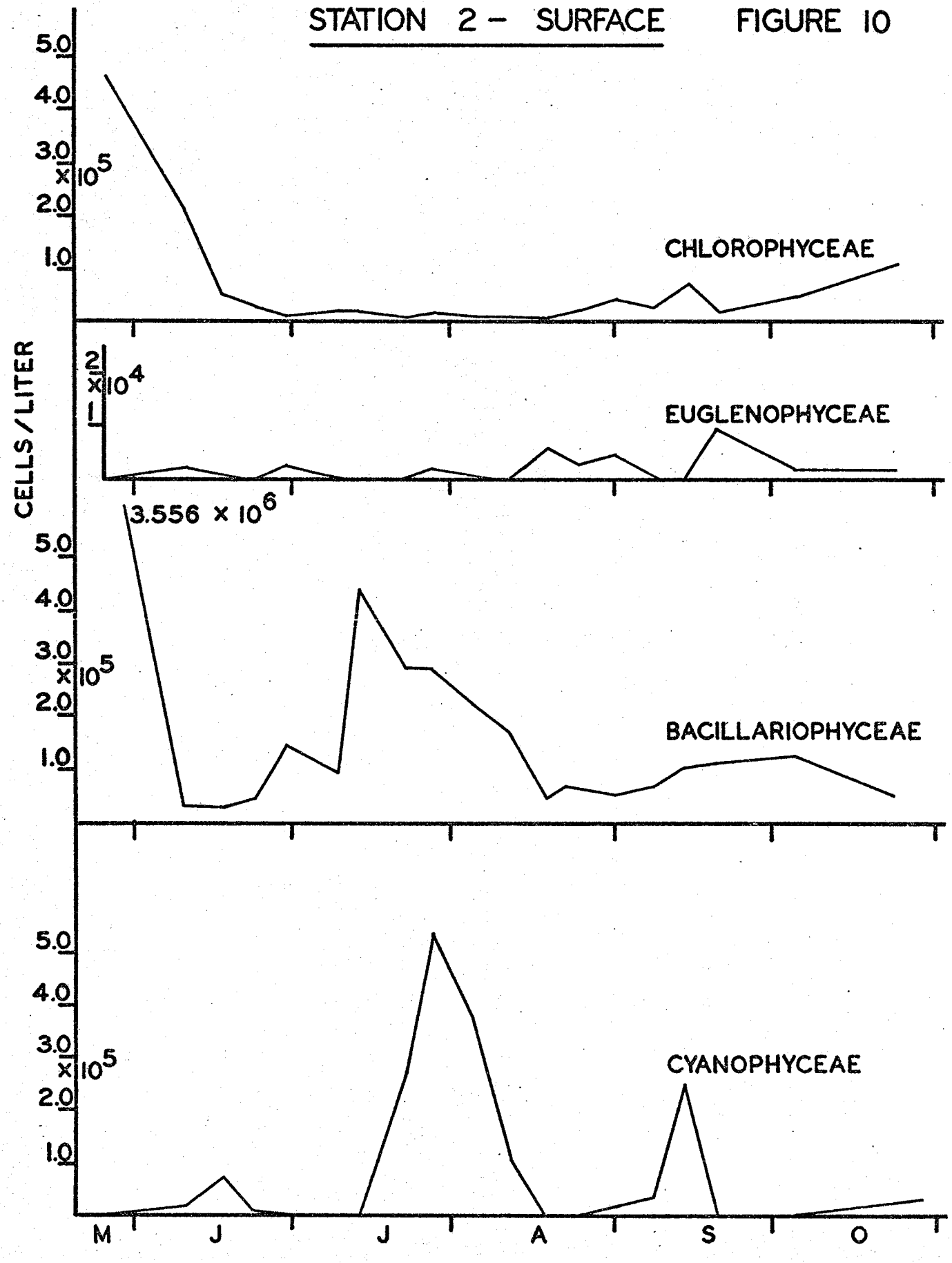
To Face Figure 10 :

Figure 10 : Seasonal changes in phytoplankton numbers (cells / liter), at station 2 - surface during 1970.

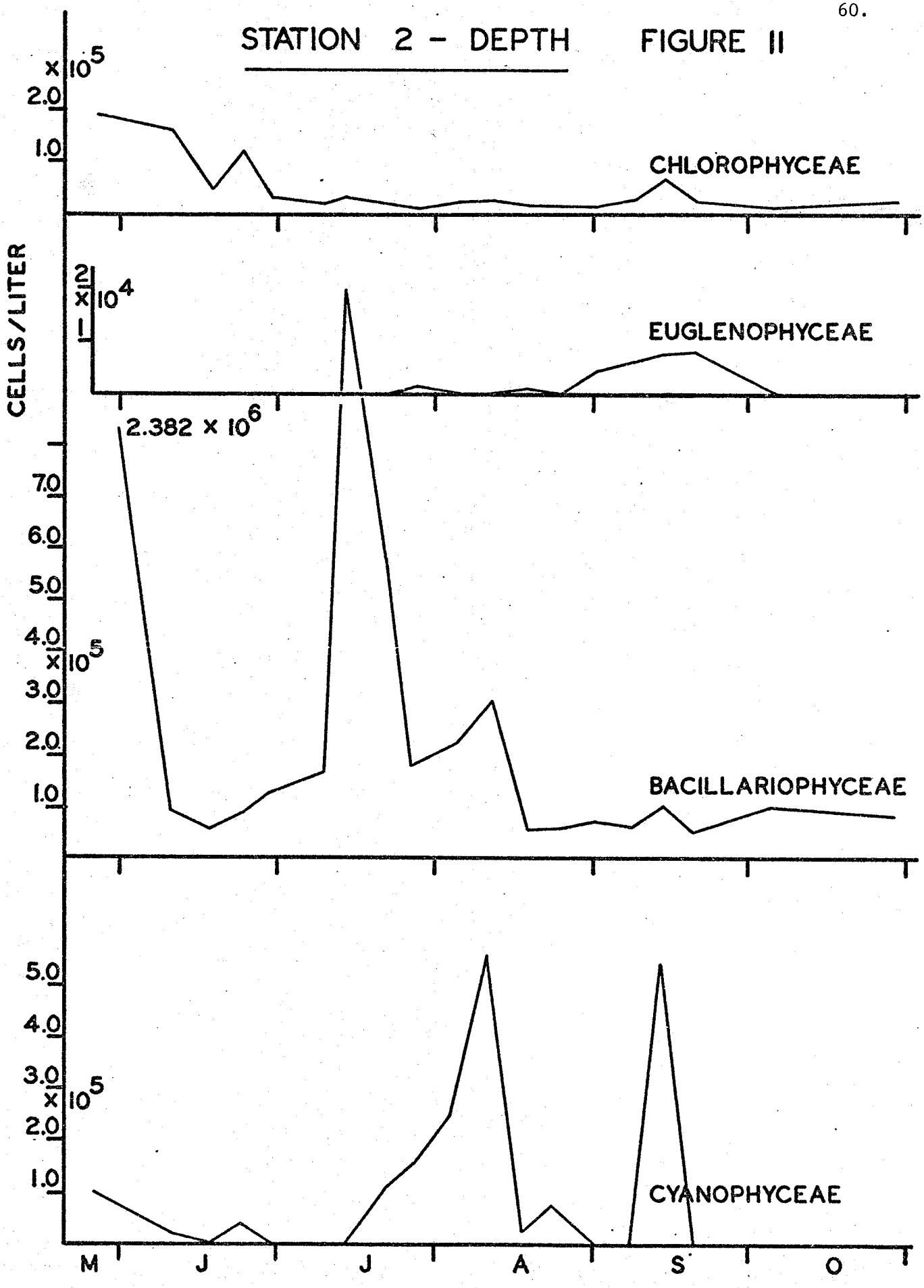
To Face Figure 11 :

Figure 11 : Seasonal changes in phytoplankton numbers (cells / liter), at station 2 - immediately above the sediment during 1970.

STATION 2 – SURFACE FIGURE 10



STATION 2 - DEPTH FIGURE 11



The Cyanophyceae population was less at station 2 than at station 1, although a similar pattern of species succession was evident. Lyngbya bergeii and Oscillatoria sp. were responsible for the peak during June. Oscillatoria sp. was the blue-green alga entirely responsible for the midsummer increase in numbers of Cyanophyceae. The presence of this peak coincided with a decrease in cell numbers of Oscillatoria sp. at station 1. Aphanizomenon flos-aquae was responsible for the mid-September increase.

Numerical data for the algae at station 2 are presented in Appendices 9 and 10.

At station 2 the mid-summer increase of Bacillariophyceae was primarily related to the increase of Navicula spp. This increase may possibly be attributed to the water fluctuations or corresponding pH drop during this period. A water level increase at this time may have been responsible for the rapid numerical increase in Bacillariophyceae by dilution of an inhibitory substance capable of restricting the growth of Navicula spp. Another theory to explain the sudden rise was a pH maximum responsible for growth restriction of Navicula. With the decrease in pH during this period, the pH restriction for growth may have been eliminated and the increase in Navicula resulted. A similar increase occurred at station 1 immediately above the sediment and at both depths of station 3, but were not as pronounced.

The lack of an autumnal increase in Bacillariophyceae was atypical (Hutchinson 1967; Patrick and Reimer 1966; Patrick 1948). The mid-summer increase of Bacillariophyceae indicate that dissolved silicates were probably not the limiting factor for growth. Therefore another theory of diatom regulation must be applied. An inhibitory substance, or a pH greater than the maximum required for growth may possibly have resulted in the low autumnal numbers. Since the largest percentage of diatoms at this time were

epiphytic, the theory of epiphytic diatom retardation on planktonic diatom growth may apply (Jorgenson 1956). The rise in the numbers of typically benthic diatoms during the autumnal period may have resulted from the increased activity of migratory waterfowl.

The Chaetophora elegans increase during October was due to wind and current action carrying the alga to station 2 from the shallower inshore areas, for no suitable substrate for its growth existed at station 2.

Both Lynbya bergeii and Oscillatoria spp. were responsible for the June peak of Cyanophyceae. The reduction in their numbers may be attributable to the warming trend evident in the water during this period. Aphanizomenon flos-aquae was the blue-green alga responsible for the mid-September peak. As at station 1, this was an atypical time for development and may have resulted from an inhibitory substance from the Oscillatoria spp., Cladophora glomerata (which was found in large numbers before the appearance of the A. flos-aquae) or another alga species retarding its development.

The small increase of Euglenophyceae during September may have resulted from the release of organic substances from decaying algae and macrophytes, for the Euglenophytes typically possess a number of organic requirements.

At station 3 (Figures 12 and 13) the spring increase in Bacillariophyceae was less than at the other two stations sampled. Navicula spp. and Synedra spp. were again responsible for the majority of the increase, while Stephanodiscus sp. was present in lesser numbers than encountered at the other stations. The numerous small diatom increases in the surface water of station 3 were attributable to fluctuations in the numbers of Navicula sp. until mid-August. Stephanodiscus sp. accounted for the remainder of the Bacillariophyceae increases. Samples collected immediately above the sediment indicated a June

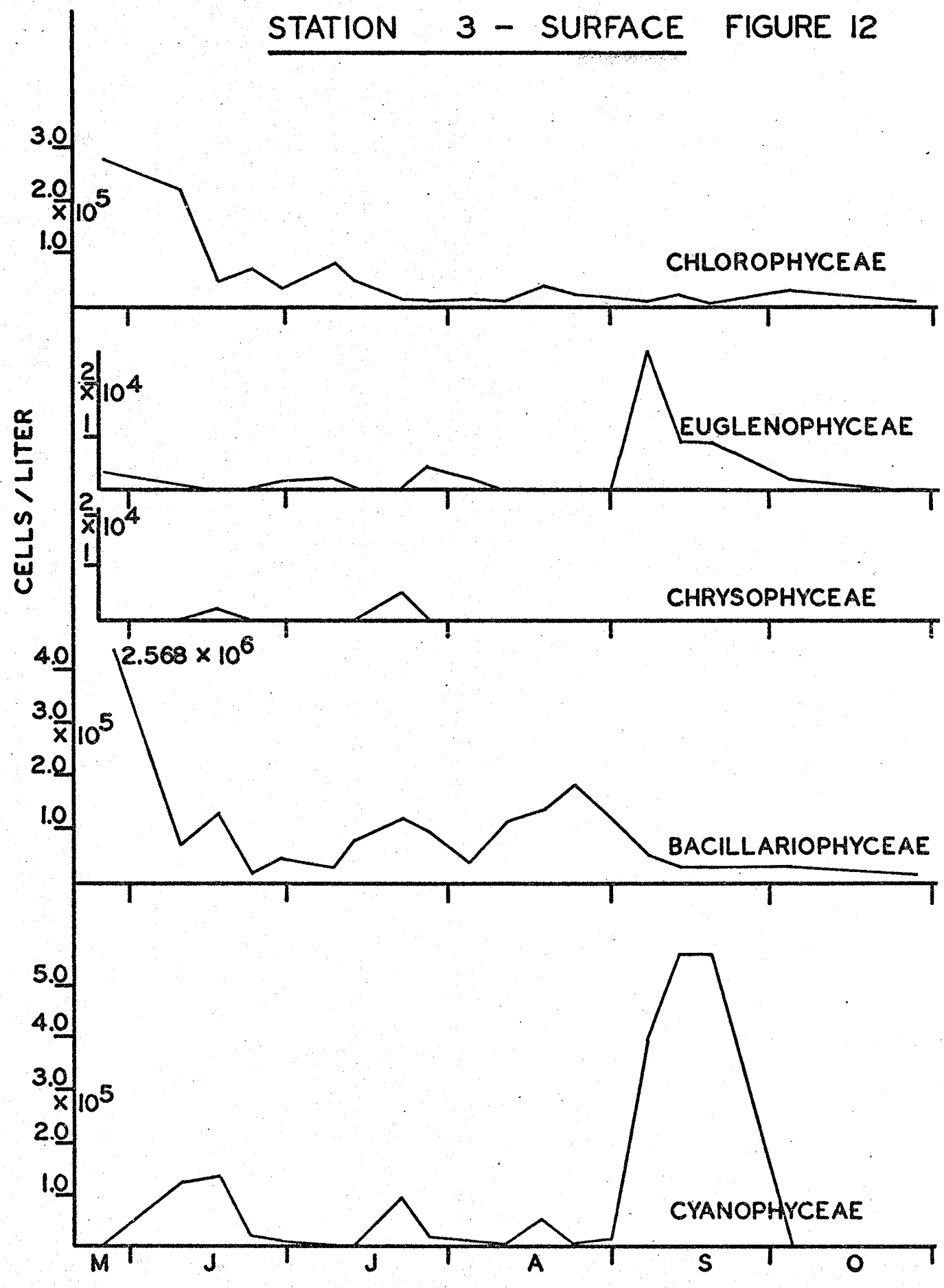
To Face Figure 12 :

Figure 12 : Seasonal changes in phytoplankton numbers (cells / liter), at station 3 - surface during 1970.

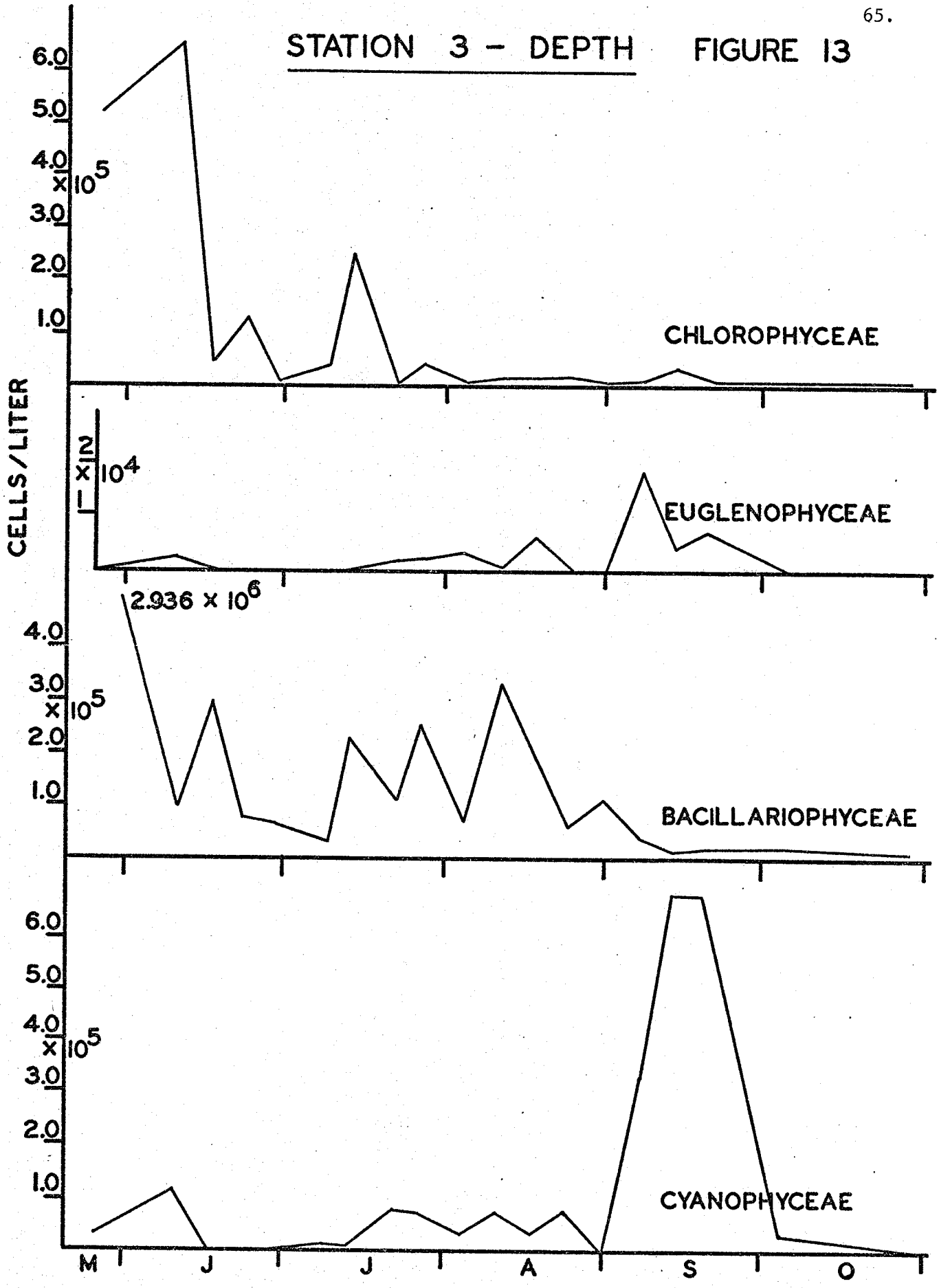
To Face Figure 13 :

Figure 13 ; Seasonal changes in phytoplankton numbers (cells / liter), at station 3 - immediately above the sediment during 1970.

STATION 3 - SURFACE FIGURE 12



STATION 3 - DEPTH FIGURE 13



increase in Fragilaria sp. with two increases in Navicula spp. immediately following. The fluctuations in numbers may have resulted from a micro-scale distribution of the algae (McAlice 1970; Cassie 1962). The autumnal increase was attributable to Stephanodiscus sp. but occurred considerably earlier than the Stephanodiscus sp. increase at the other two stations.

The Chlorophyceae succession possessed a similar pattern to that located at station 2. Schroederia setigera was primarily responsible for the spring increase in association with Stichococcus subtilis, a species not present at station 2. The typical shallow water algae forms of Ankistrodesmus, Chlamydomonas, Pediastrum and Scenedesmus (Hutchinson 1967), were subdominant genera only in the spring and occurred sporadically and in low numbers at other times of the year.

Cyanophyceae at station 3 produced a different successional pattern to that experienced at the other two stations. The initial spring occurrence was comprised of Lyngyba bergeii as well as Oscillatoria spp. Midsummer increases of blue-green algae were not present at this station. Oscillatoria sp. occurred sporadically and in low numbers at both sampling depths throughout the warm summer period. An increase in Aphanizomenon flos-aquae took place during the same period but at a larger magnitude than occurred at the other stations.

The Chrysophyceae at station 3 were of limited ecological significance, occurring sporadically and in low numbers at the surface only.

Euglenophyceae were characterized by an early autumn increase at both sampling depths, with an occassional appearance throughout the remainder of the sampling season.

Numerical data for the algae at station 3 are presented in Appendices 11 and 12.

At station 3 the high numbers of planktonic Bacillariophyceae may have resulted from the lack of epiphytic diatoms at this station, if Jorgenson's theory was adopted. The absence of an autumnal increase in diatoms may be theorized in the same manner as station 2. Low autumnal numbers of epiphytic genera resulted from the lack of filamentous algae and aquatic macrophytes.

Mid-summer blooms of Cyanophyceae were non-existent at station 3, with Oscillatoria spp.occurring sporadically and in low numbers. A possible explanation for the lack of a mid-summer increase was the presence of an inhibitory substance secreted by the large numbers of Nostoc verrucosum, a benthic algal species, which may have effectively controlled the numbers of Oscillatoria. The species of Oscillatoria encountered, O. tenuis, has been described by Prescott (1951) as a common tychoplankton algae. Since the ecological niche which a tychoplankton organism (Prescott 1956), could thrive in was not present at station 3, the growth of the organism was presumably excluded. The O. tenuis found at this station may have been the result of wind action carrying the alga from the littoral zone of the pond. The increase of Aphanizomenon flos-aquae which occurred during the same period was of a larger magnitude than that recorded for the other stations. Water temperature and solar radiation were similar at all stations and therefore cannot be considered a factor in the differential growth rates of the A. flos-aquae Hammer (1964) found that A. flos-aquae occassionally persisted past its optimum temperature of 23.5 - 26.5^{o}C and into late autumn when temperatures were low. However, Hammer (ibid) failed to postulate a reason for the shift to cooler temperatures. The growth of A. flos-aquae in other portions of the marsh occurred during the warmer summer months, with a rapid reduction in numbers during early autumn (Brown 1969). According to Hammer (ibid), a high phosphate content is necessary for its growth. This may have been

introduced into Crescent Pond from waterfowl fecal material or the decomposition of algae and macrophytes.

The Euglenophyceae had an early autumn peak, with an occasional occurrence throughout the summer of the sampling period. Their occurrence at station 3 may indicate a presence of required organic compounds being released to the water and carried to the area by wind action.

D.) PRIMARY PRODUCTION

1.) CARBON-14 EXPERIMENTATION

Field Primary Productivity

Seasonal variations in the rate of primary production, as measured by the carbon-14 uptake method for station 1, are represented by Figure 14. The integrated value representing the total milligrams of carbon fixed / meter^2/ day have been plotted against time. Three distinct increases in production were apparent as well as two negative values (ie. more dark uptake than light uptake). A comparison between the primary productivity and the phytoplankton succession at station 1, appeared to be a function of an increase in Bacillariophyceae. The first diatom peak in the spring was not sampled for primary productivity, but the remaining three increases in diatom numbers were represented by an increase in the amount of primary production. Increases in the numbers of Cyanophyceae produced no apparent change in the rate of productivity.

Primary productivity at station 2 (Figure 15), was characterized by three peaks in production. During the season, five negative production values were calculated and were apparently responsible for the erratic nature of production at this station. Primary production at station 2, possessed no distinct association to the seasonal succession of phytoplankton. When the

FIGURE 14 : SEASONAL PATTERN OF PRIMARY PRODUCTION

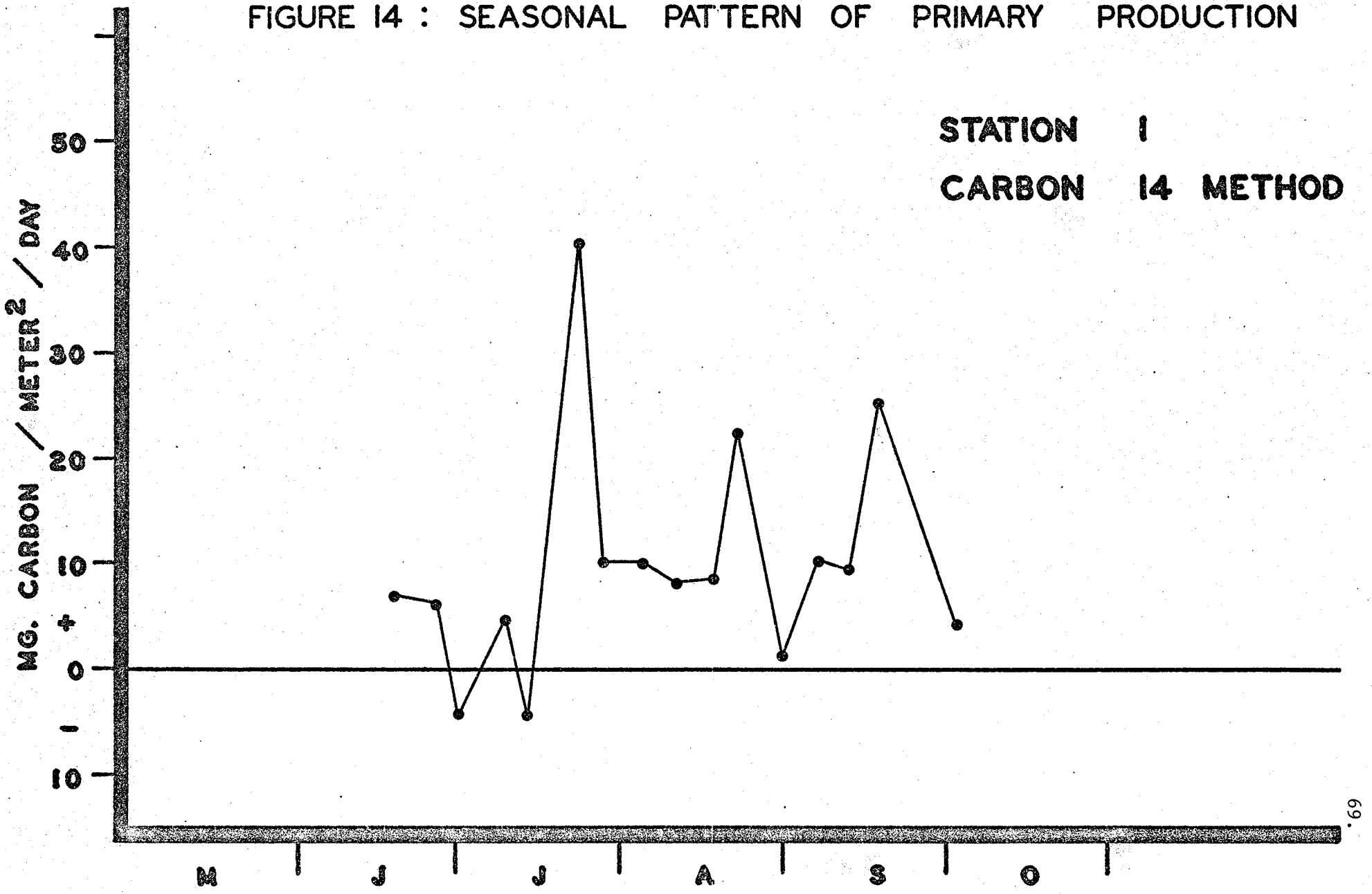
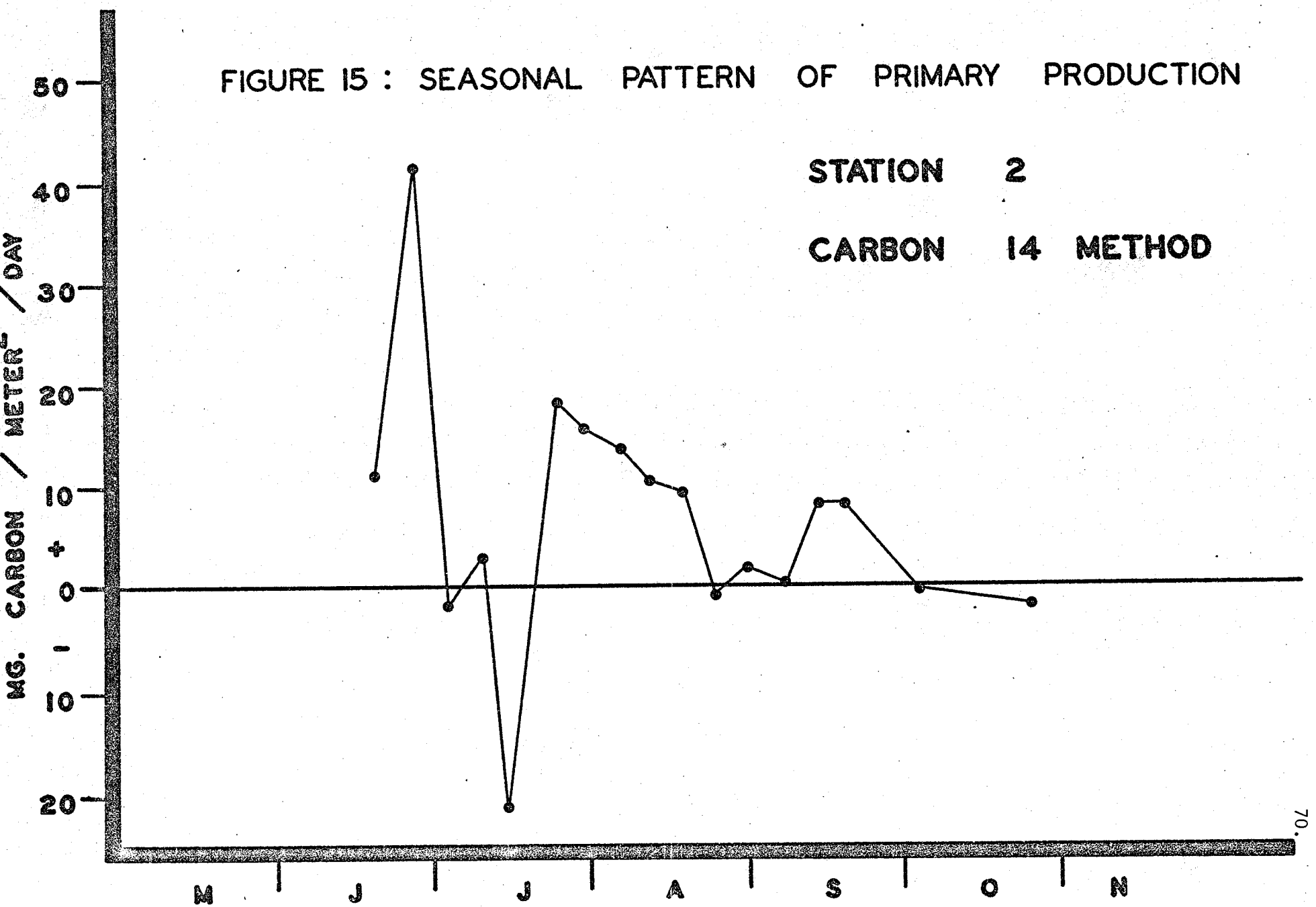


FIGURE 15 : SEASONAL PATTERN OF PRIMARY PRODUCTION



Bacillariophyceae reached a summer maximum in mid-July, the rate of primary production was a negative value. A high productivity value late in June was not attributable to any algal successional pattern. The two productivity increases in late July and September appeared to be a function of the blue-green algae increments. However, this function was not a real phenomenon for the blue-green algae recorded for these periods were ennumerated form the screened portion of the sample.

Station 3, which recorded the smallest populations of phytoplankton at any given time, was characterized by the largest productivity values for Crescent Pond (Figure 16). Three large peaks in productivity were evident as well as two negative values. Station 3 possessed the smallest algal populations and the highest productivity values for Crescent Pond, although none of the peaks corresponded to any significant increase in the algal population.

The primary productivity values for all stations on Crescent Pond showed little resemblance to each other or to any specific seasonal trend. Station 1, had the lowest productivity values but the highest algae populations. Station 2 had an intermediate algae population with an intermediate productivity value while station 3 had high values with a low phytoplankton population. In order to evaluate the carbon-14 method and to determine the cause of the high dark uptake values, as well as the generally erratic results, a series of field and laboratory methods were carried out.

Ancillary Carbon-14 Experimentation

The minimum, maximum and optimum lengths of incubation were determined and applied to the routine carbon-14 primary production methods (Figure 17; Table 6). Although these data were also quite erratic, with excessively high

TABLE 6: Determination of the minimum, optimum and maximum lengths of incubation for Crescent Pond primary productivity experiments.

Incubation Period	Bottle	cpm - Background	Efficiency	dpm
2 Hours	Light	191.4	76.0%	251.8
	Dark	2005.0	74.0	2709.5
4 Hours	Light	2312.9	75.5	3603.4
	Dark	1607.7	74.0	2172.6
6 Hours	Light	2040.6	75.0	2720.8
	Dark	1593.6	75.5	2110.8
8 Hours	Light	1113.1	76.0	1464.6
	Dark	1780.8	76.5	2374.4
10 Hours	Light	2745.2	75.5	3636.0
	Dark	2015.1	75.0	2686.6
12 Hours	Light	2377.2	74.0	3198.9
	Dark	1817.0	73.0	2489.0

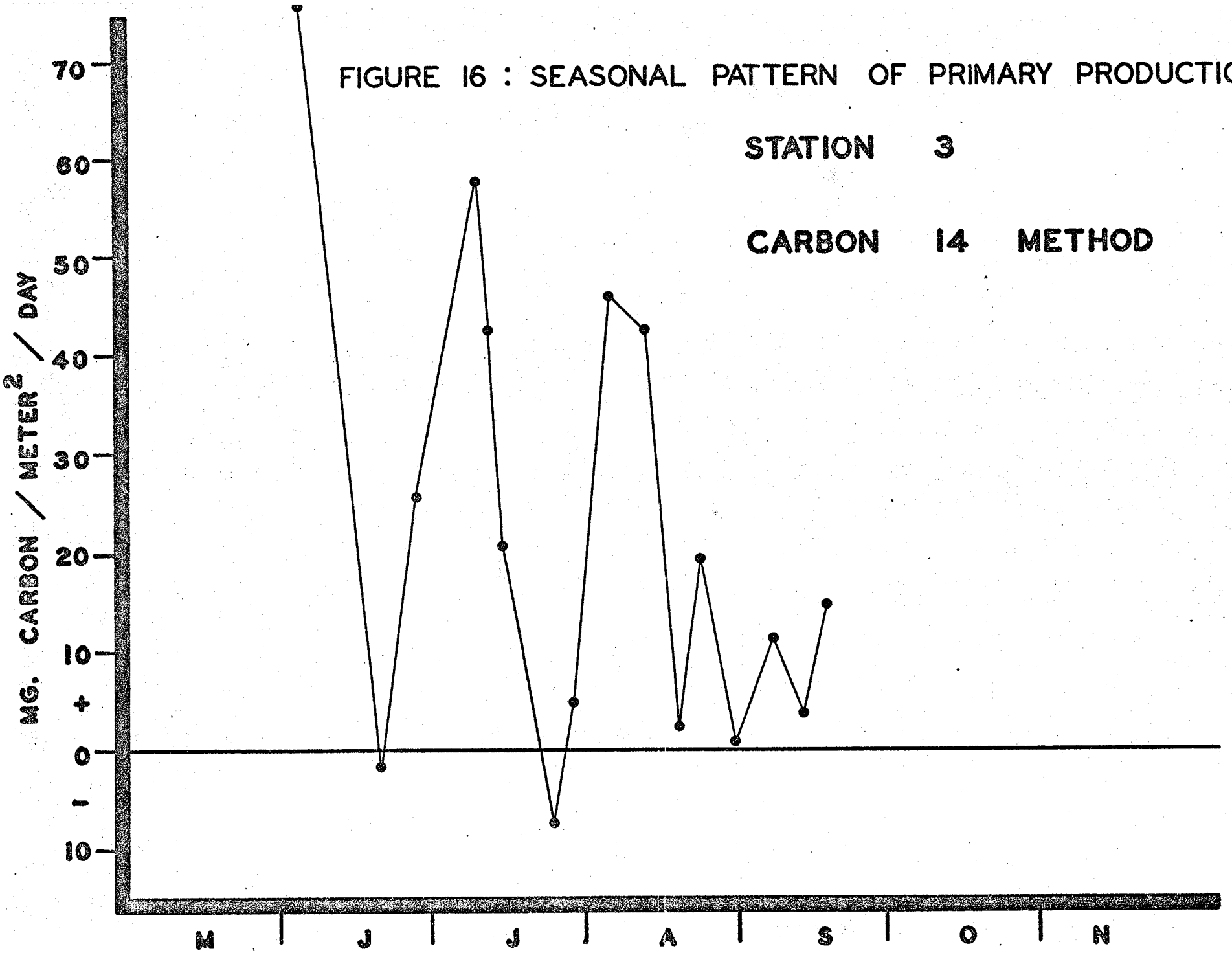
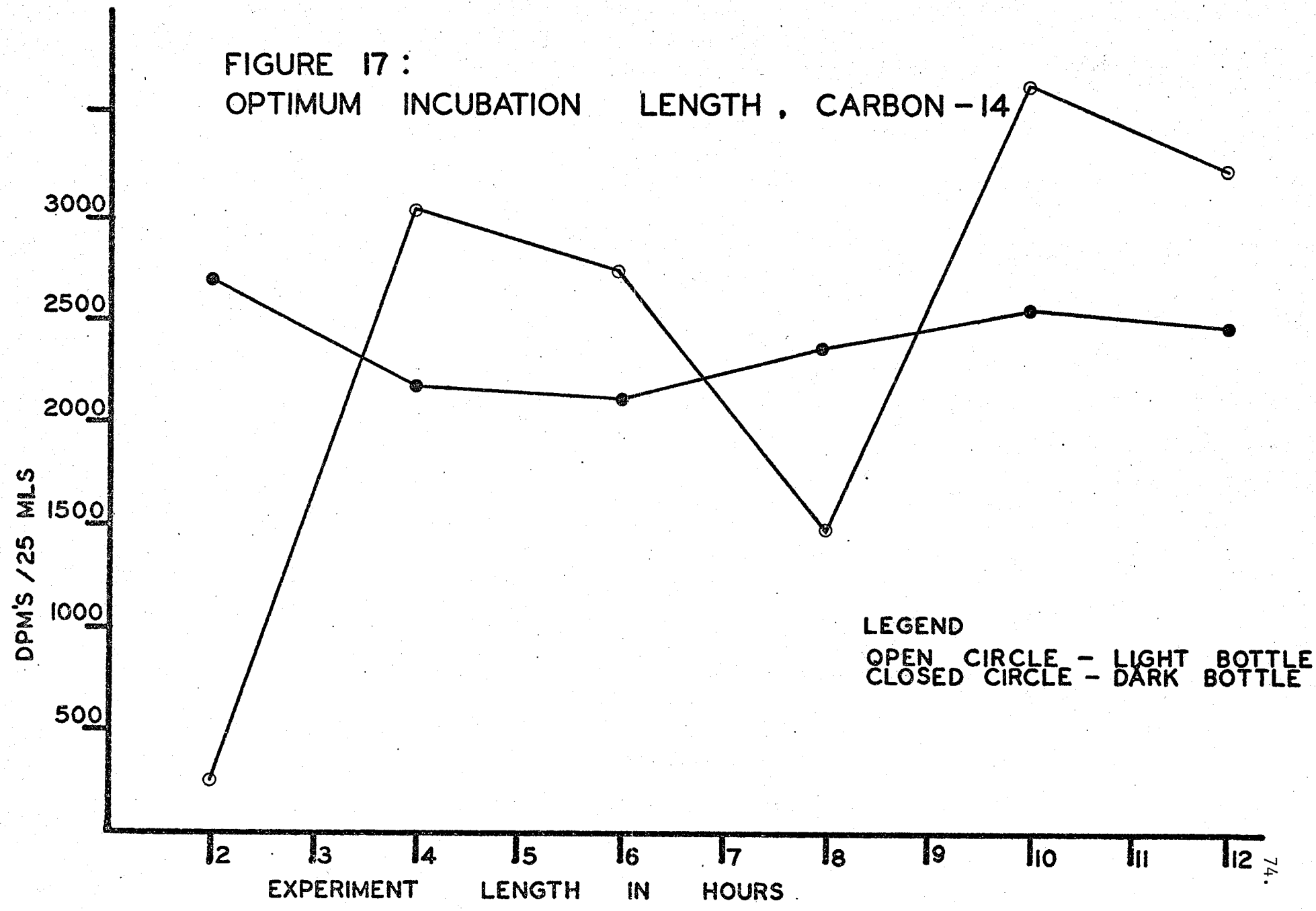


FIGURE 16 : SEASONAL PATTERN OF PRIMARY PRODUCTION
STATION 3
CARBON 14 METHOD
MG. CARBON / METER² / DAY
70
60
50
40
30
20
10
0
+
-
10
M
J
J
A
S
O
N

FIGURE 17 :
OPTIMUM INCUBATION LENGTH , CARBON - 14



values for dark uptake, it appeared that an incubation period of four hours was adequate.

Minimum, maximum and optimum values for incubated water to be filtered was experimentally determined (Figure 18; Table 7). A linear relationship was found to exist between the number of milliliters filtered and the dpm. It was apparent from this data that volumes filtered were appropriate, although the possibility of a filtration effect (Arthur and Rigler 1967; Schindler and Holmgren 1971) cannot be eliminated since filter volumes were not less than 5 mls. If a filtration effect was present it may have resulted in a very severe underestimation of primary productivity. According to Figure 18, the two values utilized throughout this study (25 and 50 mls.) were representative of the entire sample. Variations in the linearity of the line were created by variations in aliquot and bottle sampling.

Doty et al (1967) determined that the rate of primary production varies, depending upon the time of day, and found that a specific one hour period could be accurately extrapolated to the daily production rate by multiplying by twenty-four. The above one hour sampling time was not suitable for the determination of primary production in Crescent Pond due to a low carbon-14 uptake value for the first hour of incubation.

In order to integrate the rate of primary production per unit surface area, a depth curve of photosynthesis was constructed. The depth curve (Figure 19) was represented by a highly erratic line. It appeared from these data that a high rate of photosynthesis occurred at the surface and photosynthatic inhibition was taking place at the 60 cm depth. In general, photosynthesis in the surface waters would have been inhibited by shortwave radiation entering the surface waters. An explanation was not available at the time of sampling to adequately explain the occurring phenomenon. An

TABLE 7: Determination of the minimum, optimum and maximum sample volume to be filtered during primary production experimentation (carbon-14) on Crescent Pond.

Volume Filtered	cpm - Background	Efficiency	dpm
5 milliliters	246.8	75.5	326.9
10 milliliters	486.7	75.5	644.6
15 milliliters	709.7	76.0	933.8
20 milliliters	954.6	76.0	1256.1
25 milliliters	1164.4	75.5	1542.3
30 milliliters	1412.0	75.5	1870.2
35 milliliters	1285.7	76.0	1691.7
40 milliliters	1427.1	76.0	1877.8
45 milliliters	1588.6	76.0	2090.3
50 milliliters	2005.0	76.0	2638.2
60 milliliters	2398.8	75.5	3177.2
70 milliliters	2402.5	75.0	3203.3
80 milliliters	3079.5	73.0	4218.5
100 milliliters	3766.1	73.5	5123.9

FIGURE 18 :

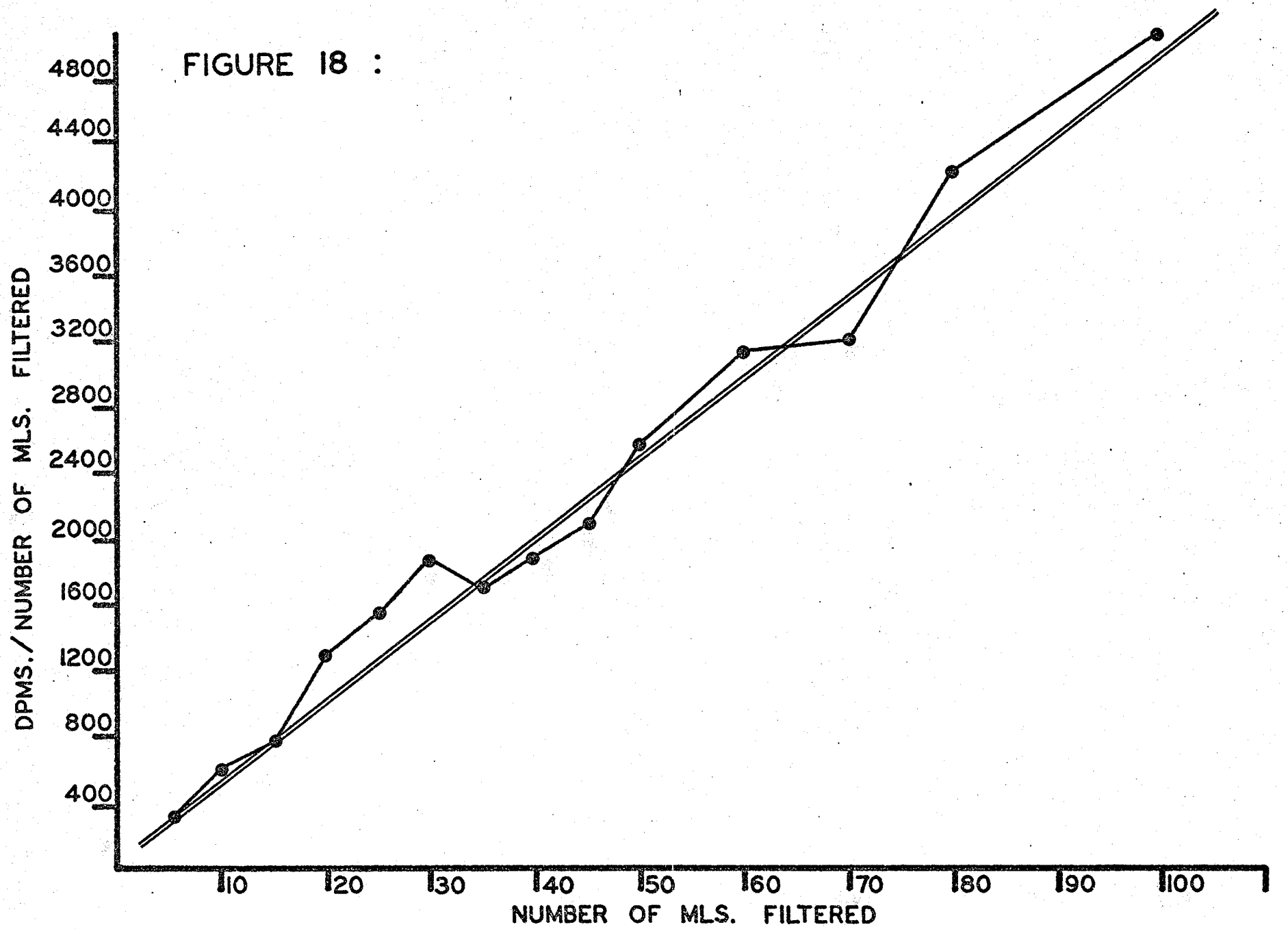
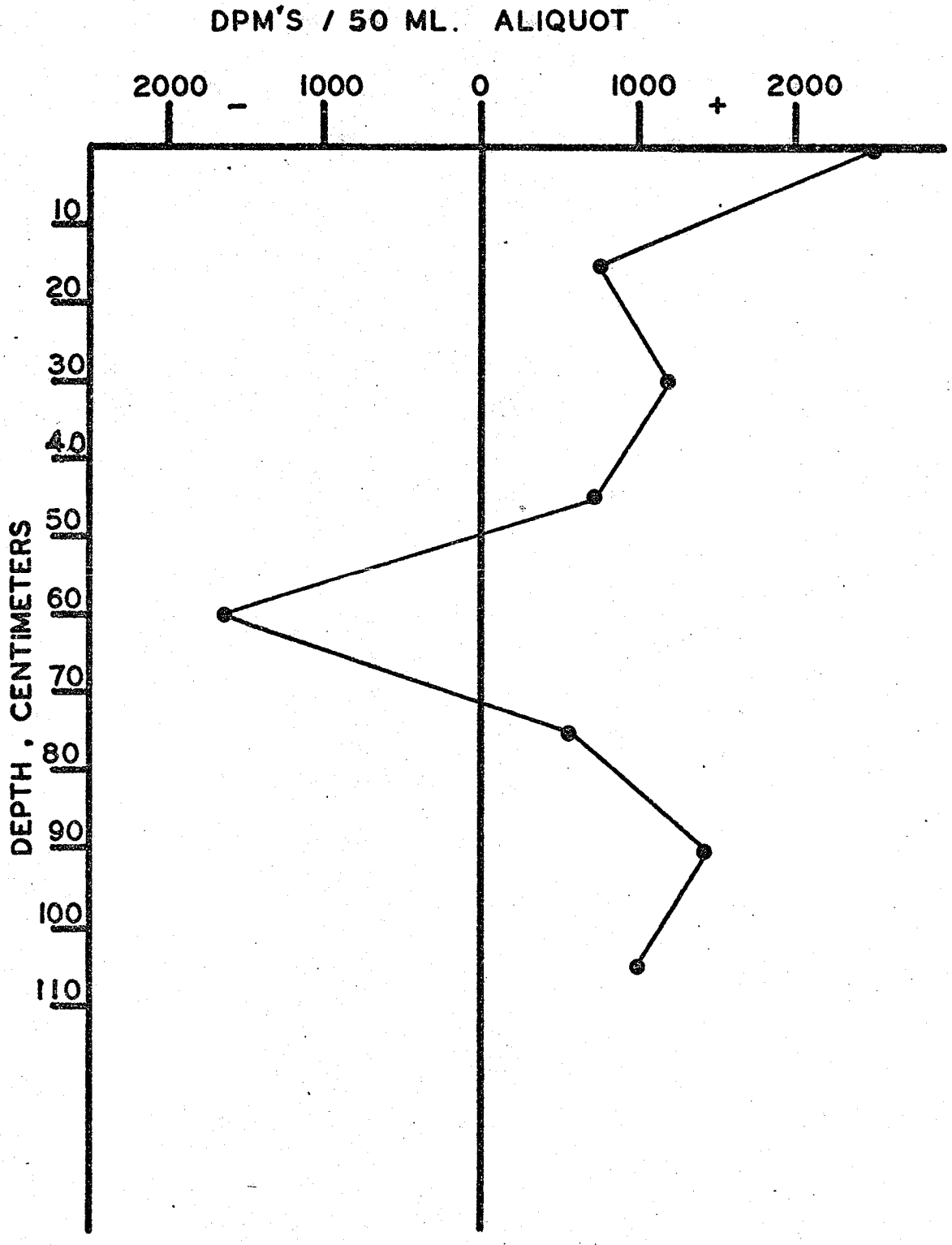

4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
DPMS./NUMBER OF MLS. FILTERED
10
20
30
40
50
60
70
80
90
100
NUMBER OF MLS. FILTERED

FIGURE 19 :
DEPTH CURVE OF PHOTOSYNTHESIS



association was not evident with solar radiation. It was assumed that fluctuations in the phytoplankton population were not great enough to create these erratic results. This variation was later attributed to the contaminated carbon-14 ampoules (NEN 555-195, 1970) utilized during this study.

A diurnal curve of photosynthesis was required in order to integrate the carbon-14 uptake results to a daily primary production rate. This curve (Figure 20), exhibited a high rate of photosynthesis in the early morning during low light intensity. A rapid decline to a negative value was evident, with negative values being recorded until late afternoon, at which time a small positive value occurred. Negative values were again recorded followed by a positive value which occurred after sunset. It was apparent from this experiment that production did not relate to incident radiation in any obvious way. It was not known at this time, however, whether or not this contradiction was due to some inherent factor in the method utilized.

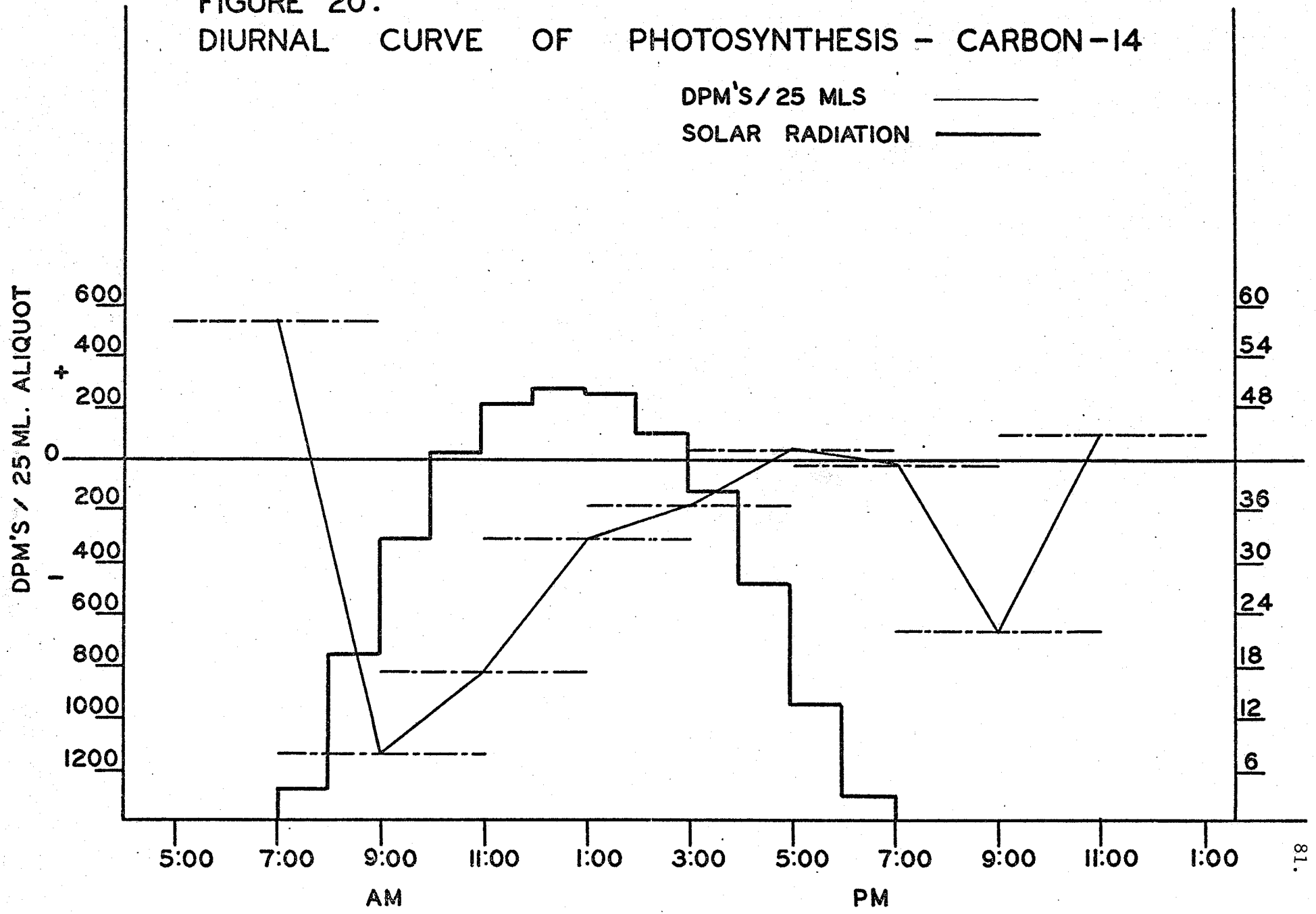
An experiment was performed to test the light exclusion ability of the dark primary productivity bottles. At station 2 (50 cm depth), two dark bottles were prepared and incubated following the procedures previously outlined. Another two dark bottles were prepared by an identical technique and then totally covered by two layers of aluminum foil. If light was entering the normal dark bottles, then a cause of high dark uptake would have been established. From Table 8 it was evident that the dark bottle procedure being utilized in routine productivity studies was adequately removing light, although poor replication occurred in the experiment. Therefore, the dark uptake of carbon-14 was not due to inadequate light exclusion.

It was thought that a variable cellular particulate organic loss through the filter may have been responsible for the erratic high dark uptake relative to the light bottle uptake. If appreciable amounts of labelled cellular

TABLE 8: Results of a carbon-14 uptake experiment to determine whether the dark bottles utilized in the routine primary productivity experiments were light-tight.

Bottle	cpm - background	Efficiency	dpm/ 25 mls	Mean
Normal Dark				
#1	609.6	63.5%	960.0	1372.5
#2	1097.7	61.5	1784.9	
Experimental Dark				
#1	1091.6	62.0	1760.6	1276.6
#2	519.1	65.5	792.5	

FIGURE 20:
DIURNAL CURVE OF PHOTOSYNTHESIS - CARBON-14



material were being carried through the 0.45 micron filter by heavy vacuum pressure, cellular rupture or filter rupture, an unusally low dpm would result. If this occurred primarily in the light bottles, the integral calculation would tend to bias and increase the effect of the dark bottles. To examine the above, a refiltration of productivity bottles was performed under low vacuum pressure. Results of this experiment (Figure 21) showed that some particulate matter could be captured on refilration, but that relative to the initial filtration capture, this was insignificant. Also, no significant difference between light and dark bottles was apparent.

Although extracellular organic loss to the filtrate would not have influenced high dark uptake per se, a significant excretion in the light bottle may have resulted in an unusually low light bottle value. In the calculation of primary productivity, this would substantially reduce the final values.

On examining the possible cellular organic loss through the filters, it was evident that high vacuum pressure and subsequent rupture of cells into the filtrate was not responsible for the high dark uptake within the limits used. Both light and dark bottles revealed similar filtration efficiences but were not consistent enough forba correction factor to be applied to the productivity values. Table 9 indicated that a significant differential in extracellular excretion existed between the light and dark bottles at both depths sampled. Both the light and dark bottles exhibited a high dark extracellular excretion at a depth of 80 cm with the dark bottle characterized by 47% greater excretion. At the surface, the light bottle excretion was approximately 6 times that of the dark bottle. From this experiment it might be suspected that excretion was greater below the surface, but there was no indication as to an explanation of high dark uptake and erratic values.

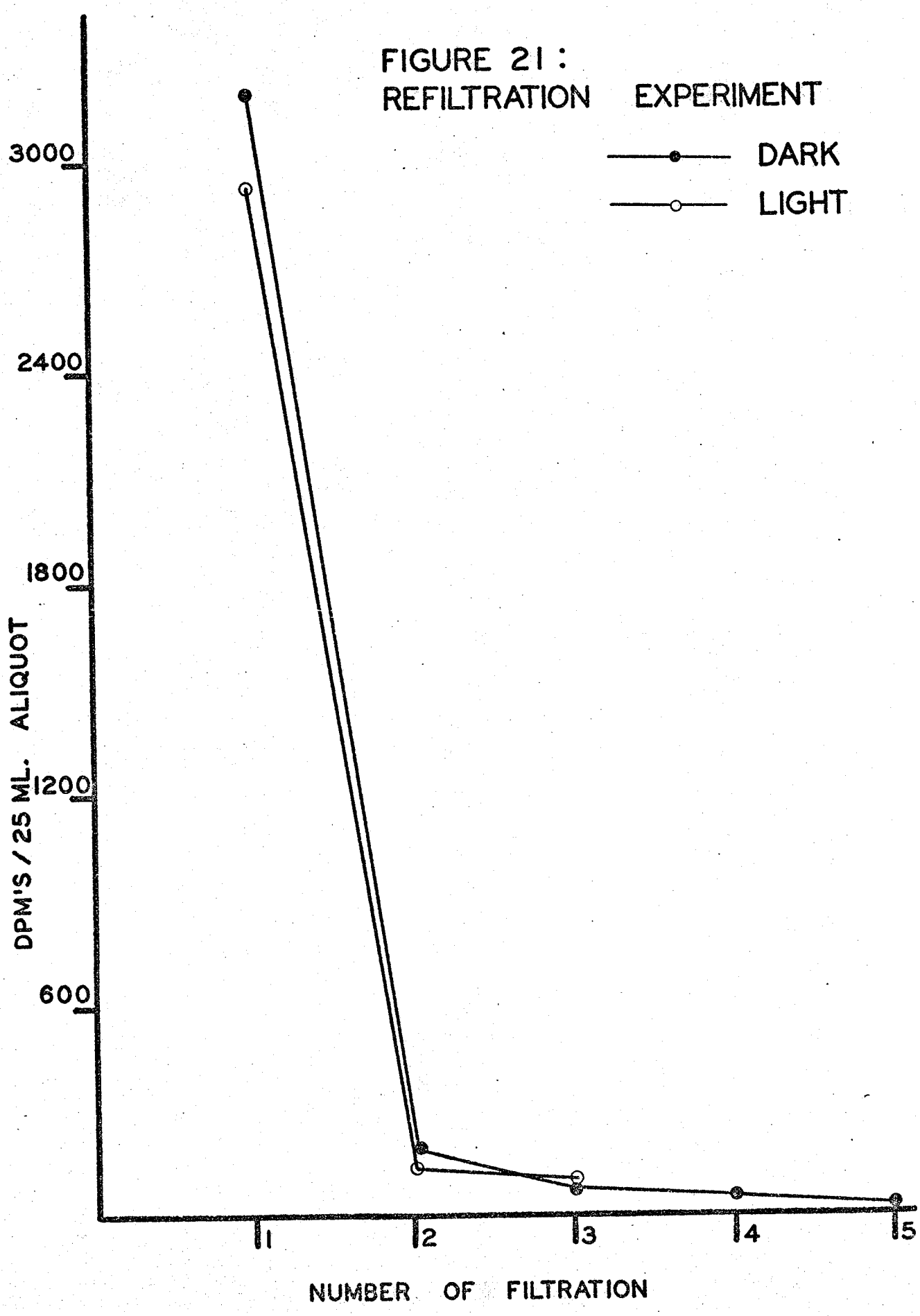
The statistical variability between subsamples of the same water sample

TABLE 9: Results of a carbon-14 experiment performed at station22, to determine whether a significant quantity of extracellular excretion was occurring.

Depth	Bottle	Aliquot	cpm - Background	Efficiency	dpm/25 mls	Mean
Surface	Light	1	165.9	53.5	310.1	
	Dark	1	29.2	56.0	52.1	53.7
	Dark	2	30.9	56.0	55.2	
Bottom*	Light	1	1044.6	61.0	1712.5	1729.9
	Light	2	1039.6	59.5	1747.2	
	Dark	1	1480.1	59.0	2508.6	2522.0
	Dark	2	1445.1	57.0	2535.3	

* Denotes a sample collected immediately above the sediment.

FIGURE 21 :
REFILTRATION EXPERIMENT



and between subsamples of different water samples were examined (Table 10). Standard deviation for the subsamples removed from any given light bottle were not significantly different. Dark bottle results showed larger values in standard deviation than existed in the light bottle subsamples. This indicated that more accurate results were obtained from any given subsample from the light bottle and that dark bottle subsamples were somewhat less accurate. The group data for dark and light bottles produced large standard deviations indicative of poor replication between aliquots of different bottles, even though they originally came from the same water sample.

As a result of the above findings, indicating poor replication between bottles, an experiment was undertaken to determine the amount of variability expected between incubated bottles from different water samples.

The group data (Table 11) was characterized by large standard errors. Therefore, the reliability of the aliquots to represent the entire population appeared inaccurate. This indicated that either the phytoplankton population was highly variable between samples collected in close proximity, or that there was some inherent error in the method.

It appeared necessary to statistically determine the amount of variability encountered within the three contours sampled. From the extremely high values of the standard deviation and standard error found within the 0 to 50 cm contour (Table 12a), it was concluded again that the phytoplankton populations were extremely variable or that a major error was inherent within the carbon-14 technique utilized. Both light and dark bottles were similarly affected. Since this contour contained large areas of emergent aquatic macrophytes, as well as a large number of submergent macrophytes and benthic algae, a variation was expected. However, the variability encountered was certainly greater than the variability inherent within the phytoplankton

TABLE 10: Statistical analysis of the group data from an experiment to determine the variability between aliquots of the same sample and aliquots of different samples. The bottles were incubated at station 2 immediately above the sediment.

Bottle	Mean dpm/25 mls	Variance	Standard Deviation	Variation of Mean	Standard Error
Group data for light bottles	1700.944	29539.923	171.870	3282.165	52.290
Group data for dark bottles	648.833	276074.411	525.428	46012.402	214.505

TABLE 11: Statistical analysis of the group data from an experiment to determine the variability between aliquots of different water samples. The experiment was conducted at station 2 from water collected and incubated immediately above the sediment.

Bottle	Mean dpm/25 mls	Variance	Standard Deviation	Variation of Mean	Standard Error
Group data for light bottles	1886.466	1235463.690	111.514	205910.615	140.615
Group data for dark bottles	1561.616	117817.757	343.245	19636.292	140.129

TABLE 12a : Statistical analysis of the group data presented in appendix 18.

Sample and Depth	Mean	Standard Deviation	Standard Error
Group data for surface light :	2311.500	2045.375	1180.898
Group data for surface dark :	1694.800	1552.401	896.898
Group data for bottom light :	2688.733	796.225	459.701
Group data for bottom dark :	1843.633	1524.152	879.970

TABLE 12b : Statistical analysis of the data presented in appendix 19.

Sample and Depth	Mean	Standard Deviation	Standard Error
Group data for surface light :	2630.800	239.834	138.468
Group data for surface dark :	1622.966	155.465	89.758
Group data for bottom light :	1395.966	1609.283	929.120
Group data for bottom dark :	2382.266	270.087	155.934

TABLE 12c : Statistical analysis of the group data presented in appendix 20.

Sample and Depth	Mean	Standard Deviation	Standard Error
Group data for surface light :	2250.833	562.445	324.728
Group data for surface dark :	2135.800	1609.331	929.147
Group data for bottom light :	2683.500	2228.043	1286.361
Group data for bottom dark :	1514.100	1049.385	605.862

population exclusively.

Results attained for the 50 - 100 cm contour (Table 12b) were in a similar range as that experienced in the 0 - 50 cm contour. Standard deviation and standard error of the mean were both large, indicating poor agreement of carbon-14 uptake among stations in the 50 - 100 cm contour. Although the algal populations probably fluctuated spatially within this contour, the variability appeared to exceed the values explicable solely by phytoplankton.

The greater than 100 cm contour (Table 12c) exhibited the largest standard deviations and standard errors with respect to the other contour data. Since low phytoplankton populations were generally present in this contour, a larger variation in primary production was probable. A smaller variation in a population with low numbers would yield a higher variance than the same deviation in a larger population. It was later determined that the results obtained during these experiments were a product of contaminated carbon-14 ampoules.

Since deviations of the magnitude found within the three contours were probably not associated with carbon-14 uptake by phytoplankton or rapid bacterial metabolism, contaminated ampoules appeared to be the cause. This possibility was examined by using acid cleaned glassware and glass fiber filtered Crescent Pond water. Carbon-14 was added, the sample agitated and an aliquot immediately removed and processed. From the results presented in Table 13 it was evident that rapid bacterial uptake of carbon-14 was not responsible for the large dark bottle activity, assuming that filtration had effectively removed bacteria. Therefore, it was surmised that the carbon-14 ampoules received from the New England Nuclear Corporation were contaminated with a particulate organic substance.

TABLE 13 : Results of an experiment to determine whether the carbon-14 ampoules utilized during routine carbon-14 primary productivity experiments, were contaminated.

Bottle	cpm - Background	Efficiency	dpm/25 mls
Light	595.3	72.5	821.1
Light	344.7	71.0	485.5
Dark	15.0	81.0	18.5
Dark	770.1	66.5	1158.0

Ancillary Carbon-14 Experimentation (Laboratory)

To provide conclusive evidence of contamination in New England Nuclear ampoules of lot numbers 555-195 (1970), 555-195 (1967) and 569-031 (1970), the ampoules were subjected to a quality test as described earlier. This test provided evidence that the ampoules were contaminated with a particulate organic substance capable of retention on a 0.45 micron filter (Table 14). The standard deviations and standard errors for the data indicated the carbon-14 labelled particulate material was not a constant amount in each ampoule. Consequently, no correction factor could be applied to the original field data in order to compensate for the particulate error.

The possibility of excessive inorganic carbon-14 retention on the filter was examined through a series of experiments where aliquots were treated as above but the filters were either rinsed with 25 mls of dilute HCl or fumed for increasing lengths of time over concentrated HCl. In the first of these experiments (Table 15), conducted on NEN 555-195 (1970) ampoules, a large standard deviation and standard error for the group data indicated that the dilute acid rinse was not able to appreciably lower the error inherent within the ampoules

From Figure 22, it was apparent that no appreciable reduction in residual carbon-14, with increased filter acidification time, resulted. The data from both experiments indicated that the carbon-14 ampoules were contaminated and that the contamination was in the form of particulate organic carbon.

From the above series of laboratory data and analysis it was deemed necessary to produce ampoules within the laboratory from stock solutions of carbon-14 (Amersham-Searle CFA 3-5 Mci). These ampoules were stored at room temperature for several days prior to experimental use.

A filter acidification experiment was conducted (Figure 22) with the

Table 14 : Results of an experiment designed to reveal the amount of particulate organic material within ampoules.

Ampoule	Bottle	Aliquot	cpm - Background	Efficiency	dpm/50 mls	Mean
NEN 555-195 (1970)	1	a	670.9	47.5%	1412.0	
"	1	b	637.2	50.0	1274.4	1343.2
"	2	a	372.6	54.0	690.0	
"	2	b	363.6	50.0	725.2	707.6
"	3	a	828.5	52.5	1578.0	
"	3	b	796.8	51.5	1547.2	1562.6
"	4	a	967.3	48.0	2015.2	
"	4	b	954.5	44.0	2169.3	2092.3
"	5	a	403.9	46.0	878.0	
"	5	b	434.8	55.0	790.5	834.3
"	6	a	385.5	46.0	838.0	
"	6	b	614.0	48.5	1266.0	1052.0
	Mean : 1265.333					
	Standard Deviation :		513.940			
	Standard Error :		209.815			
NEN 555-195 (1967)	1	a	19.0	80.5	23.6	
"	1	b	15.7	80.5	19.5	22.6
"	2	a	16.0	74.5	21.5	
"	2	b	13.3	73.0	18.2	19.9
"	3	a	8.3	52.5	15.8	
"	3	b	12.8	73.5	17.4	16.6
	Mean :		19.700			
	Standard Deviation :		3.004			
	Standard Error :		1.734			

TABLE 14 : continued

Ampoule	Bottle	Aliquot	cpm - Background	Efficiency	dpm/50 mls	Mean
NEN 560-013 (1970)	1	a	382.5	54.5%	701.8	
"	1	b	394.7	57.0	692.5	697.2
"	2	a	480.7	50.0	961.4	
"	2	b	528.5	53.5	987.9	974.7
"	3	a	493.6	59.5	829.6	
"	3	b	508.9	62.5	814.2	821.9
"	4	a	496.6	57.5	863.7	
"	4	b	517.5	57.5	900.0	881.9
"	5	a	457.1	54.5	838.7	
"	5	b	498.0	62.0	803.2	821.0
"	6	a	540.6	57.5	940.2	
"	6	b	542.0	58.5	926.5	933.4

Mean :	855.000
Standard Deviation :	98.368
Standard Error :	40.158

TABLE 15 : Values of an experiment designed to reveal whether an acid rinse of the filter was capable of eliminating the particulate organic material within the NEN 555-195 (1970) ampoules.

Bottle	Aliquot	cpm - Background	Efficiency	dpm/50 mls	Mean
1	a	733.2	46.5%	1576.8	
1	b	774.1	46.0	1682.8	1629.8
2	a	1082.3	42.0	2576.9	
2	b	1196.3	48.5	2466.6	2521.8
3	a	1153.9	48.5	2379.2	
3	b	1081.6	46.5	2326.0	2352.6

Mean : 2168.066
Standard Deviation : 473.767
Standard Error : 273.529

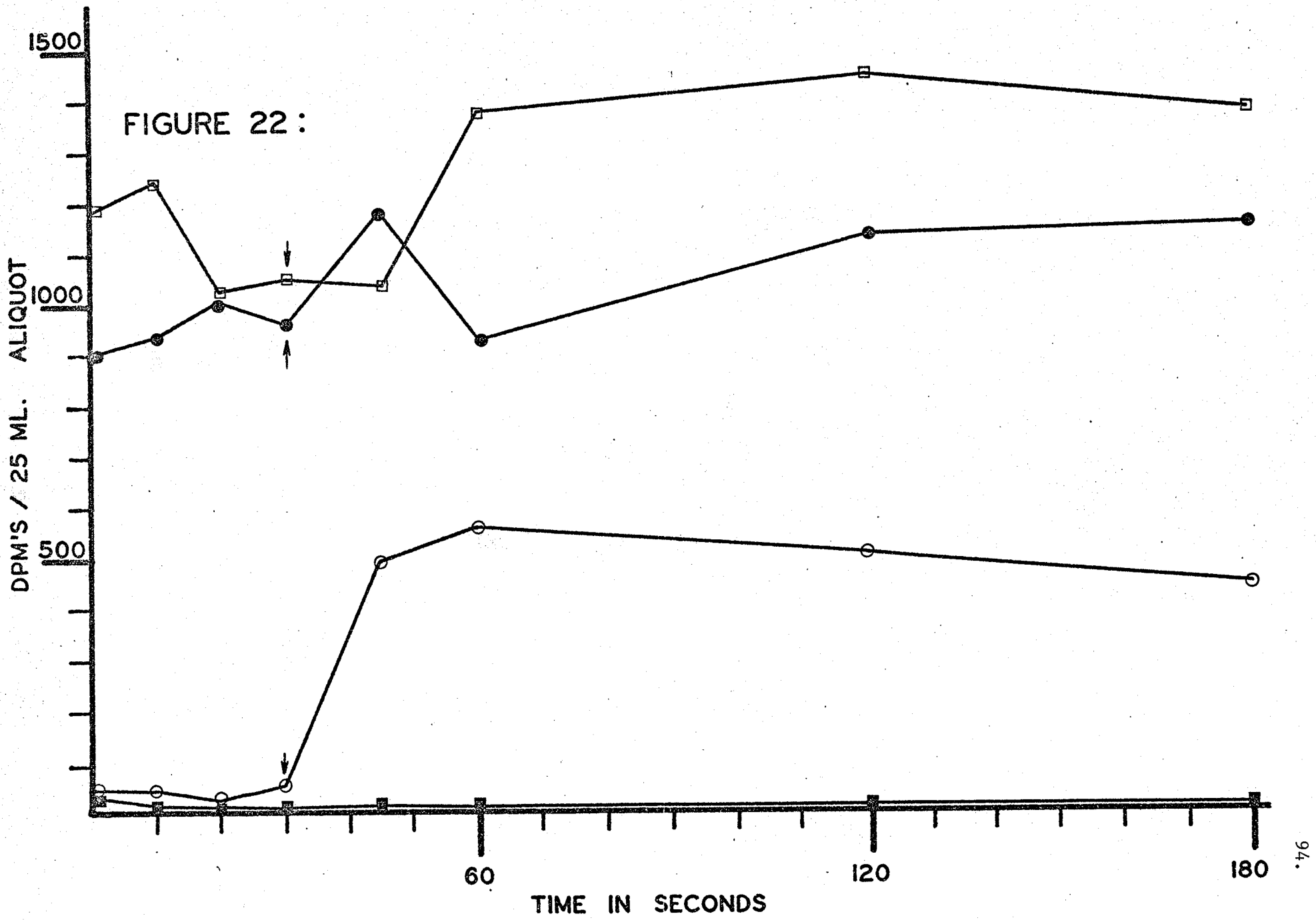
To Face Figure 22 :

The relationship between dpm/25 milliliter aliquot and the acidification time over fuming hydrochloric acid. The arrows indicate indicate the final subsample from the first bottles in each ampoule group.

Legend:

open-square	NEN 555-195 (1970)
closed-square	A-S laboratory produced ampoules
open-circle	NEN 555-195 (1967)
closed-square	NEN 560-031 (1970)

FIGURE 22 :



laboratory ampoules. The data indicated low values for acidification time, providing conclusive evidence that the 30 second acidification time used in routine experiments was sufficient to remove excess inorganic carbon-14. It was concluded that the only ampoule suitable for primary productivity evaluations was the laboratory produced type.

Platt and Irwin (1968) routinely filtered the ampoules prior to utilization in primary productivity experiments. An experiment was conducted to determine the extent of organic particulate removal during ampoule filtration. Table 16a and 16b provided evidence that filtration of carbon-14 ampoules prior to use in experiments, substantially reduces the dpm introduced by particulate organic contaminants. It was evident that the laboratory produced ampoules were relatively free of particulate organic matter and that the NEN 555-195 (1970), and NEN 560-031 (1970) ampoules contained substantial organic material capable of retention on a 0.45 micron filter. The amount of organic material remaining in the NEN 555-195 (1970) aliquots after filtration was variable. From this it was concluded that an 0.45 micron filtration prior to experimental use would not neccessarily remove the organic matter. A 0.10 micron filtration was also not suitable for accurate reduction of the contaminant to a level at which the isotope could be utilized or where a correction factor could be applied. Laboratory produced ampoules were suitable for direct experimental use without prior filtration.

Since one filtration of the ampoule contents was not capable of reducing the contaminant to a suitable level, an experiment was undertaken to determine the number of filtrations necessary to do so. Table 17 indicated that for both pore sizes, two filtrations were necessary to effectively remove the contaminant within the ampoules. NEN 560-031 (1970) were

TABLE 16a : Represents the results of experiments to determine the effect of ampoule filtration through 0.45 micron and 0.10 micron filters, prior to utilization in experiments. Values of carbon-14 retention on filters as a result of the direct filtration of ampoules.

Filter Size	Filter	NEN 555-195 (1970) dpm/filter	NEN 560-031 (1970) dpm/filter	Lab Produced dpm/filter
0.45 micron	1	1009.2	1700.7	31.3
"	2	976.9	1638.4	11.2
"	3	1222.6	1899.6	12.6
"	4	2122.3		
"	5	1107.8		
"	6	1154.4		
0.10 micron	1	36.1	1668.8	27.9
"	2	802.4	1043.0	13.9

TABLE 16b : Values in dpm/25mls from the filtered carbon-14 ampoules which were added to DDDMF water in 125 ml bottles and subsequently sampled.

Filter Size	Filter	Aliquot	NEN 555-195 (1970) dpm/25 mls	NEN 560-031 (1970) dpm/25 mls	Lab Produced dpm/25 mls
0.45 micron	1	a	70.4	15.2	12.2
"	1	b	51.0	18.6	15.0
"	2	a	133.8	25.4	39.3
"	2	b	132.3	26.9	49.4
"	3	a	107.4	57.2	17.9
"	3	b	135.9	72.4	32.1
"	4	a	16.2		
"	4	b	15.6		
"	5	a	149.6		
"	5	b	176.0		
"	6	a	255.4		
"	6	b	198.2		
0.10 micron	1	a	23.2	48.8	51.6
"	1	b	34.9	83.7	55.3
"	2	a	141.2	57.6	73.1
"	2	b	149.5	67.2	45.3

TABLE 17 : Results of an experiment to determine the number of filtrations of the carbon-14 solution which was required to effectively remove the organic particulate matter prior to utilization in experiments. The experiment was performed on two filter sizes and three ampoule types.

Filter Size	Filtration	NEN 555-195 (1970) dpm/filter	NEN 560-031 (1970) dpm/filter	Lab Produced dpm/filter
0.45 micron	1	1107.8	1700.7	32.1
"	2	176.0	15.2	12.6
"	3	11.4	5.0	2.7
"	4	3.2	3.3	2.8
"	5	1.9	4.0	1.6
"	6	2.1	3.2	1.5
0.10 micron	1	8802.4	1043.0	45.1
"	2	149.5	67.2	13.9
"	3	10.0	14.6	4.9
"	4	9.5	6.6	2.3
"	5	5.9	4.5	3.1
"	6	6.0	4.6	3.1

effectively reduced after one filtration during this experiment. The laboratory produced ampoules did not require filtration.

2.) OXYGEN EVOLUTION EXPERIMENTATION

Field Primary Productivity

Primary productivity as determined by the oxygen evolution method at stations 1, 2 and 3 (Figures 23, 24 and 25 respectively) showed that the lowest seasonal productivity occurred at station 1. At station 2, the primary productivity was greatest, while station 3 possessed an intermediate value.

Four distinct increases in primary production were evident at stations 1 and 3, while station 2 was characterized by three pulses. The main increases in production occurred at similar times of the year at all three stations. In illustrating the results, all negative values were omitted.

The primary productivity measured by the oxygen evolution method at station 1, appeared to closely approximate the rise and fall of algal populations. Initially, the primary production rates maybe attributed to the high populations of Bacillariophyceae. The second small increase in production also appeared to be the result of Bacillariophyceae while the third increase appeared to be a function of the Cyanophyceae. Since most of the Cyanophyceae were filtered from the bottles prior to incubation, the association was probably an artifact of sampling rather than a deviation in the algal population. The final increase in production resulted from an increase in Bacillariophyceae during autumn.

At station 2, the productivity values were higher than those found at station 1, even though higher populations of algae were found at the latter station. This was probably due to the depth differences between stations more

FIGURE 23: SEASONAL PATTERN OF PRIMARY PRODUCTION

STATION I

OXYGEN METHOD

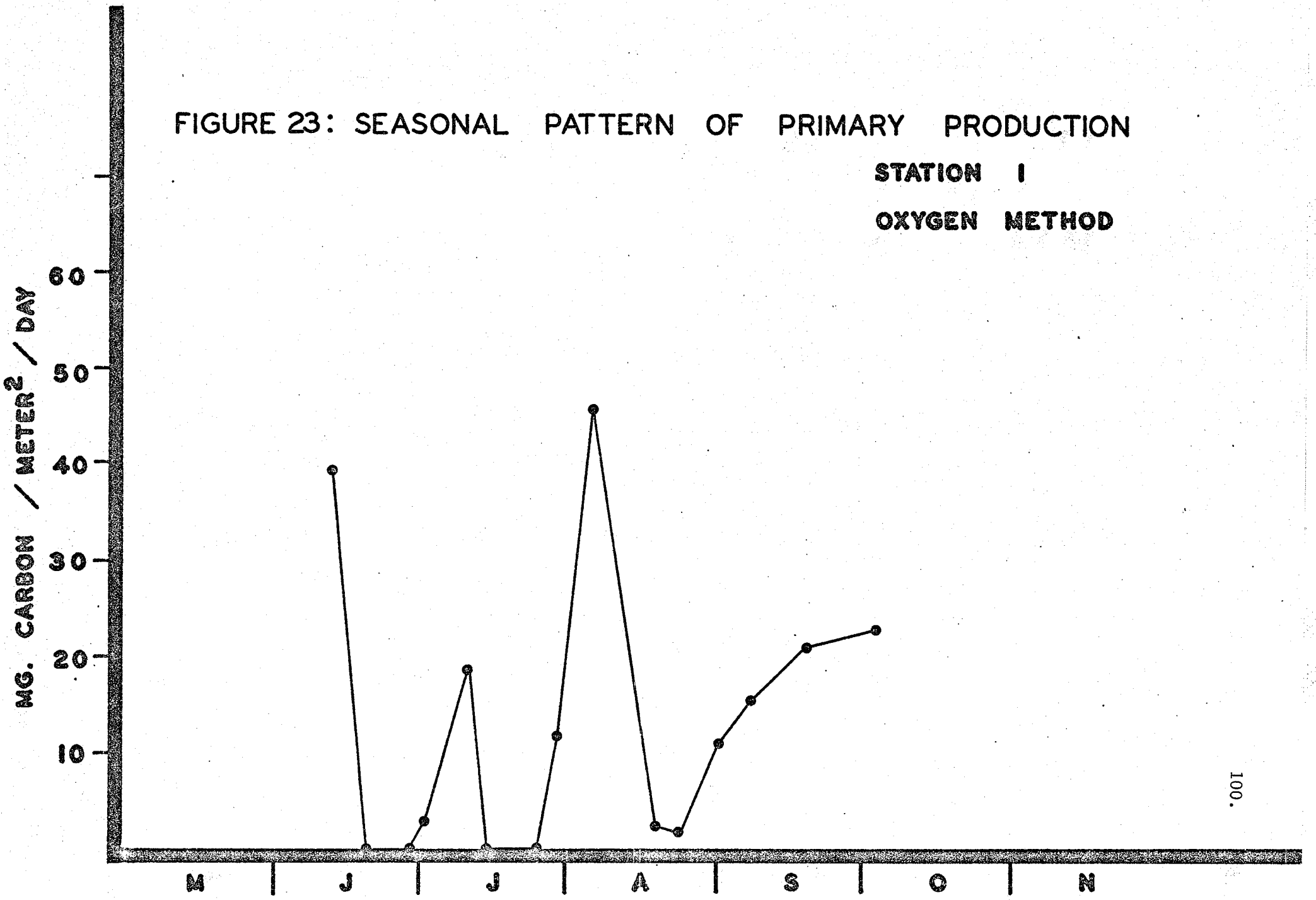


FIGURE 24: SEASONAL PATTERN OF PRIMARY PRODUCTION

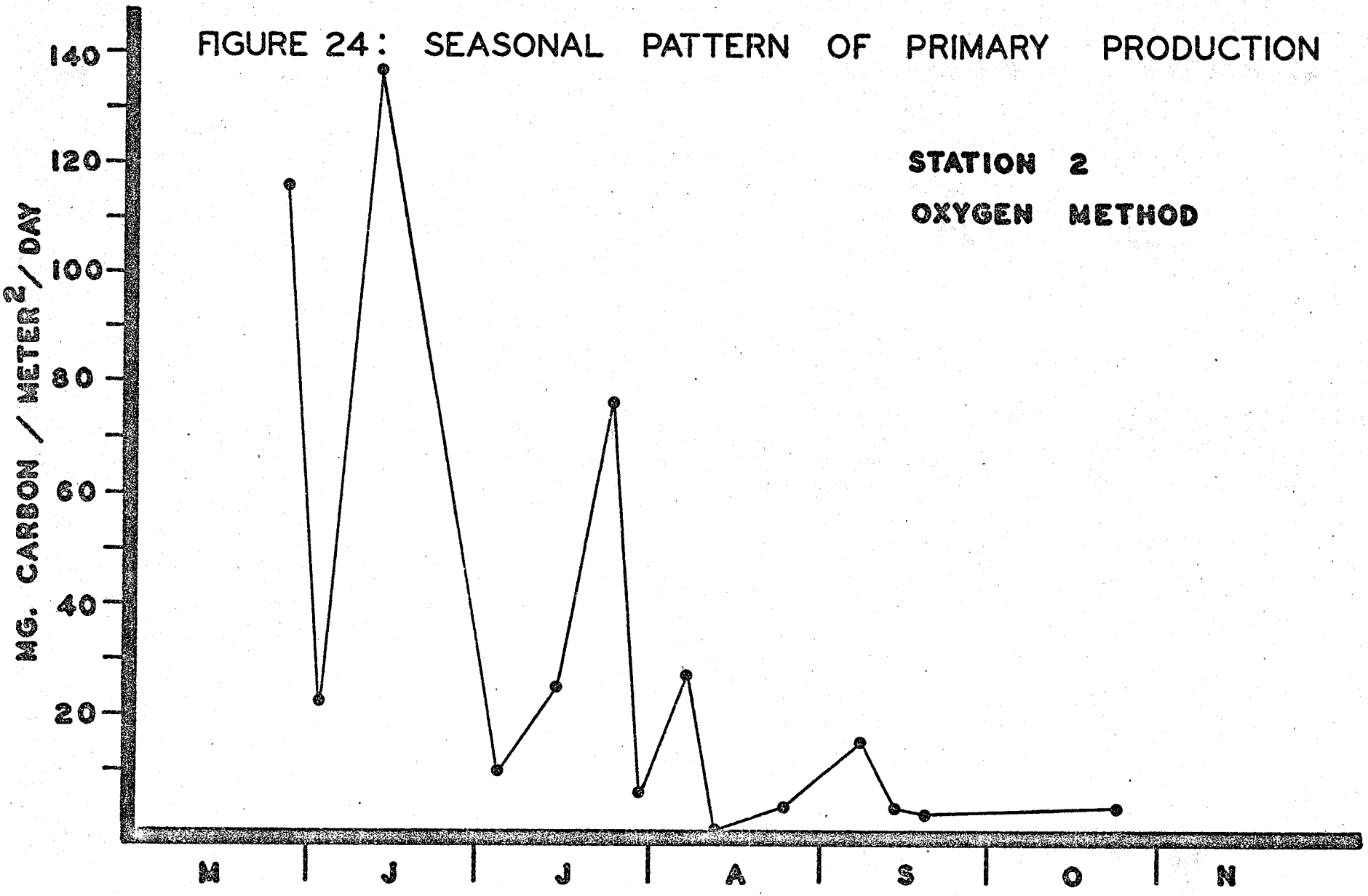
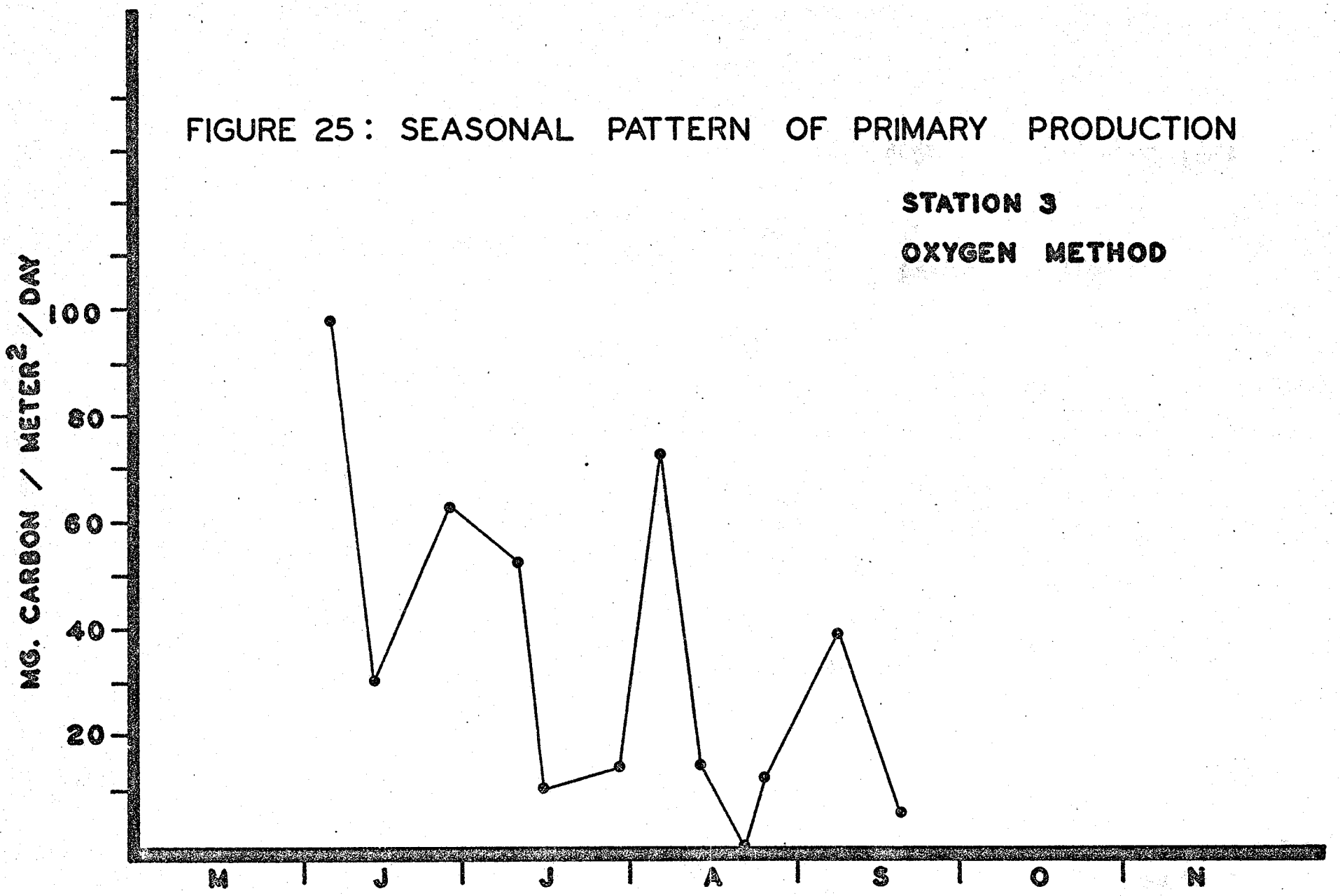


FIGURE 25: SEASONAL PATTERN OF PRIMARY PRODUCTION



than compensating for the algal population differences when an integrated value was plotted. The primary productivity values correspond to the Bacillariophyceae fluctuations at station 2 with the exception of the second increment. This increase did not correspond to any recorded algae population, but may represent an undetermined increase in algae or an artifact of sampling.

Algae populations were lower at station 3 than at the other stations and was attributed to the depth integrated values. Production values for station 3 did not correspond to any series of algal fluctuations with the exception of the first increase, which was associated with the spring rise in numbers of Bacillariophyceae. The remaining increments in primary productivity may have resulted from the unrecorded fluctuations in algae populations, or from sampling errors.

Statistical Analysis of the Oxygen Method

The accuracy of the oxygen values from one van Dorn water sampler was examined (Table 18). An analysis of variance yielded a value which was significant at both the 5% and the 1% levels (Table 18). The value indicated that the reliability of the titrations to accurately assess the oxygen was well within the limit of the 0.05 mg/liter which was the highest titration differential recorded.

Statistical reproducibility of production values was examined by multiple simultaneous incubations of samples. The statistical analysis of the data showed a low standard deviation for the light bottles with slightly higher values for the dark bottles at the surface (Table 19). Extremely accurate replication of light bottle titrations occurred at the surface. Replication of the dark bottles was not as constant as that found in the light

TABLE 18 : Results of an experiment to determine reproducibility of the dissolved oxygen concentrations from the same and from different water samples.

Water Sample	Aliquot A	Aliquot B	Aliquot C	Mean
1	7.95	8.05	8.05	8.02
2	8.03	8.05	8.10	8.06
3	8.05	8.00	8.05	8.03
4	8.10	8.10	8.05	8.08

An analysis of variance (F test) of the above data yielded a value of 1.333 which was significant at both the 5% (4.07) and 1% (7.59) levels.(Richmond 1964). Therefore the hypothesis that variation within water samples was equal to the variability between samples (ie. the data are homogeneous), may be accepted.

TABLE 19 : Results of an oxygen evolution experiment designed to reveal the reproducibility of productivity values determined by multiple simultaneous incubation of bottles. Results are expressed as mg of dissolved oxygen / liter.

Depth	Water Sample	Initial Dissolved Oxygen	Light Bottle	Dark Bottle	Light - Dark
Surface	1	5.40 mg/1	5.20 mg/1	5.10 mg/1	+0.10
"	2	5.25	5.15	5.15	0.00
"	3	5.40	5.15	5.15	0.00
"	4	5.35	5.20	5.20	0.00
"	5	5.40	5.20	5.30	-0.10
"	6	5.30	5.15	5.05	+0.10
80 cm	1	5.30	5.15	5.10	+0.05
"	2	5.35	5.05	5.10	-0.05
"	3	5.35	5.15	5.05	+0.10
"	4	5.40	5.15	5.10	+0.05
"	5	5.40	5.20	5.15	+0.05
"	6	5.40	5.20	5.15	+0.05

TABLE 19b : Statistical analysis of the data presented in Table 19.

Depth	Bottle	Mean	Standard Deviation	Standard Error
Surface	Initial Dissolved Oxygen	5.350	0.054	0.000
"	Light Bottle	5.175	0.000	0.000
"	Dark Bottle	5.158	0.083	0.031
80 cms	Initial Dissolved Oxygen	5.366	0.031	0.000
"	Light Bottle	5.150	0.044	0.000
"	Dark Bottle	5.108	0.031	0.000

and may be responsible for natural fluctuations in primary production utilizing the oxygen evolution method.

The standard deviations of samples immediately above the sediment, for both light and dark bottles, were well below the 0.05 mg/liter limit of the titration. Statistical analysis of the data indicated that the oxygen evolution method of primary production was relatively accurate in spite of the low oxygen changes measured, or may have been insensitive to change at the particular oxygen level at which the tests were conducted.

The ability of each of the stations 1, 2 and 3 to represent the entire contour in which they were present was examined by simultaneous sampling of the three random stations within each contour.

Standard errors were calculated from the mean of the initial dissolved oxygen concentrations for both the surface and the above sediment samples. In addition, standard deviations were determined for the net values of production.

The 0 to 50 cm contour (Table 20) was characterized by large standard errors at both the surface and immediately above the sediment, indicating large differences in initial dissolved oxygen concentrations. The net values for the surface possessed a standard error which approached the limits of the method. Net values above the sediment were characterized by a low standard error.

Initial dissolved oxygen concentrations varied considerably less in the 50 to 100 cm contour (Table 20). Net values for both depths had standard errors which exceeded the limits of the dissolved oxygen test (Table 20).

From the computed statistics of the initial oxygen concentrations in the greater than 100 cm contour (Table 20), it was evident that the

TABLE 20 : Statistical analysis of the dissolved oxygen concentrations within the three contours. Samples were collected at the surface and immediately above the sediment at three stations in each of the three contours.

Contour	Depth	Analysis	Mean	Standard Deviation	Standard Error
0 to 50 cm contour					
	Surface	Initial Oxygen	5.643	0.786	0.454
	"	Light - Dark	0.026	0.068	0.039
	Depth*	Initial Oxygen	5.613	0.810	0.468
	"	Light - Dark	0.087	0.040	0.022
50 to 100 cm contour					
	Surface	Initial Oxygen	7.853	0.0927	0.0529
	"	Light - Dark	0.060	0.0818	0.0469
	Depth*	Initial Oxygen	8.637	0.060	0.035
	"	Light - Dark	0.0233	0.0927	0.0529
Greater than 100 cm contour					
	Surface	Initial Oxygen	5.937	0.500	0.286
	"	Light - Dark	0.027	0.055	0.032
	Depth*	Initial Oxygen	5.377	0.395	0.228
	"	Light - Dark	0.100	0.050	0.028

* Denotes a sample collected immediately above the sediment.

dissolved oxygen did not vary greatly. Standard errors for the net values were within the limits of the test. Data indicated that the variation in productivity was greatest in the 0 t0 50 cm contour and was more uniform in the other two contours. Therefore, primary productivity data collected for station 1 was considerably less accurate in representing the entire contour than the data collected for stations 2 and 3.

Oxygen Evolution Field Experimentation

The optimum, minimum and maximum length of incubation for oxygen productivity samples was examined by varying the length of the incubation period. Data in Figure 26 indicated a minimum incubation time of two hours and that maximum and optimum incubation times were not reached. A time period of four hours was selected for use in experiments to correspond with the carbon-14 experiment incubations. This enabled the direct comparison of primary production between the oxygen and carbon-14 methods.

The diurnal curve of photosynthesis produced by the oxygen evolution method was characterized by a bimodal curve (Figure 27). However, values were not consistent enough to apply a correction factor for daily production estimates. The morning peak of production was greater than that which occurred in the afternoon and was consistent with other studies (Doty et al 1967; Doty and Oguri 1957; Odum 1957; Verduin 1957; Ryther 1956; Jackson and McFadden 1954). It appeared from Figure 27 that the reduction in oxygen evolution corresponded to incident solar radiation (Doty et al 1967; Doty and Oguri 1957).

Utilizing gross photosynthesis measurements, Odum 1957 produced a method based on diurnal oxygen fluctuations. Other authors (McConnell 1965, 1962; Kemmerer and Neuhold 1969) have used the method with success.

FIGURE 26 :
OPTIMUM INCUBATION LENGTH , OXYGEN METHOD

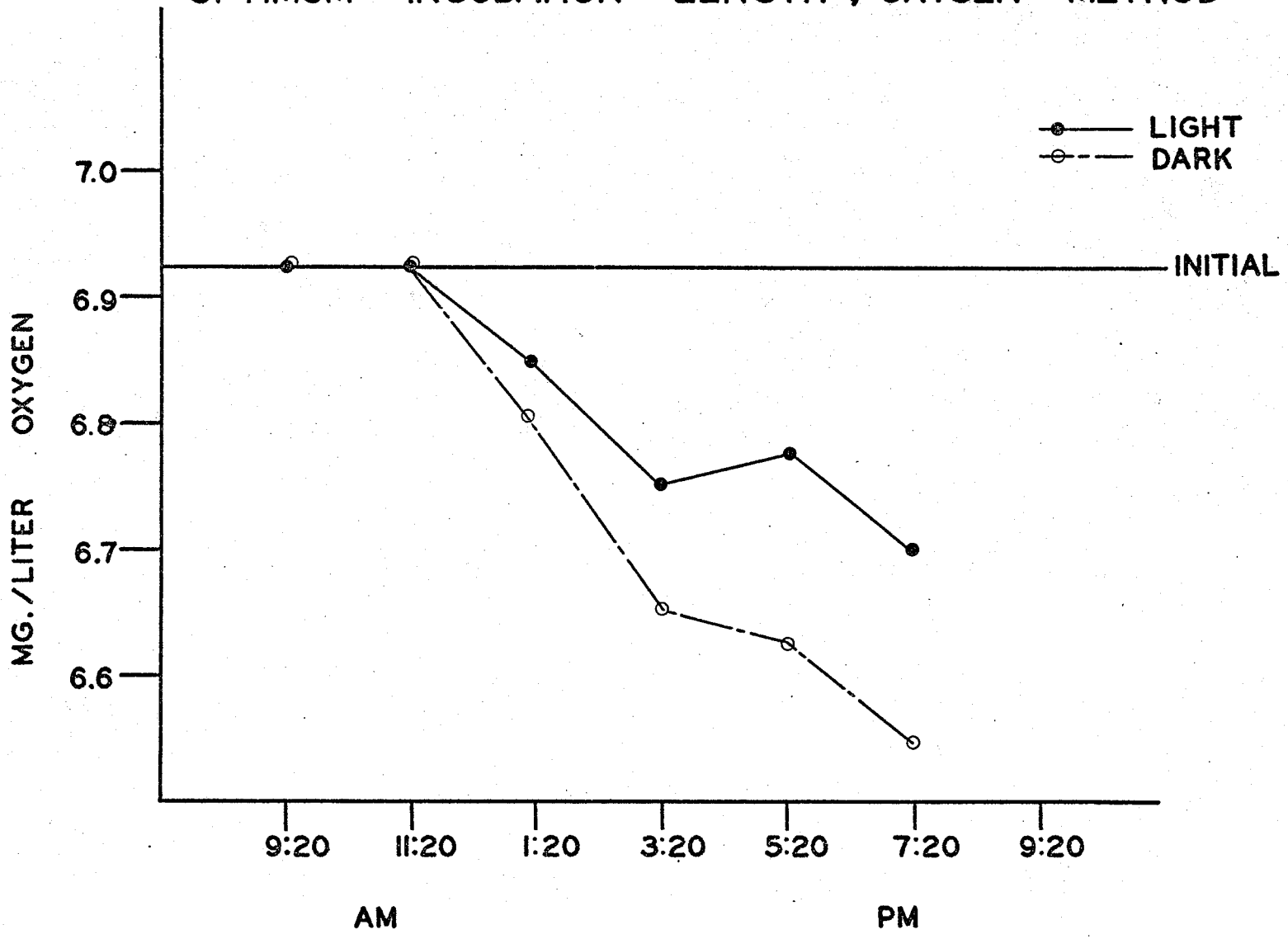
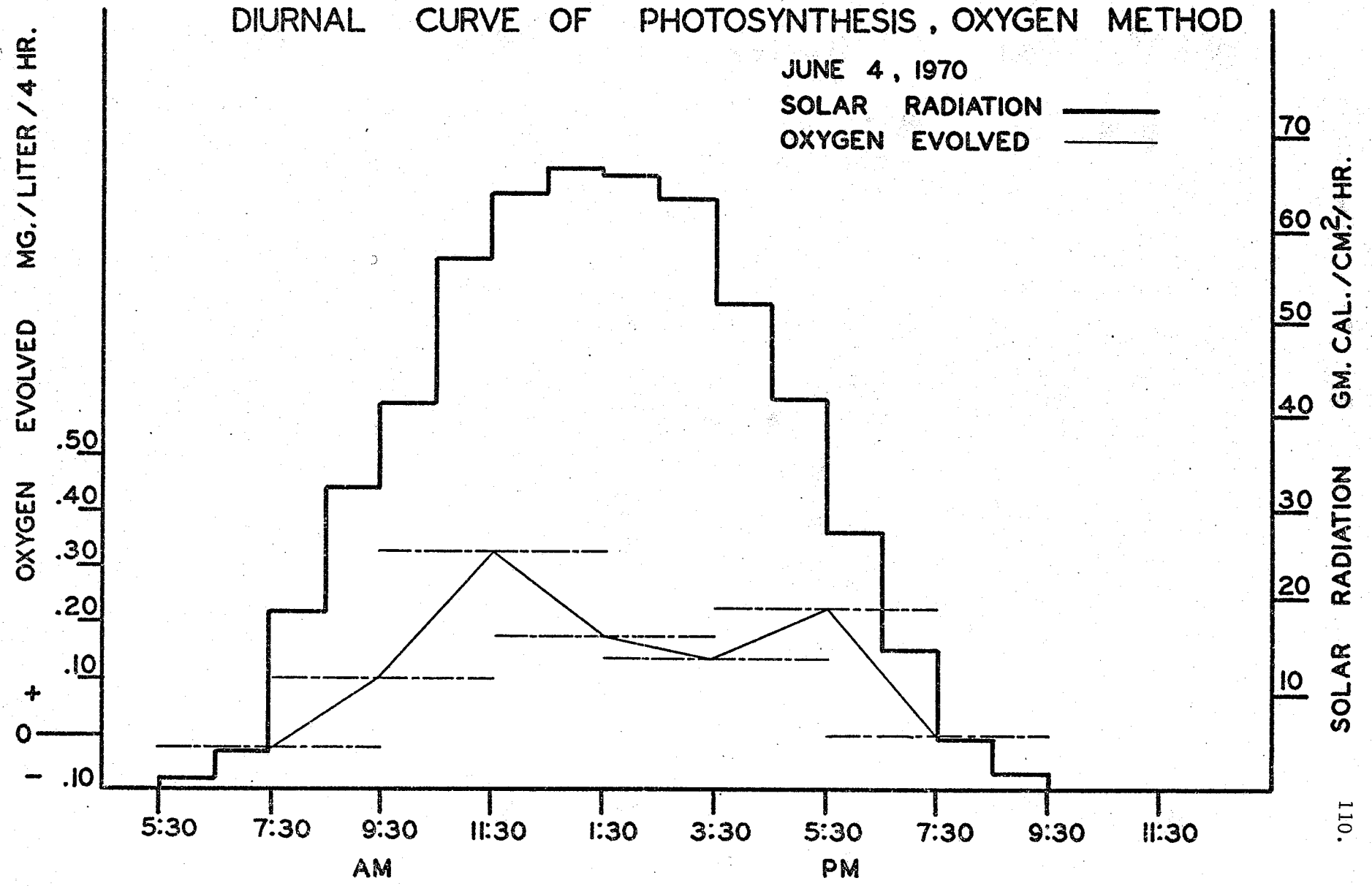


FIGURE 27 :
DIURNAL CURVE OF PHOTOSYNTHESIS , OXYGEN METHOD



Crescent Pond could have been regulated by this method if overall gross photosynthesis was the only value required.

The bimodal diurnal curve of photosynthesis was characterized by a peak production in the morning, being consistent with the findings of many authors (Newhouse et al 1967; Doty and Oguri 1957; Odum 1957; Verduin 1957; Ryther 1956; Jackson and McFadden 1954). The data indicated that the reduction in the rate of oxygen evolution was related to the amount of incident solar radiation (Newhouse et al 1967; Doty and Oguri 1957). Bamforth (1961) found the diurnal oxygen cycle to be minimal before sunrise and maximal two to three hours prior to sunset. These changes in oxygen concentrations have been attributed to the migration of planktonic organisms (Bamforth 1961; Blum 1954). If the phytoplankton migrate away from an area during the high light periods of the day, a reduction in the rate of primary production would have resulted. Although the migration may occur in other areas, it appeared that incident solar radiation was the limiting factor due to the lack of large numbers of phytoplankton capable of a migratory pattern.

The photosynthesis depth curve (Table 21) was highly irregular. A positive value was present at the 10 cm depth while zero values were recorded for the 20 and 30 cm depths. A negative value was present at the 40 cm depth, the only depth at which this occurred. A value of 0.05 mg/liter was produced at 50, 60, 70 and 80 cm depths. At 90 cm, 0.15 mg/liter were evolved.

TABLE 21 : Results of an experiment performed at station 3 to determine the photosynthetic depth curve with respect to the oxygen evolution method.

Depth	Initial Dissolved Oxygen	Light Bottle	Dark Bottle	Light - Dark
10 cms	7.90	7.75	7.60	+0.15
20 cms	7.95	7.80	7.80	+0.00
30 cms	8.00	7.75	7.75	+0.00
40 cms	7.90	7.75	7.85	-0.10
50 cms	7.90	7.85	7.80	+0.05
60 cms	7.90	7.85	7.80	+0.05
70 cms	7.95	7.80	7.75	+0.05
80 cms	7.85	7.80	7.75	+0.05
90 cms	7.85	7.80	7.65	+0.15

SUMMARY AND CONCLUSIONS

Crescent Pond had no long-term thermal stratification due to its shallow depth. However, daily temperature fluctuations were often pronounced and periodically created a micro-thermal stratification.

A relationship between pH and water depth, where an increase in pH occurred with a decrease in depth, was most noticeable in late May, mid-July and late September. The analytical carbon dioxide content declined rapidly with the increase in pH and the decrease in water depth, and reached 0 mg/l by late June at all stations. The changes in the pH, CO_2 and total alkalinity were considerable and undoubtedly had an effect on the biological components of Crescent Pond.

The concentration of dissolved oxygen often fluctuated widely among stations and between the two depths sampled. Values generally were higher in the surface than immediately above the sediment at station 1, while stations 2 and 3 were characterized by higher concentrations in the bottom waters.

The seasonal succession of the phytoplankton varied considerably among the three stations as well as between the two depths sampled. This was atypical of the larger water bodies within Delta Marsh and contained many algal forms typical of epiphytic and benthic communities. The lack of similarity in a successional pattern of the phytoplankton, among stations and between depths, was probably due to the differing ecological niches in each area.

The primary production, as determined by the carbon-14 method, was highly variable among stations and between depths. When compared to the algal succession, an association was not evident. Station 1 possessed the lowest production values but the highest algae populations. Station 2 had

intermediate productivity values while station 3 was characterized by high values of production with a low phytoplankton population. At all stations and depths, high values for dark uptake occurred sporadically and resulted in negative production values for that period.

In order to evaluate the carbon-14 method and to determine the cause of the high dark uptake, as well as the generally erratic results, a series of field and laboratory experiments were carried out. In situ experiments were carried out to determine the following:

a.) minimum, maximum and optimum incubation length,

b.) minimum, maximum and optimum amounts of incubated water to be filtered,

c.) the rate of primary production with respect to depth,

d.) the rate of primary production with respect to the diurnal rate,

e.) the extent of cellular particulate organic loss through the filter,

f.) the extent of extracellular excretion.

The statistical variability between subsamples of the same water sample and between subsamples of different water samples were examined. Results indicated that subsamples obtained from any given bottle were statistically equal, while those removed from different bottles were considerably less accurate.

Due to the erratic results obtained in most experiments, a number of additional experiments were conducted to provide conclusive evidence of particulate organic contamination within the New England Nuclear ampoules of lot numbers 555-195 (1970), 555-195 (1967) and 569-031 (1970) . Ampoules of carbon-14 were produced within the laboratory from radioactive stock solutions, and examined in an identical manner as the commercially produced ampoules. The laboratory produced ampoules were found to be free

of particulate organic matter.

Primary production as measured by the carbon-14 uptake method, was not accurate due to a particulate organic substance contained within the commercially prepared New England Nuclear ampoules. The ampoules produced in the laboratory from radioactive stock solutions contained no appreciable organic particulate contamination and are recommended for use in routine primary production studies.

The primary production values at different stations as determined by the oxygen evolution method, showed a similarity with respect to periods of increase. Production values were more closely associated with the algal fluctuations than was found during the carbon-14 analyses. Similar in situ field experiments and statistical analyses, as those conducted for the carbon-14 method, were performed utilizing the oxygen evolution method.

The oxygen evolution method was more accurate in representing the primary production of the phytoplankton component. However, if contamination had been absent from the carbon-14 ampoules, then the radio-carbon method, due to its greater accuracy at low levels of production, would probably have been more suitable considering the low numbers of phytoplankton present.

LITERATURE CITED

Akehurst, S.C. 1931. Observations on pond life, with special reference to the possible causation of swarming of phytoplankton. J. Royal Microscop. Soc. 51: 237-265.

Allen, M.B. 1962. Our knowledge of the kinds of organisms in Pacific phytoplankton. Symp. Marine Productivity In The Pacific, 10th Pac. Sci. Cong., Honolulu U.S. Atomic Energy Comm., TID-7633.

American Public Health Association. 1965. Standard methods for the examination of water and waste water, 11th ed. APHA 769 pp.

Anderson, G.C. 1958. Seasonal characteristics of two saline lakes in Washington. Limnol. Oceanogr. 3: 51-68.

Anderson, G.C., G.W. Comita and V. Engstrom-Heg. 1955. A note on the phytoplankton-zooplankton relationships in two lakes in Washington. Ecology 36: 757-759.

Anderson, G.C. and R.P. Zeutschel. 1970. Release of dissolved organic matter by marine phytoplankton in coastal and offshore areas of the Northeast Pacific Ocean. Limnol. Oceanogr. 15: 402-407.

Arthur, C.R. and F.H. Rigler. 1967. A possible source of error in the ^{14}C method of measuring primary productivity. Limnol. Oceanogr. 12: 121-124.

Atkins, W.R.G. 1922. The hydrogen ion concentration of sea water and its biological relations. J. Mar. Biol. Assoc. U.K. 12: 717-753.

_____. 1923. The hydrogen ion concentration of open sea water and its variation with depth and season. ibid 13: 754-771.

_____. 1924. The hydrogen ion concentration of sea water and its relationship to the growth of the algal plankton. ibid 13: 93, 437.

Bailey, L.W. 1925. An annotated catalogue of the diatoms of Canada showing their geographical distribution. Contributions to Can. Biology, N.S. 2: 33-65.

_____. and A.H. Mackay. 1918-1920. The diatoms of Canada. Contributions to Can. Biology, 1918-1920: 115-124.

Ballantine, D. 1953. Comparison of the different methods of estimating nannoplankton. J. Mar. Biol. Assoc. U.K. 32: 129-148.

Bamforth, S.S. 1961. Diurnal changes in shallow aquatic habitats. Limnol. Oceanogr. 7: 348-353.

Barnett, A.M. and J. Hirota. 1967. Changes in the apparent rate of ^{14}C uptake with length of incubation period in natural phytoplankton populations. Limnol. Oceanogr. 12: 349-353.

Barr, D.J.S. and C.J. Hickman. 1967a. Chytrids and algae I. Host-substrate range and morphological variation of species of Rhizophydium. Can. J. Bot. 45: 413-430.

_____ and _____. 1967b. Chytrids and algae II. Sectors influencing parasitism of Rhizophydium sphaerocarpum on Spirogyra. Can. J. Bot. 45: 431-440.

Bartsch, A.F. 1959. Algae in relation to oxidation processes in natural waters In, The Ecology of Algae, ed. by C.A. Tryon and R.T. Hartman. University of Pittsburgh. 96 pp.

Bellis, V. J. and D.A. McLarty. 1967. Ecology of Cladophora glomerata Kutz in southern Ontario. J. Phycol. 3: 57-63.

Biological Methods Panel Committee on Oceanography. 1969. Recommended Procedures for Measuring the Productivity of Plankton Standing Stock and Related Oceanic Properties. Nat. Acad. Sci., Wash. D.C. 59 pp.

Blum, J.L. 1956. The ecology of river algae. Bot Rev. 22: 291-341.

Bozniak, E.G. and L.L. Kennedy. 1968. Periodicity and ecology of the phytoplankton in an oligotrophic and eutrophic lake. Can. J. Bot. 46: 1259-1271.

Bray, G.A. 1960. A simple efficient liquid scintillator for counting aqueous solutions in a liquid scintillation counter. Anal. Biochem 1: 279-285.

Brown, D.J. 1969. Unpublished data.

Brown, A.H., E.W. Fager and H. Gaffron. 1949. Kinetics of photochemical intermediates in photosynthesis. In, Photosynthesis in Plants. Monogr. Amer. Soc. Plant Physiol., 403-422.

Bunt, J. 1969. Measurements of photosynthesis and respiration in a marine diatom with the mass spectrometer and with carbon-14. Nature 207: 1373-1375.

Canter, H.M. 1949. The importance of fungal parasitism in limnology. Verh. Int. Ver Limnol. 10: 107-108.

_____ and J.W.G. Lund. 1951. Studies on plankton parasites III. Examples of the interaction between parasitism and other factors determining the growth of diatoms. Ann. Bot. 15: 359-371.

_____ and _____. 1953. Studies on plankton parasites II. The parasitism of diatoms with special reference to lakes in the English Lake District. Trans. Brit. Mycol. Soc. 36: 13-37.

Carlucci, A.F. and P.M. Bowes. 1970a. Production of vitamin B_{12}, thiamine and biotin by phytoplankton. J. Phycol. 6: 351-357.

Carlucci, A.F. and P.M. Bowes. 1970b. Vitamin production and utilization by phytoplankton in mixed culture. J. Phycol. 6: 393-400.

Cassie, R.M. 1962 Microdistribution and other error components of ^{14}C primary production estimates. Limnol. Oceanogr. 7: 121-130.

Chandler, D.C. and O.B. Weeks. 1945. Limnological studies of Western Lake Erie V. Relation of limnological and meteorological conditions to the production of phytoplankton in 1942. Ecol. Monogr. 15: 435-457.

Daft, M.J., J. Begg and W.D.P. Stewart. 1970. A virus of blue-green algae from freshwater habitats in Scotland. New Phytol. 69: 1029-1038.

Dickman, M. 1968. The effects of grazing by tadpoles on the structure of a periphyton community. Ecology 49: 1188-1190.

Doty, M.S., H.R. Jitts, O.J. Koblentz-Mishke and Y. Saijo. 1965. Intercalibration of marine plankton primary productivity techniques. Limnol. Oceanogr. 10: 282-288.

_____, J. Newhouse and R.T. Tsuda. 1967. Daily phytoplankton productivity relative to hourly rates. Arch. Oceanogr. Limnol. 15: 1-9.

_____ and M. Oguri. 1957. Evidence for a photosynthetic daily periodicity. Limnol. Oceanogr. 2: 37-40.

Dugdale, R.C. and J.T. Wallace. 1960. Light and dark bottle experiments in Alaska. Limnol. Oceanogr. 5: 230-231.

Efford, I.E. 1967. Temporal and spatial differences in phytoplankton productivity in Marion Lake, British Columbia. J. Fish. Res. Bd. Canada 24: 2283-2307.

Elster, H.J. 1965. Absolute and relative assimilation rates in relation to phytoplankton populations. p. 77-103. In, C.R. Goldman (ed.), Primary Productivity In Aquatic Environments. Mem. Ist. Ital. Idrobiol., 18 Suppl., University of California Press, Berkeley.

Eyster, C. 1968. Microorganic and microinorganic requirements for algae. p. 27-36. In, D.F. Jackson (ed.), Algae, Man and the Environment. Proc. of an Int. Symp., Syracuse University, June 18-30, 1967.

Fogg, G.E. 1952. The production of extracellular nitrogenous substances by a blue-green alga. Proc. Roy. Soc. B 139: 372-397.

_____. 1958. Extracellular products of phytoplankton and the estimation of primary production. Rapp. Proc. Verb. Reun. 144: 56-60.

_____. 1965. Algal Cultures and Phytoplankton Ecology. University of Wisconsin Press, Madison, Wisconsin. 126 pp.

_____ and C. Nalewajko. 1964. Glycollic acid as an extracellular product of phytoplankton. Verh. Int. ver Limnol. 15: 806-810.

Fogg, G.E. and W.D. Watt. 1965. The kinetics of release of extracellular products of photosynthesis by phytoplankton. p 165-174. In, C.R. Goldman (ed.), Primary Productivity In Aquatic Environments. Mem. Ist. Ital. Idrobiol., 18 Suppl., University of California Press, Berkeley.

_____ and D.F. Westlake. 1955. The importance of extracellular products of algae in freshwater. Verh. Int. ver Limnol. 12: 219-232.

Gaarder, T. and H.H. Gran. 1927. Investigations of the production of plankton in the Oslo Fjord. J. Cons. Internat. Explor. Mer 42: 1-48.

Garrels, R.M. and C.L. Christ. 1965. Solutions, Minerals and Equilibria. Harper Row, New York.

Gerletti, M. 1969. Dark bottle measurements in primary productivity studies. Mem. Ist. Ital. Idrobiol. 23: 199-208.

Gessner, F. and F. Pannier. 1958. Influence of oxygen tension on respiration of phytoplankton. Limnol. Oceanogr. 3: 478.

Goldman, C.R. 1960. Primary productivity and limiting factors in three lakes of the Alaska Penninsula. Ecol. Monogr. 30: 207-230.

_____. 1962. A method of studying nutrient limiting factors in situ in water columns isolated by polyethylene film. Limnol. Oceanogr. 7: 99-101.

_____. 1963. The measurement of primary productivity and limiting factors in freshwater with carbon-14. Proc. Conf. Prim. Prod. Measure, U.S. Atomic Energy Commission, TID 7633, 237 pp.

_____. 1965. Micronutrient limiting factors and their detection in natural phytoplankton populations. p. 121-135. In, C.R. Goldman (ed.) Primary Productivity In Aquatic Environments. Mem. Ist. Ital. Idrobiol., 18 Suppl., University of California Press, Berkeley.

_____ and D.T. Mason. 1962. Inorganic precipitation of carbon in productivity experiments utilizing carbon-14. Science 125: 1049-1050.

_____, E. Steemann-Nielsen, R.A. Vollenweider and R.G. Wetzel. 1969. The ^{14}C light and dark bottle technique. p 70-73. In, R.A. Vollenweider (ed.), A Manual On Methods For Measuring Primary Production In Aquatic Environments, IBP Handbook #12. Blackwell Scientific Publications, Oxford. 213 pp.

Griffiths, B.M. 1923. The phytoplankton of bodies of freshwater and the factors determining its occurence and composition. J. Ecol. 11: 184-213.

Guillard, R.R.L. and P.J. Wangersky. 1958. The production of extracellular carbohydrates by some marine flagellates. Limnol. Oceanogr. 3: 449-454.

Hammer, V.T. 1964. The succession of bloom species of blue-green algae and causal factors. Verh. Int. ver Limnol. 15: 829-836.

Hardy, A.C. 1935-1936. Plankton ecology and the hypothesis of animal exclusion. Proc. of Linnean Soc. of London 148: 64-70.

Hartman, R.T. 1960. Algae and metabolites of natural waters. p 38-55. In, C.A. Tyron and R.T. Hartman (eds.), The Ecology of Algae. Special Publication #2, Pymatuning Laboratory of Field Biology, University of Pittsburgh. 96 pp.

Harvey, H.W., L.H.N. Cooper, M.V. Lebour and F.S. Russell. 1935. Plankton production and its control. J. Mar. Biol. Assoc. U.K. 20: 407.

Heukelekian, H. and A. Heller. 1940. Relation between food concentration and surface for bacterial growth. J. Bacteriol. 40: 547-558.

Holmes, R.W. 1961. Paper presented at a symposium on marine microbiology. Chicago, April, 1961.

_____ and T.M. Widrig. 1956. The ennumeration and collection of marine phytoplankton. J. Cons. Internat. Explor. Mer 22: 21-32.

Hrbacek, J. 1964. Contribution to the ecology of waterbloom forming blue-green algae Aphanizomenon flos-aquae and Microcystis aeruginosa. Verh. Int. ver Limnol. 15: 837-846.

Hutchinson, G.E. 1957. A Treatise On Limnology Vol. I. John Wiley and Sons Inc., New York. 1015 pp.

_____. 1967. A Treatise On Limnology Vol. II. John Wiley and Sons Inc., New York

Jackson, D.F. and J. McFadden. 1954. Phytoplankton photosynthesis in Sanctuary Lake, Pymatuning Reservoir. Ecology 35: 1-4.

Jitts, H.R. and B.D. Scott. 1961. The determination of zero-thickness activity in Geiger counting of C-14 solutions used in marine productivity studies. Limnol. Oceanogr. 6: 116-123.

Jorgensen, E.G. 1956. Growth inhibiting substances formed by algae. Physiol Plant. 9: 712-726.

Kalff, J. 1967. Phytoplankton abundance and primary production rates in two Arctic ponds. Ecology 48: 558-565.

_____. 1969. A diel periodicity in the optimum light intensity for maximum photosynthesis in natural phytoplankton populations. J. Fish. Res. Bd. Canada 26: 463-468.

Kemmerer, A.J. and J.M. Neuhold. 1969. A method for gross primary productivity measurements. Limnol. Oceanogr. 14: 607-610.

Kramer, P.J. 1957. Outer space in plants. Science 125: 633-635.

Krieger, W. 1933. Die Desmidiaceen der Deutschen limnologischen Sunda-expedition. Arch. Hydrobiol., Suppl. 11: 129-230.

Krogh, A. 1931. Dissolved substances as food for aquatic organisms. Biol. Rev. 6: 412-442.

Kuehne, P.E. 1941. The phytoplankton of southern and central Saskatchewan. Can. J. Res. C 19: 292-322.

Kuhl, A. 1968. Phosphate metabolism of green algae. p. 37-52. In, D.F. Jackson (ed.), Algae,Man and the Environment. Proc. of an Int. Symp. Syracuse University, June 18-30, 1967.

Kuznetov, S.I. 1955. The use of radiocarbon dioxide (C^{14}) for the study of comparitive values of photo and chemosynthesis in lakes of various types. Isotopes In Microbiology. Pub. House Acad. Sci., USSR, Moscow. pp 132-143.

Lasker, R. and R.W. Holmes. 1957. Variability in retention of marine phytoplankton by membrane filters. Nature 180: 1295-1296.

Lind, O.T. and R.S. Campbell. 1969. Comments on the use of liquid scintillation for routine determination of ^{14}C activity in production studies. Limnol. Oceanogr. 14: 787-789.

Lohmann, H. 1908. Untersuchungen zur Feststellung des rollstandigen Gehaltes des meeres an plankton. Wiss. Meeresunters. NF Abt. Kiel 10: 131-370.

Lorenzen, C.J. 1963. Diurnal variation in photosynthetic activity of natural phytoplankton populations. Limnol. Oceanogr. 8: 56-62.

Lowe, C.W. 1924. The freshwater algae of central Canada. Royal Soc. of Canada, Proc. 18(5): 19.

Lund, J.W.G. 1964. Primary productivity and periodicity in phytoplankton. Verh. Int. ver Limnol. 15: 37-56.

_____. 1965. The ecology of freshwater phytoplankton. Biol. Rev. 40: 231-293.

Margalef, R. 1965. Ecological correlations and the relationship between primary productivity and community structure. p. 355-364. In, C.R. Goldman (ed.), Primary Productivity In Aquatic Environments. Mem Ist Ital Idrobiol., 18 Suppl., University of California Press, Berkeley.

McAlice, B.J. 1970. Observations on the small scale distribution of estuarine phytoplankton. Mar. Biol. 7: 100-111.

McAllister, C.D. 1961. Observations on the variations of planktonic photosynthesis with light intensity, using both O_2 and C^{14} methods. Limnol. Oceanogr. 6: 483-485.

McCombie, A.M. 1953. Factors influencing the growth of phytoplankton. J. Fish. Res. Bd. Canada 10: 253-282.

McConnell, W.J. 1962. Productivity relations in carboy microcosms. Limnol. Oceanogr. 7: 335-343.

_____. 1965. Relationship of herbivore growth to rate of gross photosynthesis in microcosms. Limnol. Oceanogr. 10:539-543.

Nalewajko, C. and L. Marin. 1969. Extracellular production in relation to growth of four planktonic algae and of phytoplankton populations from Lake Ontario. Can. J. Bot. 47: 405-413.

Newhouse, J., M.S. Doty and R.T. Tsuda. 1967. Some diurnal features of a nertic surface population. Limnol. Oceanogr. 12:207-212.

Nygaard, G. 1955. On the productivity of five Danish waters. Verh. Int ver Limnol. 12: 123-133.

Odum, H.T. 1957. Primary production measurements in eleven Florida springs and a marine turtle-grass community. Limnol. Oceanogr. 2: 85-97.

Ohle, W. 1958. Diurnal production and destruction rates of phytoplankton in lakes. Rapp. Proc. Verb. Reun. 144: 129-131.

_____. 1961. Tagesrhythmen der photosynthese von planktonbiocoesen. Verh. Int. ver Limnol. 14: 113-119.

Paasche, E. 1961. On the relationship between primary production and standing crop of phytoplankton. J. Cons. Internat. Explor. Mer 26: 33-48.

Patrick, R. 1948. Factors affecting the distribution of diatoms. Bot. Rev. 14: 473-524.

_____ and C.W. Reimer. 1966. The Diatoms of the United States. Monogr. Acad. Nat. Sci. Philadelphia 13. 688p.

Pearsall, W.H. 1932. Phytoplankton in the English Lakes II. The composition of the phytoplankton in relation to dissolved substances. J. Ecol. 20; 241-262.

Pennak, R.W. 1946. The dynamics of freshwater plankton populations. Ecol. Monogr. 16: 339-355.

Platt, T. and B. Irwin. 1968. Primary productivity measurements in St. Margrets Bay, 1967. Canada Fish. Res. Bd. Tech. Rept. #77.

Pratt, D.M. and H. Berkson. 1959. Two sources of error in the oxygen light and dark bottle method. Limnol. Oceanogr. 4: 328-334.

Prescott, G.W. 1951. Algae of the Western Great Lakes Region. Wm. C. Brown Co., Dubuque, Iowa. 977 pp.

Prescott, G.W. 1956. A guide to the literature on ecology and life histories of the algae. Bot. Rev. 22: 167-240.

Pugh, P.R. 1970. Liquid scintillation counting of 14-C diatom material on filter papers for use in productivity studies. Limnol. Oceanogr 15: 652-655.

Rawson, D.S. 1953. The standing crop of net plankton in lakes. J. Fish. Res. Bd. Canada 10: 224-237.

_____. 1955. Morphometry as a dominant factor in the productivity of large lakes. Verh. Int. ver Limnol. 12: 164-175.

_____. 1956. Algal indicators of trophic lake types. Limnol. Oceanogr. 1: 18-25.

_____. 1960. A limnological comparison of twelve large lakes in Northern Saskatchewan. Limnol. Oceanogr. 5: 195-211.

Rhode, W. 1958. The primary production in lakes: Some results and restrictions of the method (^{14}C). Rapp. Proc. Verb. Reun. 144: 122-128.

_____, R.A. Vollenweider and A. Nauwerck. 1958. The primary production and standing crop of algae. In, A.A. Buzzati-Traverso (ed), Perspectives In Marine Biology. University of California Press, Berkeley. 621.pp.

Richmond, S.B. 1964. Statistical Analysis, 2nd. edition. Ronald Press, New York. 633 pp.

Riley, G.A. 1940. Limnological studies in Connecticut III. The plankton of Linsley Pond. Ecol. Monogr. 10: 279-306.

Ryther, J.H. 1956. Photosynthesis in the ocean as a function of light intensity. Limnol. Oceanogr. 1: 61-70.

_____.1958. The ratio of photosynthesis to respiration in marine plankton algae and its affect on the measurement of productivity. Deep Sea Res. 2: 134-139.

_____ and R.F. Vaccaro. 1954. A comparison of the oxygen and C^{14} methods of measuring marine photosynthesis. J. Cons. Internat. Explor. Mer 20: 25-37.

Saijo, J.H. and S. Ichimura. 1962. A review of the recent development of techniques measuring primary production. Proc. Conf. Prim. Prod. Measure. U.S. Atomic Energy Commission, TID 7633. 237 pp.

Saunders, G.W. 1957. Interrelation of dissolved organic matter and phytoplankton. Bot. Rev. 23: 389-499.

Schindler, D.W. 1966. A liquid scintillation method for measuring C^{14} uptake in photosynthesis. Nature 211: 844-845.

Schindler, D.W. and S.K. Holmgren. 1971. Primary production and the phytoplankton in the Experimental Lakes Area, Northwestern Ontario, and other low-carbonate waters, and a liquid scintillation method for determining ^{14}C activity in photosynthesis. J. Fish. Res. Bd. Canada 28: 189-201.

Sorokin, Yu. I. 1955. Akademiia Nauk. SSSR 105: 1343-1345.

_____. 1956. The use of radioactive carbon C^{14} for studying the production of reservoirs. Tr. Vses. Gidrobiol. Obsch. 7: 271-286.

Steemann-Nielsen, E. 1951. Measurement of the production of organic matter in the sea by means of carbon-14. Nature 167: 684-685.

_____.1952. The use of radioactive carbon (C^{14}) for measuring organic production in the sea. J. Cons. Internat. Explor. Mer 18: 117-140.

_____. 1955. The interaction of photosynthesis and respiration and its importance for the determination of C^{14} discrimination in photosynthesis. Physiol. Planta 8: 945-953.

_____. 1958. Experimental methods for measuring organic production in the sea. Rapp. Proc. Verb. Reun. 144: 92-95.

_____. 1960. Fertility of the oceans, Productivity, definition and measurement. In, The Sea.

_____. 1960a. Dark fixation of CO_2 and measurements of organic production, with remarks on chemosynthesis. Physiol. Planta 13: 348-357.

_____. 1964. On a complication in marine productivity work due to the interference of ultraviolet light. J. Cons. Internat. Explor. Mer. 29: 130-135.

_____ and V.K. Hansen. 1959. Measurements with C^{14} technique of the respiration rates in natural populations of phytoplankton. Deep Sea Res. 5: 222-232.

_____ and A. Kholy. 1956. Use of C^{14} technique in measuring photosynthesis of phosphorus or nitrogen deficient algae. Physiol. Planta 9: 144-153.

Stern, D.H. 1968. A limnological investigation of the microbiota of an Illinois pond. Amer. Midland Natur. 79: 476-498.

Stewart, W.D.P. 1968. Nitrogen input into aquatic ecosystems. p. 33-72. In, D.F. Jackson (ed.), Algae, Man and the Environment. Proc. of an Int. Symp., Syracuse University, June 18-30, 1967.

Strickland, J.D.H. 1960. Measuring the production of marine phytoplankton. Fish. Res. Bd. Canada Bull. # 122.

Strickland, J.D.H. and T.R. Parsons. 1968. A practical handbook of seawater analysis. Fish. Res. Bd. Canada Bull. # 167.

Taylor, C.B. and V.G. Collins. 1948. Development of bacteria in waters stored in glass containers. J. Gen. Microbiol. 3: 32-42.

Vance, D.B. 1965. Composition and succession of Cyanophycean water blooms. J. Phycol. 1: 81-86.

van Norman, R.W. and A.H. Brown. 1952. The relative rates of photosynthetic assimilation of isotopic forms of carbon dioxide. Plant Physiol. 27: 691-709.

Verduin, J. 1957. Daytime variations in phytoplankton photosynthesis. Limnol. Oceanogr. 2: 333-336.

Vinberg, G.G. 1960. The Primary Production of Bodies of Water. U.S. Atomic Energy Commission Translation, TR 5692. 601 pp.

Vinetskaya, N.I. 1956. The influence of green fertilization on the production of organic matter and hydrochemical regime of fish farm "Yamat". Tr. All-Union Sc. Res. Inst. Maratime Fish Ind. and Oceanogr. 32: 29-53.

Vollenweider, R.A. 1965. Calculation models of photosynthesis depth curves and some implications regarding day rate estimates in primary production measurements. p. 425-457. In, C.R. Goldman (ed.), Primary Productivity In Aquatic Environments. Mem. Ist. Ital Idrobiol., 18 Suppl., University of California, Berkeley.

_____. 1969. A Manual On Methods For Measuring Primary Production In Aquatic Environments. IBP Handbook #12. Blackwells, Oxford, England. 213 pp.

_____ and A. Nauwerck. 1961. Some observations on the C^{14} method for measuring primary production. Verh. Int. ver Limnol. 14: 134-139.

Walker, J.M. 1965. Vegetation changes with falling water levels in the Delta Marsh, Manitoba. PhD Thesis, University of Manitoba, Dept. of Botany.

Wallen, D.J. and G.H. Geen. 1968. Loss of radioactivity during storage of ^{14}C-labelled phytoplankton on membrane filters. J. Fish. Res. Bd. Canada 25: 2219-2224.

Wang, C.H. and D.L. Willis. 1965. Radiotracer Methodology in Biological Science. Prentice-Hall. 366 pp.

Ward, F.J. and M. Nakanishi. 1971. A comparison of Geiger-Mueller and liquid scintillation counting methods in estimating primary productivity. Limnol. Oceanogr. 16: 560-563.

Wetzel, R.G. 1964. A comparitive study of the primary productivity of higher plants, periphyton and phytoplankton in a large shallow lake. Int. Rev. Ges. Hydrobiol. 49: 1-61.

Wetzel, R.G. 1965. Nutritional aspects of algal productivity in marl lakes with particular reference to enrichment bioassays and their interpretation p. 137-157. In, C.R. Goldman (ed.), Primary Productivity In Aquatic Environments. Mem. Ist. Ital. Idrobiol., 18 Suppl., University of California Press, Berkeley.

Wolfe, D.A. and C.L. Schelske. 1967. Liquid scintillation and Geiger counting efficiencies for carbon-14 incorporation by marine phytoplankton in productivity measurements. J. Cons. Internat. Explor. Mer 31: 31-37.

Wright, J. 1971. Personal communication.

Yentsch, C.S. and R.W. Lee. 1966. A study of photosynthetic light reactions and a new interpretation of sun and shade phytoplankton. J. Mar. Res. 24: 319-337.

Zobell, C.E. and Q. Anderson. 1936. Observations on the multiplication of bacteria in different volumes of stored sea water and the influence of oxygen tension and solid surfaces. Biol. Bull. 61: 324-332.

APPENDICES

APPENDIX 1 : Determination of total activity of New England Nuclear ampoules (Lot Number 555-195, 1970) derived from three - one lambda aliquots from each of three ampoules.

Ampoule	Aliquot	cpm-Background	Efficiency	dpm	Specific Activity
1	a	32751.3	81.5	40185.6	10.05×10^6
1	b	30324.0	79.0	38384.8	9.60×10^6
1	c	32751.3	82.0	29940.6	9.99×10^6
2	a	33420.0	81.5	41006.1	10.25×10^6
2	b	31491.0	80.0	39363.8	9.84×10^6
2	c	31491.0	81.5	38639.3	9.66×10^6
3	a	32108.8	80.5	30886.7	9.97×10^6
3	b	31491.0	80.5	39119.3	9.78×10^6
3	c	30324.0	81.0	37437.0	9.36×10^6

Sum of Specific Activity : 88.50×10^6

Mean Specific Activity : 9.833×10^6

APPENDIX 2 : Determination of total activity of laboratory produced ampoules (Amersham-Searle stock solution) derived from three - one lambda aliquots from each of five ampoules.

Ampoule	Aliquot	cpm-Background	Efficiency	dpm	Specific Activity
1	a	6924.5	81.0	8548.8	8.549×10^6
1	b	6924.5	80.5	8601.9	8.602×10^6
1	c	7136.7	81.0	8810.7	8.811×10^6
2	a	7362.3	81.0	9089.3	9.089×10^6
2	b	7674.1	80.5	9533.0	9.533×10^6
2	c	7296.4	80.5	9063.9	9.064×10^6
3	a	7362.3	80.0	9202.9	9.203×10^6
3	b	7429.4	80.5	9229.1	9.229×10^6
3	c	7074.7	81.0	8734.2	8.734×10^6
4	a	6308.0	81.0	7787.7	7.788×10^6
4	b	6141.5	80.5	7629.2	7.629×10^6
4	c	6211.8	80.5	7716.5	7.717×10^6
5	a	6954.0	80.5	8638.5	8.639×10^6
5	b	7199.0	81.0	8887.7	8.888×10^6
5	c	6752.3	80.5	8388.0	8.388×10^6

Sum of Total Activity : 129.86×10^6

Mean Total Activity : 8.656×10^6

APPENDIX 3 : Temperature regime of Crescent Pond for the summer of 1970. The temperature was recorded in degrees centigrade.

Date	Station 1 Surface	Station 1 Bottom*	Station 2 Surface	Station 2 Bottom*	Station 3 Surface	Station 3 Bottom*	Mean
May 12			7.0				7.0
May 15			5.8				5.8
May 17			13.5				13.5
May 21	15.0	12.5	14.5	14.3	14.8	14.0	14.2
May 22			17.0				17.0
May 23			18.0				18.0
May 26	13.0	12.8	13.0	12.8	12.8	11.3	12.6
May 29			13.0				13.0
June 2	23.0	22.3	23.5	22.5	23.0	23.0	22.9
June 5			21.5				21.5
June 6			23.8				23.8
June 9	20.0	20.0	20.0	20.0	20.0	20.0	20.0
June 10			20.5				20.5
June 11	19.5	19.5	20.0	20.0	20.0	20.0	19.83
June 12			19.5				19.5
June 13			22.0				22.0
June 14			24.0				24.0
June 16	21.0	21.0	21.5	21.5	21.8	21.8	21.4
June 19			18.5				18.5
June 20	21.5	21.5	20.5	21.0	20.0	20.0	20.8
June 23	18.5	18.5	18.0	18.0	18.0	18.0	18.1
June 24			23.5				23.5
June 25			20.5				20.5
June 30	22.0	22.0	22.3	22.5	22.5	23.0	22.4
July 5			21.0				21.0
July 9	23.5	23.5	23.3	23.0	23.0	23.0	23.2
July 10			26.3				26.3
July 14	28.0	27.0	28.0	27.0	27.0	27.0	27.34
July 17			23.5				23.5
July 22					21.5	21.5	21.5

* Refers to sample temperature taken immediately above the benthic sediments

continued.....

APPENDIX 3 : continued

Date	Station 1 Surface	Station 1 Bottom*	Station 2 Surface	Station 2 Bottom*	Station 3 Surface	Station 3 Bottom*	Mean
July 23	19.5	19.5	19.8	19.8	19.8	19.8	19.7
July 24			19.5				19.5
July 27	24.5	22.5	24.0	24.0	23.3	23.5	23.6
July 28	23.5	23.0	24.0	23.5	23.8	23.8	23.6
July 30	24.0	24.5	24.0	24.5	24.0	24.0	24.2
July 31			21.0				21.0
Aug. 4	19.5	19.0	20.0	19.5	20.0	20.0	19.7
Aug. 6	24.5	24.0	24.5	24.0	24.0	24.0	24.2
Aug. 7			25.0				25.0
Aug. 11	22.0	21.5	22.5	22.5	23.0	23.0	22.4
Aug. 13	25.0	24.5	24.0	24.0	24.5	24.0	24.33
Aug. 14			22.0				22.0
Aug. 18	23.5	23.0	22.0	22.0	22.0	22.0	22.42
Aug. 20	17.0	17.0	16.5	16.5	16.5	16.5	16.8
Aug. 21			15.0				15.0
Aug. 24	18.5	18.0	18.0	18.0	18.0	18.0	18.1
Aug. 28			18.0				18.0
Sept. 1	17.0	16.8	17.3	17.3	17.5	17.3	17.2
Sept. 3	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Sept. 8	15.5	15.5	16.0	16.0	16.5	16.0	15.9
Sept. 10	12.0	11.8	12.0	12.0	13.5	13.5	12.5
Sept. 13	10.5	10.5	9.5	9.5	9.0	9.0	9.7
Sept. 15	10.0	10.0	10.0	9.5	9.5	9.5	9.75
Sept. 18	12.3	12.3	13.5	13.5	13.5	13.5	13.1
Oct. 4	6.0	6.0	7.0	7.0	10.5	10.4	7.8
Oct. 25	7.5	7.5			7.5	7.5	7.5

* Refers to sample temperature taken immediately above the benthic sediments.

APPENDIX 4 : pH, carbon dioxide and alkalinity values for Crescent Pond during the summer of 1970 (Station 1).

Date	Depth	pH	Carbon Dioxide	Phenolphthalein Alkalinity	Total Alkalinity
May 27	Surface	8.00	7.0 mg/1	0.0 mg/1	178 mg/1
	Depth*	8.00	6.5	0.0	178
June 3	Surface	7.90	5.0	0.0	205
	Depth	7.90	6.0	0.0	208
June 10	Surface	7.80	7.0	0.0	214
	Depth	7.70	8.0	0.0	216
June 17	Surface	7.90	6.0	0.0	214
	Depth	7.90	6.0	0.0	216
June 24	Surface	8.00	7.0	0.0	214
	Depth	7.90	7.5	0.0	214
July 1	Surface	8.35	0	3.0	263
	Depth	8.30	0	0.0	267
July 9	Surface	8.60	0	10.0	281
	Depth	8.60	0	8.0	270
July 15	Surface	8.15	3.0	0.0	237
	Depth	8.18	2.0	0.0	231
July 22	Surface	8.65	0	14.0	270
	Depth	8.60	0	12.0	257
July 29	Surface	8.50	0	8.0	248
	Depth	8.50	0	8.0	245
Aug. 13	Surface	8.70	0	20.0	266
	Depth	8.75	0	20.0	266
Aug. 18	Surface	8.95	0	32.0	289
	Depth	8.80	0	25.0	271

* Depth denotes a sample collected immediately above the sediments.

continued.....

APPENDIX 4 : continued

Date	Depth	pH	Carbon Dioxide	Phenolphthalein Alkalinity	Total Alkalinity
Aug. 24	Surface	9.05	0 mg/1	34.0 mg/1	272 mg/1
	Depth*	8.95	0	36.0	284
Aug. 31	Surface	9.15	0	38.0	261
	Depth	9.13	0	37.0	260
Sept. 8	Surface	9.15	0	39.0	267
	Depth	9.15	0	38.0	263
Sept. 13	Surface	8.90	0	24.0	276
	Depth	8.90	0	24.0	272
Sept. 19	Surface	8.80	0	18.0	275
	Depth	8.80	0	18.0	276
Oct. 4	Surface	8.70	0	17.0	317
	Depth	8.70	0	15.0	278
Oct. 25	Surface	8.60	0	15.0	317
	Depth	8.60	0	16.0	317

* Depth denotes a sample collected immediately above the sediments.

APPENDIX 5 : pH, carbon dioxide and alkalinity values for Crescent Pond during the summer of 1970 (Station 2).

Date	Depth	pH	Carbon Dioxide	Phenolphthalein Alkalinity	Total Alkalinity
May 27	Surface	8.10	6.0 mg/1	0 mg/1	170 mg/1
	Depth*	8.10	6.5 mg/1	0 mg/1	173 mg/1
June 3	Surface	7.90	5.0	0	202
	Depth	7.90	5.0	0	202
June 10	Surface	7.85	6.5	0	214
	Depth	7.85	6.5	0	217
June 17	Surface	8.00	5.0	0	218
	Depth	8.00	5.0	0	220
June 24	Surface	8.20	5.5	0	222
	Depth	8.15	3.5	0	218
July 1	Surface	8.50	0	11.0	265
	Depth	8.50	0	13.0	265
July 9	Surface	8.70	0	16.0	287
	Depth	8.70	0	20.0	279
July 15	Surface	8.10	5.0	0	245
	Depth	8.10	5.0	0	239
July 22	Surface	8.90	0	29.0	263
	Depth	8.70	0	16.0	255
July 29	Surface	8.50	0	7.0	248
	Depth	8.50	0	8.0	248
Aug. 13	Surface	8.90	0	28.0	265
	Depth	8.90	0	24.0	266
Aug. 18	Surface	8.80	0	24.0	266
	Depth	8.85	0	28.0	268

* Depth denotes a sample collected immediately above the sediments.

continued.....

APPENDIX 5 : continued

Date	Depth	pH	Carbon Dioxide	Phenolphthalein Alkalinity	Total Alkalinity
Aug. 24	Surface	9.10	0 mg/1	46.0 mg/1	271 mg/1
	Depth*	9.15	0	46.0	270
Aug. 31	Surface	9.18	0	39.0	258
	Depth	9.20	0	40.0	258
Sept. 8	Surface	9.00	0	28.0	261
	Depth	8.95	0	27.0	263
Sept. 13	Surface	9.10	0	34.0	264
	Depth	9.10	0	34.0	266
Sept. 19	Surface	8.83	0	22.0	276
	Depth	8.83	0	21.0	273
Oct. 4	Surface	8.80	0	18.0	278
	Depth	8.80	0	18.0	280
Oct. 25	Surface	8.60	0	14.0	318
	Depth	8.70	0	16.0	321

* Depth denotes a sample collected immediately above the sediments.

APPENDIX 6 : pH, carbon dioxide and alkalinity values for Crescent Pond during the summer of 1970 (Station 3).

Date	Depth	pH	Carbon Dioxide	Phenolphthalein Alkalinity	Total Alkalinity
May 27	Surface	8.10	7.0 mg/1	0.0 mg/1	175 mg/1
	Depth*	8.10	7.5	0.0	176
June 3	Surface	8.20	2.0	0.0	213
	Depth	8.15	1.0	0.0	201
June 10	Surface	8.10	2.5	0.0	223
	Depth	8.10	3.5	0.0	220
June 17	Surface	8.10	4.5	0.0	220
	Depth	8.20	4.0	0.0	222
June 24	Surface	8.10	3.0	0.0	216
	Depth	8.20	5.0	0.0	223
July 1	Surface	8.35	0	3.0	276
	Depth	8.50	0	7.5	265
July 9	Surface	8.70	0	18.0	274
	Depth	8.70	0	20.0	280
July 15	Surface	8.15	4.0	0	235
	Depth	8.15	4.0	0	237
July 22	Surface	8.55	0	12.0	253
	Depth	8.70	0	15.0	263
July 29	Surface	8.75	0	10.0	245
	Depth	8.70	0	11.0	250
Aug. 13	Surface	9.00	0	30.0	260
	Depth	9.00	0	36.0	264
Aug. 18	Surface	8.95	0	30.0	268
	Depth	8.95	0	30.0	266

* Depth denotes a sample collected immediately above the sediment.

APPENDIX 6 : continued

Date	Depth	pH	Carbon Dioxide	Phenolphthalein Alkalinity	Total Alkalinity
Aug. 24	Surface	9.20	0 mg/1	30.0 mg/1	268 mg/1
	Depth*	9.20	0	52.0	274
Aug. 31	Surface	9.30	0	51.0	262
	Depth	9.30	0	51.0	262
Sept. 8	Surface	9.40	0	52.0	261
	Depth	9.40	0	54.0	261
Sept. 13	Surface	9.15	0	37.0	263
	Depth	9.20	0	37.0	264
Sept. 19	Surface	9.45	0	59.0	262
	Depth	9.45	0	62.0	265
Oct. 4	Surface	8.90	0	40.0	270
	Depth	8.90	0	36.0	271
Oct. 25	Surface	9.00	0	34.0	315
	Depth	9.00	0	35.0	314

* Depth denotes a sample collected immediately above the sediment

APPENDIX 7 : Phytoplankton population in cells per liter at Station 1, surface during the summer of 1970.

Date	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae	Chrysophyceae
May 26	3,132,000	304,000	-	-	-
June 10	78,000	14,000	47,600	-	-
June 17	96,200	99,000	2,110	-	-
June 23	224,550	34,600	-	-	1,500
June 29	57,000	8,650	-	-	-
July 9	166,250	21,250	-	-	-
July 13	196,875	23,500	-	-	-
July 22	345,625	17,725	1,228,750	1,250	-
July 27	105,000	9,400	136,500	4,500	-
Aug. 4	177,000	10,000	475,500	-	-
Aug. 11	129,000	37,250	1,770,000	-	-
Aug. 18	346,250	18,750	351,250	2,500	-
Aug. 24	313,750	13,000	572,500	1,250	-
Aug. 31	196,250	16,250	63,750	1,250	1,250
Sept. 7	357,000	3,500	-	18,000	-
Sept. 13	514,500	42,000	111,940	14,000	-
Sept. 19	549,000	27,000	56,250	11,250	-
Oct. 4	596,600	75,600	-	2,000	-
Oct. 25	125,000	21,000	140,000	-	-

APPENDIX 8 : Phytoplankton population in cells per liter at Station 1, immediately above the sediment, during the summer of 1970.

Date	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae	Chrysophyceae
May 26	3,041,000	353,500	31,500	10,500	7,000
June 10	120,415	290,983	41,940	10,670	2,670
June 17	58,200	96,000	6,450	-	1,500
June 23	25,450	30,000	5,000	-	1,000
June 29	183,000	7,000	-	-	-
July 9	52,500	11,325	-	-	-
July 13	346,000	22,000	-	2,000	2,000
July 22	689,000	29,375	597,500	2,500	-
July 27	108,500	18,250	30,000	4,000	-
Aug. 4	173,750	29,500	552,500	-	-
Aug. 11	175,000	8,250	1,530,000	-	-
Aug. 18	150,000	29,375	239,000	3,000	2,000
Aug. 24	552,000	72,000	72,000	6,000	-
Aug. 31	113,000	13,375	-	2,000	-
Sept. 7	425,000	33,275	-	10,000	5,000
Sept. 13	504,000	28,000	144,060	12,000	-
Sept. 19	876,200	79,300	161,260	19,500	-
Oct. 4	787,100	403,500	75,000	15,000	-
Oct. 25	146,250	8,750	-	-	-

APPENDIX 9 : Phytoplankton population in cells per liter at Station 2, surface during the summer of 1970.

Date	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae	Chrysophyceae
May 26	3,556,000	464,000	-	-	-
June 10	30,000	208,750	18,750	1,250	-
June 17	24,600	48,000	75,020	-	-
June 23	44,600	30,000	5,770	-	-
June 29	143,750	10,250	-	2,500	-
July 9	91,250	20,175	-	-	-
July 13	437,000	21,250	-	-	-
July 22	288,000	6,450	270,000	-	-
July 27	290,000	12,250	538,000	2,000	-
Aug. 4	226,500	5,125	375,000	-	-
Aug. 11	168,000	8,000	103,000	-	-
Aug. 18	40,500	3,000	-	6,000	-
Aug. 24	66,250	17,500	-	2,500	-
Aug. 31	51,000	37,500	12,000	4,500	-
Sept. 7	64,750	22,750	33,250	-	-
Sept. 13	102,000	66,750	252,940	-	-
Sept. 19	112,500	15,750	-	9,000	-
Oct. 4	127,500	48,000	-	1,500	-
Oct. 25	48,000	104,000	30,000	1,500	-

APPENDIX 10 : Phytoplankton population in cells per liter at Station 2, immediately above the sediment, during the summer of 1970.

Date	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae	Chrysophyceae
May 26	2,382,000	90,000	99,000	-	-
June 10	90,180	159,320	21,140	-	-
June 17	53,200	45,000	-	-	-
June 23	80,700	121,300	38,020	-	-
June 29	133,550	27,275	-	-	-
July 9	164,000	17,750	-	-	-
July 13	1,101,500	32,250	-	-	-
July 22	579,000	15,000	108,000	-	-
July 27	177,500	5,875	156,250	1,250	-
Aug. 4	220,000	16,800	248,000	-	-
Aug. 11	307,500	23,500	561,250	-	-
Aug. 18	53,750	16,500	25,000	1,250	-
Aug. 24	57,000	13,500	75,000	-	-
Aug. 31	69,750	11,250	-	4,500	-
Sept. 7	58.750	24,750	-	6,250	-
Sept. 13	101,400	64,075	548,060	7,800	-
Sept. 19	48,000	22,000	-	8,000	-
Oct. 4	100,000	8,000	-	-	-
Oct. 25	82,500	20,000	-	-	-

APPENDIX 11 : Phytoplankton population in cells per liter at Station 3, surface during the summer of 1970.

Date	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae	Chrysophyceae
May 26	2,568,000	273,000	-	3,000	-
June 10	68,000	220,000	119,340	-	-
June 17	128,040	43,520	132,000	-	1,500
June 23	16,300	69,250	18,000	-	-
June 29	46,400	24,700	5,910	1,000	-
July 9	36,000	81,000	-	1,500	-
July 13	75,000	40,500	-	-	-
July 22	120,000	10,000	90,000	-	4,000
July 27	92,000	8,000	18,000	4,000	-
Aug. 4	43,000	10,250	4,000	2,000	-
Aug. 11	110,000	5,000	-	-	-
Aug. 18	136,000	32,000	50,000	-	-
Aug. 24	181,500	19,900	-	-	-
Aug. 31	117,500	12,500	12,500	-	-
Sept. 7	45,000	1,250	389,625	26,250	-
Sept. 13	25,000	21,250	555,000	8,750	-
Sept. 19	26,250	-	555,000	8,750	-
Oct. 4	29,750	24,500	-	1,750	-
Oct. 25	15,000	5,000	-	-	-

APPENDIX 12 : Phytoplankton population in cells per liter at Station 3, immediately above the sediment, during the summer of 1970.

Date	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae	Chrysophyceae
May 26	2,936,000	520,000	32,000	-	-
June 10	102,000	646,040	116,780	2,000	-
June 17	297,600	44,040	-	-	-
June 23	76,300	132,050	-	-	-
June 29	61,500	6,375	-	-	-
July 9	29,650	41,775	2,000	-	-
July 13	226,025	251,250	-	-	-
July 22	110,000	4,825	80,000	2,000	-
July 27	247,000	42,625	68,000	2,000	-
Aug. 4	71,000	1,500	30,000	3,000	-
Aug. 11	328,750	13,750	72,500	-	-
Aug. 18	186,000	9,000	30,000	6,000	-
Aug. 24	57,000	13,500	75,000	-	-
Aug. 31	110,000	2,000	-	-	-
Sept. 7	38,750	2,500	333,000	18,750	-
Sept. 13	12,000	32,000	666,000	4,000	-
Sept. 19	16,000	4,000	640,000	7,000	-
Oct. 4	19,500	2,700	30,000	-	-
Oct. 25	11,000	7,000	-	-	1,000

APPENDIX 13 : Determination of the variation in photosynthesis with depth within Crescent Pond. The experiment was conducted at Station 3.

Depth	Bottle	cpm - Background	Efficiency	dpm	Light - Dark
Surface	Light	2252.4	74.0%	3043.8	
"	Dark	368.8	75.0	491.7	2552.1
15 centimeter	Light	2255.5	74.0	3048.0	
15 "	Dark	1679.2	73.5	2284.6	763.4
30 centimeter	Light	2403.2	74.0	3247.6	
30 "	Dark	1486.2	72.5	2049.9	1197.7
45 centimeter	Light	1764.0	70.0	2520.0	
45 "	Dark	1320.6	74.0	1784.6	735.4
60 centimeter	Light	406.9	74.5	546.2	
60 "	Dark	1626.4	73.5	2212.8	-1666.6
75 centimeter	Light	1969.0	73.5	2678.9	
75 "	Dark	1578.4	74.0	2133.0	545.9
90 centimeter	Light	1976.3	65.5	3017.3	
90 "	Dark	1174.7	74.0	1587.4	1429.9
105 centimeter	Light	1947.6	75.0	2596.8	
105 "	Dark	1214.0	75.0	1618.7	978.1

APPENDIX 14 : Results of a carbon-14 uptake experiment to determine the diurnal variation in photosynthesis of Crescent Pond.

Incubation Time	Bottle	cpm - Background	Efficiency	dpm	Mean	Light - Dark
5:00 AM to 9:00 AM	Light	1173.8	72.5%	1619.0		
	Light	1257.9	73.5	1711.4	1665.2	
	Dark	845.8	73.0	1150.7		+530.4
	Dark	816.8	73.0	1118.9	1134.8	
7:00 AM to 11:00 AM	Light	92.9	74.0	125.5		
	Light	89.9	72.0	124.7	125.1	
	Dark	926.1	72.5	1277.4		-1157.4
	Dark	927.1	72.0	1287.6	1282.5	
9:00 AM to 1:00 PM	Light	99.9	69.0	144.8		
	Light	101.5	73.5	138.1	141.9	
	Dark	668.5	71.0	941.5		-818.1
	Dark	694.1	71.0	977.6	959.6	
11:00 AM to 3:00 PM	Light	940.9	73.5	1280.1		
	Light	907.5	72.5	1251.7	1265.9	
	Dark	1149.2	72.5	1581.5		-307.5
	Dark	1171.2	75.0	1561.6	1573.4	
1:00 PM to 5:00 PM	Light	851.2	71.0	1198.9		
	Light	814.3	71.0	1146.9	1172.9	
	Dark	987.8	73.0	1353.2		-190.4
	Dark	1036.9	75.5	1373.4		

continued.....

APPENDIX 14 : continued

Incubation Time	Bottle	cpm - Background	Efficiency	dpm	Mean	Light - Dark
3:00 PM to 7:00 PM	Light	1043.0	71.0%	1469.0		
	Light	1131.2	74.0	1528.6	1498.8	
	Dark	1077.0	71.0	1420.4		+30.1
	Dark	1008.5	71.0	1420.4	1468.7	
5:00 PM to 9:00 PM	Light	868.6	72.0	1206.4		
	Light	973.3	74.5	1306.4	1256.4	
	Dark	926.1	74.5	1243.1		-11.5
	Dark	943.7	73.0	1292.7	1267.9	
7:00 PM to 11:00 PM	Light	734.7	73.0	1006.4		
	Light	769.9	74.5	1306.4	1019.9	
	Dark	1227.9	73.0	1682.1		-677.6
	Dark	1258.9	73.5	1712.8	1697.5	
9:00 PM to 1:00 AM	Light	886.8	72.5	1222.9		
	Light	897.2	72.5	1237.5	1230.2	
	Dark	827.6	73.0	1133.7		+92.4
	Dark	844.9	74.0	1141.8	1137.8	

APPENDIX 15 : Represents the results of a carbon-14 experiment to determine whether a loss of labelled organic matter was occurring through the filter. The experiment was performed at Station 3, with incubation of bottles immediately above the sediment. Refiltration of the aliquots yielded the following values.

Bottle	Filtration	cpm - Background	Efficiency	dpm/25 mls
Light	Initial	1792.7	73.5%	2439.0
	2	79.2	75.0	105.6
	3	59.1	75.0	78.8
Dark	Initial	1990.1	75.0	2653.5
	2	107.2	76.5	140.1
	3	52.7	79.5	66.3
	4	25.9	68.5	37.8
	5	16.2	83.0	19.5

APPENDIX 16 : Results of an experiment to determine the variability between aliquots of the same sample and aliquots of different samples. The bottles were incubated at Station 2, immediately above the sediment.

Bottle	Aliquot	cpm - Background	Efficiency	dpm/25 mls	Mean
Light A	1	1102.5	73.0%	1510.3	
	2	1080.8	72.5	1490.8	1517.3
	3	1101.0	71.0	1550.7	
Light B	1	1421.9	74.0	1921.5	
	2	1395.8	73.5	1899.0	1908.2
	3	1399.5	73.5	1904.1	
Light C	1	1229.3	73.0	1684.0	
	2	1247.1	73.0	1708.4	1677.4
	3	1205.2	73.5	1639.7	
Dark A	1	172.7	75.0	230.3	
	2	106.2	74.5	142.6	171.4
	3	104.5	74.0	141.2	
Dark B	1	839.0	71.5	1173.4	
	2	777.7	73.5	1058.1	1126.3
	3	831.9	72.5	1147.4	

APPENDIX 17 : Results of an experiment to determine the variability between aliquots of different water samples. The experiment was conducted at Station 2, from water collected and incubated immediately above the sediment.

Bottle	Number	cpm - Background	Efficiency	dpm/25 mls	Mean
Light	1	1697.2	73.5%	2309.1	
	2	2723.2	70.5	3862.7	
	3	1004.2	74.5	1347.9	
	4	1246.6	72.5	1719.4	1886.5
	5	451.1	72.0	626.5	
	6	1053.6	72.5	1453.2	
Dark	1	894.6	72.0	1242.5	
	2	1455.5	72.5	2007.6	
	3	1138.8	73.0	1560.0	
	4	1163.8	73.5	1583.4	1561.6
	5	820.2	73.5	1115.9	
	6	1376.6	74.0	1860.3	

APPENDIX 18 : Results of an experiment to determine the statistical variability in carbon-14 uptake among sampling stations in the 0 to 50 cm contour.

Station	Depth	Bottle	Aliquot	cpm - Background	Efficiency	dpm/ 25 mls	Mean
1	Surface	Light	a	19.4	75.0%	25.9	
1	"	"	b	35.0	74.0	47.0	36.5
1	"	Dark	a	154.6	74.5	207.5	
1	"	"	b	146.0	75.0	194.7	201.1
1	50 cm	Light	a	1621.1	73.5	2209.7	
1	"	"	b	1564.4	72.5	2155.0	2182.4
1	"	Dark	a	2125.7	72.0	2952.4	
1	"	"	b	2145.5	72.0	2979.9	2966.2
93	Surface	Light	a	2134.1	74.5	2864.6	
93	"	"	b	2186.2	74.5	2934.5	2899.6
93	"	Dark	a	1112.4	74.0	1503.2	
93	"	"	b	1233.0	74.0	1663.5	1583.4
93	45 cm	Light	a	1900.3	69.0	2754.1	
93	"	"	b	1856.5	68.5	2710.2	2732.2
93	"	Dark	a	82.4	74.0	111.4	
93	"	"	b	77.6	73.5	105.6	108.5
189	Surface	Light	a	2899.6	72.0	4026.8	
189	"	"	b	2858.4	72.0	3970.0	3978.4
189	"	Dark	a	2362.9	72.0	3281.8	
189	"	"	b	2372.3	71.5	3317.9	3299.9
189	40 cm	Light	a	2705.6	72.0	3757.8	
189	"	"	b	2969.6	72.0	3745.3	3751.6
189	"	Dark	a	1715.9	71.0	2416.8	
189	"	"	b	1734.4	69.5	2495.5	2456.2

APPENDIX 19 : Results of an experiment to determine the statistical variability in carbon-14 uptake among sampling stations in the 50 to 100 cm contour.

Station	Depth	Bottle	Aliquot	cpm - Background	Efficiency	dpm/25 mls	Mean
2	Surface	Light	a	2106.3	73.5%	2865.7	
2	"	"	b	1994.3	72.0	2769.9	2817.8
2	"	Dark	a	1044.5	73.5	1421.1	
2	"	"	b	1048.6	71.5	1466.6	1443.9
2	80 cms	Light	a	383.8	73.0	525.8	
2	"	"	b	337.6	74.0	456.2	491.0
2	"	Dark	a	1584.0	72.0	2200.0	
2	"	"	b	1481.6	73.0	2029.6	2114.8
62	Surface	Light	a	1738.2	75.0	2317.6	
62	"	"	b	1790.4	74.5	2403.2	2360.4
62	"	Dark	a	1273.1	73.5	1732.1	
62	"	"	b	1269.0	74.0	1714.9	1723.5
62	80 cms	Light	a	362.0	74.5	485.9	
62	"	"	b	301.9	75.5	399.9	442.9
62	"	Dark	a	1755.2	74.0	2371.9	
62	"	"	b	1762.9	74.0	2382.3	2377.1
53	Surface	Light	a	2009.2	74.0	2715.1	
53	"	"	b	1994.3	73.5	2713.3	2714.3
53	"	Dark	a	1253.1	74.0	1693.4	
53	"	"	b	1265.0	74.0	1709.5	1701.5
53	60 cms	Light	a	2397.0	74.5	3217.4	
53	"	"	b	2451.5	74.5	3290.6	3254.0
53	"	Dark	a	1948.6	73.0	2669.3	
53	"	"	b	1927.5	73.0	2640.4	2654.9

APPENDIX 20 : Results of an experiment to determine the statistical variability in carbon-14 uptake among sampling stations in the greater than 100 cm contour.

Station	Depth	Bottle	Aliquot	cpm - Background	Efficiency	dpm/25 mls
3	Surface	Light	a	1826.1	72.0%	2536.3
3	"	Dark	a	341.7	73.0	468.2
3	120 cms	Light	a	3529.4	71.0	4971.0
3	"	Dark	a	1587.8	69.0	2301.2
81	Surface	Light	a	1178.1	73.5	1602.5
81	"	Dark	a	2722.9	74.0	3679.6
81	105 cms	Light	a	1855.6	72.5	2559.4
81	"	Dark	a	238.8	74.0	322.7
113	Surface	Light	a	1881.6	72.0	2613.3
113	"	Dark	a	1672.2	74.0	2259.7
113	100 cms	Light	a	382.3	73.5	520.1
113	"	Dark	a	1400.4	73.0	1918.4

APPENDIX 21 : Results of an experiment to determine whether the acidification time utilized in carbon-14 uptake experiments was sufficient to remove all inorganic carbon-14 retained on the filter.

Acidification Time	cpm - Background	Efficiency	dpm/25 mls Aliquot
NEN 555-195 (1970)			
0 seconds	760.8	64.0%	1188.8
10 "	790.7	63.5	1245.2
20 "	641.1	62.5	1025.8
30 "	653.2	62.0	1053.5
45 "	639.4	61.5	1039.7
60 "	855.1	62.0	1379.2
120 "	892.3	61.5	1450.9
180 "	813.5	58.5	1390.6
NEN 560-031 (1970)			
0 seconds	673.6	79.0	852.7
10 "	538.5	56.5	935.9
20 "	512.1	51.0	1004.1
30 "	456.3	47.5	960.0
45 "	548.4	46.5	1179.4
60 "	482.7	42.0	928.3
120 "	397.2	35.0	1134.9
180 "	405.4	35.0	1158.3

continued.....

APPENDIX 21 : continued

Acidification Time	cpm - Background	Efficiency	dpm/25 mls Aliquot
NEN 555-195 (1967)			
0 seconds	29.3	69.0%	42.5
10 "	17.9	42.0	42.6
20 "	14.2	62.0	22.9
30 "	14.9	35.0	42.6
45 "	220.4	44.5	495.3
60 "	255.5	45.5	561.5
120 "	238.6	46.5	513.1
180 "	239.0	43.0	450.9
Amersham-Searle Laboratory Produced Ampoules			
0 seconds	27.4	77.5	35.4
10 "	11.7	80.0	14.6
20 "	10.4	78.5	13.2
30 "	8.3	78.5	10.6
45 "	8.7	67.0	13.0
60 "	8.9	79.9	11.3
120 "	3.3	20.0	16.5
180 "	4.0	37.5	10.7

APPENDIX 22 : Results of an experiment to determine the statistical variability in oxygen evolution among stations in the 0 to 50 cm contour.

Station	Depth	Sample #	Initial Oxygen	Light	Dark	Light - Dark
1	Surface	a	4.65 mg/1	4.60 mg/1	4.60 mg/1	0.00
1	"	b	4.85	4.50	4.60	-0.10
1	"	Mean	4.75	4.55	4.60	-0.05
1	50 cms	a	4.65	4.40	4.35	+0.05
1	"	b	4.70	4.60	4.50	+0.10
1	"	Mean	4.675	4.50	4.425	+0.075
93	Surface	a	6.20	5.95	6.05	-0.10
93	"	b	6.25	5.95	6.00	-0.05
93	"	Mean	6.225	5.95	6.325	-0.075
93	45 cms	a	6.15	6.10	6.10	0.00
93	"	b	6.10	6.10	6.00	+0.10
93	"	Mean	6.125	6.10	6.05	+0.05
189	Surface	a	5.95	5.70	5.70	0.00
189	"	b	5.95	5.80	5.70	+0.10
189	"	Mean	5.95	5.75	5.70	+0.05
189	40 cms	a	6.05	5.90	5.75	+0.15
189	"	b	6.00	5.95	5.85	+0.10
189	"	Mean	6.025	5.925	5.80	+0.125

APPENDIX 23 : Results of an experiment to determine the statistical variability in oxygen evolution among stations in the 50 to 100 cm contour.

Station	Depth	Sample	Initial Oxygen	Light	Dark	Light - Dark
2	Surface	a	7.80 mg/1	7.40 mg/1	7.35 mg/1	+0.05
2	"	b	7.95	7.50	7.30	+0.20
2	"	Mean	7.875	7.45	7.325	+0.125
2	80 cms	a	8.50	7.85	8.05	-0.20
2	"	b	8.85	8.70	8.65	+0.05
2	"	Mean	8.625	8.275	8.35	-0.075
53	Surface	a	7.95	7.70	7.60	+0.10
53	"	b	7.90	7.80	7.75	+0.05
53	"	Mean	7.925	7.75	7.675	+0.075
53	70 cms	a	8.65	8.40	8.30	+0.10
53	"	b	8.75	8.55	8.45	+0.10
53	"	Mean	8.70	8.475	8.375	+0.10
62	Surface	a	7.65	7.50	7.50	0.00
62	"	b	7.85	7.45	7.50	-0.05
62	"	Mean	7.75	7.475	7.50	-0.025
62	80 cms	a	8.10	7.85	7.70	+0.15
62	"	b	9.05	8.90	8.95	-0.05
62	"	Mean	8.575	8.375	8.325	-0.05

APPENDIX 24 : Results of an experiment to determine the statistical variability in oxygen evolution among stations in the greater than 100 cm contour.

Station	Depth	Sample	Initial Oxygen	Light	Dark	Light - Dark
3	Surface	a	6.30 mg/l	5.90 mg/l	5.80 mg/l	+0.10
3	"	b	6.35	6.00	6.05	-0.05
3	"	Mean	6.325	5.95	5.925	+0.025
3	120 cms	a	4.80	4.90	4.70	+0.20
3	"	b	5.10	4.95	4.85	+0.10
3	"	Mean	4.95	4.925	4.775	+0.15
81	Surface	a	6.15	5.85	5.80	+0.05
81	"	b	6.05	5.85	5.95	-0.10
81	"	Mean	6.10	5.85	5.875	-0.025
81	105 cms	a	5.70	5.50	5.45	+0.05
81	"	b	5.75	5.60	5.45	+0.15
81	"	Mean	5.725	5.55	5.45	+0.10
113	Surface	a	5.40	5.20	5.25	-0.05
113	"	b	5.35	5.20	5.00	+0.20
113	"	Mean	5.375	5.20	5.125	+0.075
113	100 cms	a	5.45	5.05	5.05	0.00
113	"	b	5.45	5.25	5.15	+0.10
113	"	Mean	5.45	5.15	5.10	+0.05

APPENDIX 25 : Results of an oxygen evolution experiment to determine the minimum, optimum and maximum incubation lengths for Crescent Pond primary productivity experiments.

Incubation Length	Bottle	Sample A	Sample B	Mean
2 hours	Light	6.90 mg/1	6.95 mg/1	6.925 mg/1
2 hours	Dark	7.00	6.85	6.925
4 hours	Light	6.85	6.85	6.85
4 hours	Dark	6.80	6.80	6.80
6 hours	Light	6.75	6.75	6.75
6 hours	Dark	6.65	6.65	6.65
8 hours	Light	6.80	6.75	6.925
8 hours	Dark	6.60	6.65	6.625
10 hours	Light	6.65	6.75	6.70
10 hours	Dark	6.55	-	6.55