PEEL-HARVEY
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TECHNICAL REPORT

CYANOBACTERIA AND
NITROGEN FIXATION

OCTOBER 198

A.L. Huber

DEPARTMENT OF CONSERVATION AND ENVIRONMENT
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A TECHNICAL REPORT to

THE PEEL–HARVEY ESTUARINE SYSTEM STUDY (1976–1980)

CYANOBACTERIA AND NITROGEN FIXATION IN THE PEEL–HARVEY ESTUARINE SYSTEM

by

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PUBLICATIONS:

THE PEEL–HARVEY ESTUARINE SYSTEM STUDY (1976–1980)

This report is one of 14 technical reports that were presented to the Environmental Protection Authority's Estuarine and Marine Advisory Committee as part of the Peel–Harvey Estuarine System Study (1976–1980).

The publications arising from the study are listed below and are available from the Department of Conservation and Environment, 1 Mount Street, Perth, WA 6000.

- The Peel–Harvey Estuarine System Study (1976–1980). A report to the Estuarine and Marine Advisory Committee December 1980. E.P. Hodgkin, P.B. Birch, R.E. Black, and R.B. Humphries, Department of Conservation and Environment, Report No 9.

- The Peel–Harvey Estuarine System Study. A report by the Estuarine and Marine Advisory Committee to the Environmental Protection Authority, March 1981. Department of Conservation and Environment, Bulletin No 88.

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89 The Peel Inlet and Harvey Estuary System Hydrology and Meteorology. R.E. Black and J.E. Rosher, June 1980

90 Sediments and Organic Detritus in the Peel–Harvey Estuarine System. R.G. Brown, J.M. Treloar and P.M. Clifton, August 1980

91 The Ecology of Cladophora in the Peel–Harvey Estuarine System. D.M. Gordon, P.B. Birch and A.J. McComb, 1981

92 The Decomposition of Cladophora. J.O. Gabrielson, P.B. Birch and K.S. Hamel, October 1980

93 The Control of Phytoplankton Populations in the Peel–Harvey Estuarine System. R.J. Lukatelich and A.J. McComb, 1981

94 Cyanobacteria and Nitrogen Fixation in the Peel–Harvey Estuarine System. A.L. Huber, October 1980

95 Phosphatase Activities in the Peel–Harvey Estuarine System. A.L. Huber, October 1980

96 The Sediment Contribution to Nutrient Cycling in the Peel–Harvey Estuarine System. J.O. Gabrielson, 1981

97 Aspects of the Biology of Mulluscs in the Peel–Harvey Estuarine System, Western Australia. F.E. Wells, T.J. Threlfall and B.R. Wilson, June 1980

98 The Fish and Crab Fauna of the Peel–Harvey Estuarine System in Relation to the Presence of Cladophora. I.C. Potter, R.C.J. Lenanton, N. Loneragan, P. Chrystal, N. Caputi and C. Grant, 1981

99 Phosphorus Export from Coastal Plain Catchments into the Peel–Harvey Estuarine System, Western Australia. P.B. Birch, October 1980

100 Systems Analysis of an Estuary. R.B. Humphries, P.C. Young and T. Beer, 1981

101 Peel–Harvey Nutrient Budget. R.B. Humphries and R.E. Black, October 1980

102 Nutrient Relations of the Wetlands Fringing the Peel–Harvey Estuarine System. T.W. Rose and A.J. McComb, August 1980

SUMMARY

The ecology and physiology of the cyanobacteria (blue green bacteria) in the Peel–Harvey Estuary system are being examined. This report deals specifically with the concentrations and types present in the system as a function of season, sampling location and sample depth, and with an analysis of a Nodularia spumigena bloom which occurred in the summer of 1978–79.

The following observations have been made :

1 Nodularia spumigena is the main cyanobacterial species in the estuarine system; Nostoc is the next most prominent genus.

2 From the results of two large surveys and the weekly/biweekly monitoring program, the estuary system can be divided into several areas. The Peel Inlet can be subdivided into two sections. The western half of the Peel has low cyanobacterial concentrations in general while the eastern side has a high non–Nodularia population. The Harvey Estuary has higher numbers of blue greens than the Peel Inlet; Nodularia is the dominant organism.

3 There is a high inoculum potential, especially of Nodularia, in the sediments.

4 A bloom of N. spumigena occurred in the Harvey Estuary from November 1978 to January 1979. This did not extend into the Peel Inlet.

5 Acetylene reduction activities (which reflect nitrogen fixation potentials) were most closely related to heterocyst numbers. Rates of nitrogen fixation could be increased by increasing heterocyst number (#/ml), heterocyst frequency (heterocyst to vegetative cell ratio), or heterocyst activity (nmoles N_2 reduced/heterocyst/h).

6 The heterocyst concentration and acetylene reduction activity were maximum on the surface, but cell concentrations were highest at 0.5 m. The acetylene reduction activity of samples incubated in situ decreased with depth. Total nitrogen decreased with depth, but soluble nitrogen increased.

7 The bloom resulted in high nitrogen concentrations in the water. Total nitrogen was high during the bloom. Subsequently, ammonia–nitrogen increased followed by nitrate and nitrite–nitrogen. The N:P ratios in the water were very high during this time.

8 An elevated level of phosphorus in the water as a result of Harvey River flow may have initiated the bloom. In general, the Harvey R. has a high phosphorus to nitrogen ratio.

9 Calculations based on total nitrogen contained in the bloom indicate that 309 tonnes of nitrogen could have been contributed by the Nodularia bloom.

10 Further work will be based on an examination, under laboratory conditions, of nutritional (nitrogen, phosphorus, salt) and non-nutritional (pH, light, temperature) factors which may regulate the activity of the major species, in particular Nodularia spumigena.

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PREFACE

The work reported here is part of an ongoing Ph.D. research program. This report, therefore, is a summary of progress rather than a final report.

Many people have, and are continuing to contribute to this project. In particular I would like to thank my supervisor, Dr. D.K. Kidby, for his help and guidance, and J. Gabrielson for his ready assistance and patience. I would like to especially thank Dr. E.P. Hodgkin for his interest in this project, and to Dr. P. Birch and Dr. R. Field, and the other members of DCE for their help. My sincere appreciation goes to Prof. A.J. McComb and the members of the Botany Department, especially R. Leukatelich, for their help. I am also very grateful to those who helped me during the course of the Nodularia bloom especially T. Chiffings, S. Bilham, T. Gigengack, and F. Bunny, and B. Toussaint. Also, I would like to thank B. and S. Humphries for their assistance, interest and useful discussions. Thanks go to B. Simmons for the magnesium and iron determinations, and to the other members of the Soil Science and Plant Nutrition Department, especially the members of the workshop. My sincere appreciation goes to G. Heather for typing the tables in this report, and to Jim Sullivan and Tony Berman for the Figures.

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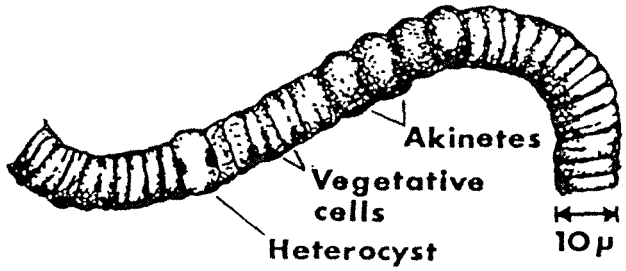
INTRODUCTION

A widespread characteristic among the cyanobacteria (blue green bacteria) is the ability to convert atmospheric nitrogen (N_2) to ammonia (NH_3) which is utilizable by themselves or other organisms. This process can be very significant when nitrogen-limited situations occur in bodies of water such as the Peel-Harvey Estuary system.

The aims of the present study are to firstly, determine the types and numbers of cyanobacteria in the estuary system, and secondly, to elucidate the mechanisms controlling their growth and, in particular, nitrogen fixation. The first part of this work has been completed. Determination of the controlling mechanisms will enable analyses of events which have already occurred during the course of this study in terms of why these events occurred and their overall effect on the system. More importantly in terms of management, it should allow analyses of possible effects that management options may have on this particular group of organisms, and subsequently, on the nutrient loads, and on other groups of organisms in the system.

This report mainly deals with those cyanobacteria which are capable of nitrogen fixation. These are generally the heterocystous, filamentous blue green bacteria. A schematic diagram of Nodularia spumigena, the most significant species of this study, is presented below.



Both the heterocysts and the akinetes are specialized cell types, derived from the vegetative form. Akinetes are resting cells, or spores, which are highly resistant and are important in terms of survival, and probably, in this system, dispersal and growth. Heterocysts are the cell form in which most of the nitrogenase activity (i.e. nitrogen fixation) takes place. In them, atmospheric nitrogen is converted to ammonia which is then exported to the vegetative cells for use in amino acid synthesis.

There have been few studies on the blue green bacteria of Western Australia. Blooms of Trichodesmium have been reported in Cockburn Sound (Chiffings, 1979; Kennealy, 1973; Sammy, 1973; Smith, 1972). Findlayson and McComb, 1978 and Congdon, 1979, determined rates of nitrogen fixation by cynaobacteria in Lake Joondalup. Terrestrial nitrogen fixation activities were measured in the wetlands surrounding the Blackwood Estuary (Findlayson and McComb, 1978). With respect to the Peel-Harvey Estuary System, Rippingale (1975) reported high numbers of Oscillatoria, a non-nitrogen fixing genus.

Nitrogen fixation in oceans has been reviewed by Fogg (1968). Many freshwater systems have been studied in detail, for example Lake Mendota, Washington and Clear Lake, California. Horne (1978) has reviewed nitrogen fixation in eutorophic lakes.

According to Horne (1977) there had been no thorough study of nitrogen fixation in an estuarine system prior to 1977. The biological cycling of nitrogen in intertidal and supralittoral marine environments has been reviewed by Stewart, 1975.

Literature on Nodularia is very limited. There have been two reports of its occurrence in Australian waters : Lake Alexandria in South Australia (Francis, 1878) and Lake Corangamite in Victoria (Bayley and Williams, 1966). Elsewhere, massive blooms of Nodularia spumigena have been reported in the Baltic Sea (Jansson, 1978; Ostrom, 1976; Ulbricht and Schmidt, 1977). Nodularia has been reported in Egypt in Nile waters (El-Nawawy and Hamdi, 1975), Moroccan soils (Renaut et al., 1975) and Swedish soils (Granhall, 1975). It occurs in intertidal and supralittoral areas (see Stewart, 1965, 1975).

This report deals with two main aspects of the project. Firstly, there is the determination of spatial distribution of cyanobacteria in the Peel-Harvey Estuarine system, and the annual variation in numbers and types. Secondly, a bloom of Nodularia spumigena which occurred from November 1978 to February 1979, is discussed.

2 METHODS

2.1 Enumeration, Isolation and Identification

The enumeration and isolation of cyanobacteria was carried out as shown in Figure 2. The water samples were collected and transported, on ice, to the laboratory. Ten to 100 ml were then concentrated by filtration under negative pressure onto a gridded membrane filter (normally Millipore^{R} cellulose acetate, 0.45 μm mesh). The filters were placed onto solid media and incubated under continuous light, at 20 to 25°C. After four and eight weeks, colonies were counted. For routine enumeration, the media was either modified BG11 without nitrogen (Hughes, Gorham and Zehnder, 1958) or solidified filter sterilized estuary water supplemented with one-half strength BG11 nutrients (fsP) (see Table 2.1).

For isolations, small pieces of single colonies were transferred onto solid media. Liquid media were sometimes used in addition to the above.

Identifications were attempted from both primary and subsequent isolations (from membrane filters). The main taxonomic keys used were those of Desichakary, 1959; Geitler, 1932; Prescott, 1962; and Rippka, 1979. (see Table 2.2).

Stock cultures were maintained by periodic transfer to fresh solid and/or liquid medium.

2.2 Nitrogen Fixation Assays

Nitrogen fixation rates were determined in the field using the acetylene reduction assay. Water samples were put into incubation vessels which were then tightly sealed; a 10% atmosphere of air was removed and replaced with acetylene gas. Two systems were used: either 900 ml Vacola^{R} jars, each with a Tygon^{R} tubing sampling port inserted into the lid and sealed with a rubber Subaseal^{R}, or 500 ml serum bottles closed with rubber lined sampling caps. The sample volumes used were 200 and 100 ml, respectively. Incubation was either *in situ* at the appropriate depth in the water column, or on-board the boat. Periodically, samples of the atmosphere within the vessels were removed with vacutainers^{R}.

The gas samples were later analysed for ethylene production using a Proropak-N^{R} column in a Varian gas chromatograph.

2.3 Fluorometry

Fluorometry was carried out with a 10-A05 Fluorometer, Turner Designs, Inc.

2.4 Nutrient and Pigment Analyses

Nutrients (nitrite and nitrate, ammonia, Kjeldahl, organic and total nitrogen; ortho- and total phosphorus) and pigments (chlorophyll *a* and phaeophytin) were analysed by the Department of Botany University of Western Australia. (see McComb *et al*, 1980).

3 RESULTS

3.1 ISOLATIONS AND TAXONOMY

3.1.1 Primary Isolations

As part of a regular monitoring program, the cyanobacteria in the estuarine waters have thus far been cultered on 30 occasions. On 18 of these, the isolates were grouped into broad taxonomic categories and the occurrence of each type at each sampling location recorded. Under standardized conditions of growth medium, light and temperature, cells or filaments of cyanobacteria will grow into characteristic colonies. The results are listed in Table 3.1.1.

Nodularia spumigena is the most frequently isolated species. The genus next in importance is Nostoc and specifically, the N. carneum - N. Linkia group. There are several species in this group, and they are often difficult to separate taxonomically. Other species of Nostoc occur only occasionally. For Anabaena and Calothrix isolates, all species have been grouped under the genus name. Anabaena occurs more frequently than Calothrix. All of the above organisms are heterocystous filamentous types, and are important because of their capacity to transform atmospheric nitrogen into ammonia and, subsequently, to organic nitrogen forms.

The family Oscillatoreacea includes the non-heterocystous filamentous blue greens. They do not normally fix atmospheric nitrogen and, therfore, are of less significance to this study. The LPP groups (Lyngbya-Phormidium-Plectonema) are members of this family, but have been separated since they occur mainly as contaminants in colonies of the heterocystous, filamentous cyanobacteria, especially Nostoc.

All unicellular cyanobacteria have been grouped together. They frequently occur but, because they do not have the capacity to fix atmospheric nitrogen under normal conditions, they have not been considered of great significance for the purposes of this study.

The totals of the different types at each station indicate that Station 4 has the highest frequency of non-Nodularia isolates. In most cases, except for Stations P58, 24, and 28, which are located in one area of the Harvey Estuary, the Nostoc carneum-N. Linkia group makes up almost 50% of the isolates.

During the course of this project, there has been a single major proliferation of a cyanobacterial species: Nodularia spumigena. This took place from November 1978 to January 1979. It is dealt with in Section 3.5 of this report.

In November 1979, Oscillatoria princeps, along with a Lyngbya species, formed a dense covering on the sediment surface of the Harvey Estuary, below Island and Herron Points. This extended slightly north of this area in the shallower regions and was found growing on sediment traps as far north as Station 1. Since this species does not fix nitrogen, and since it did not proliferate in the water column, it will not be dealt with further in this report.

3.1.2 Taxonomy

The species isolated thus far are indicated in Table 3.1.2. Most of the taxonomic characteristics normally used for identification of the cyanobacteria have been based on field specimens. These are often inconsistent with laboratory cultured blue greens. Therefore the identifications given in the Table are often affinity groups. The plates supplied are only representative photomicrographs of the species listed and not all of the characteristics of an organism can be shown in a single photograph. The main taxonomic references used are listed in Table 2.2.

Because of its importance to this study, a brief description of Nodularia spumigena types isolated from the Peel-Harvey Estuarine system is given below. See also Plates 3.1.2a to 3.1.4h.

The filaments are usually single but may tend to clump. The sheath is thin and often hard to distinguish. Cells are disc shape, 1/2 to 1/3 as long as broad. The varieties found in the Peel-Harvey Estuary are vacuolated. Heterocysts are slightly larger than the vegetative cells and occur singly. There appears to be two varieties: a "coarse" and a "fine" type. The average cell width of the coarse variety is usually greater than, or equal to, 10 μm, while that of the fine type is less than 9 μm This characteristic is persistent through several transfers on laboratory culture medium. Akinetes are spherical, broader than the vegetative cells, and are covered with a yellow-brown wall in their more mature stages. Akinete production is variable with respect to frequency, but appears to be a characteristic of individual colonies.

A taxonomic revision of the genus Nodularia has recently been published (Nordin and Stein, 1980).

3.2 GRID STUDIES

3.2.1 To estimate concentrations and types of cyanobacteria in the estuarine system, two large surveys in March 1979 (36 sites) and July 1979 (23 sites) were conducted. These represent conditions at the end of summer and mid-winter, respectively. In the March survey, both top and bottom waters were examined. Figure 3.2.1 is a map of the sampling station locations. The data for the surveys are presented in Figures 3.2.2 and 3.2.3, and Tables 3.2.2.1-3 and 3.2.3.1-2. For comparison, the data from the March 1980 samplings of the weekly/biweekly monitoring program are presented in Figure 3.2.4.

3.2.2 March 1979

The data for March 1979 are listed in Tables 3.3.1-2. Because of the predominance of Nodularia spumigena (Section 3.1), the number of viable heterocystous cyanobacteria have been placed into two categories: Nodularia and "others". In the above figures, the data represented are the total numbers of cyanobacteria and the percentage of that number which is Nodularia.

Three main points arise from these data. Firstly, there is a large variation in both numbers and types of cyanobacteria over the estuary. The total numbers ranged from 115 at Station 26 in the Harvey Estuary, 86% of which was Nodularia, to 0 throughout much of the Peel Inlet. The percentage of Nodularia making up the viable counts ranged from 0 to 100%. Similarly, in July 1978, total numbers ranged from 0 to 35 and the percentage Nodularia from 0 to 100.

Despite this variation however, the estuarine system can be divided into areas which are consistent within themselves. The data in Tables 3.2.2.1–3 are presented and summarized according to these divisions. The Peel Inlet and the Harvey Estuary can each be subdivided into two or, in the case of the Peel in March 1979, three areas according to numbers and types of cyanobacteria which occur. This partitioning is shown in Figure 3.2.2.

For March 1979, the Peel Inlet can be divided into, basically, a northwestern and a southeastern sector and a small southwestern portion. The former have low total numbers; surface waters of the northwest and southeast sections had mean counts of 0.8 and 8.5 viable cyanobacteria per 100 ml, respectively. The corresponding percentages of Nodularia were 0 to 10.6 (see Table 3.2.2.1–1). The eastern section could be further subdivided into a central area with very low numbers (1 count per 100 ml), and an outer area with higher numbers (total counts average 12.9) but low relative Nodularia concentrations (8.7%).

Numbers of heterocystous cyanobacteria other than Nodularia were greater in the southeast part. As well, non-heterocystous cyanobacteria were present in large numbers in this area (Table 3.2.2.2). Indeed, this has been the only time that Oscillatoria has been observed in significant numbers in the phytoplankton over a large area. Oscillatoria has been reported to be present in the Estuary (Rippingale, 1975). The other occurrence of Oscillatoria has already been discussed (Section 3.1.1). Since it cannot fix nitrogen, its significance in the estuary in relatively low concentrations is limited.

The southwest section of the Peel appears to have been influenced more by the Harvey than the Peel. The average count was seven cyanobacteria per 100 ml sample, 87.2% of which was Nodularia.

The Harvey Estuary can be divided into two sectors as well. That part north of Station 1 (see Figure 3.2.2) had an average cyanobacterial count of 12.7 per ml while the average of the southern half was 22.0. In both cases however, Nodularia made up over 90% of the total.

The reverse situation appears to be the case for bottom samples in the Harvey Estuary. The total cell count for the northern half is 26.4, whereas that for the southern part is 15.4 (Table 3.2.2.3). The higher number can be accounted for by an unusually high count for Station 26 bottom waters; this station may have been more stirred than the rest. Without that site being taken into account, the average total count for bottom waters in the northern section is 13.6; lower, in fact, than the southern end. This is consistent with the surface water results.

3.2.3 July 1979

A similar situation existed in July 1979. Samples were taken from points midway between the regular sampling stations. The division in the Peel Inlet is farther to the east than in March, and there is no southeastern section which is different enought to warrant a separation. The numbers were higher in this survey: 15.4 and 9.5 viable cyanobacteria per 100 ml water sample in the eastern and western sections, respectively. Again, the percentage of the total attributable to Nodularia is much lower in the eastern side (20.8%) than in the western side (72.6%).

The situation in the Harvey Estuary was very similar to that in March 1979. Again the southern sector had higher total numbers of cyanobacteria: 21.0/100 ml compared to 11.7/100 ml in the northern area. Again Nodularia dominated the population: 95.7% in the northern section and 87.1% in the southern half. Only surface waters were examined.

3.2.4 March 1980

The data for March 1980 (Figure 3.2.4) shows patterns similar to those of March 1979. The Harvey Estuary waters have higher numbers than the Peel Inlet waters (17.1 and 11.9 compared to 3.6 and 7.6 on the sampling days shown). Nodularia makes up 90% and 85% of the population in the Harvey on the two days; in the Peel, it represents 56% and 53%. There are not enough data points to usefully separate the Estuary into sections. However, it does appear that the northern half of the Harvey Estuary is predominant, especially on the 13.03.80 sampling.

3.2.5 Comparison of the Peel Inlet and Harvey Estuary

The most interesting comparisons are those between the Peel Inlet and the Harvey Estuary. The overall averages for the March 1979 study are given in Table 3.2.2.2 for the Peel and 3.2.2.3 for the Harvey. Summaries of the July survey are presented in Tables 3.2.3.1 and 3.2.3.2.

In March 1979, the mean for Peel surface waters was 6.6 counts per 100 ml (30.9% Nodularia), and for the Harvey, 16.7 (85.5%). For July 1979, the mean total counts were 12.5 (40.9% Nodularia) and 16.4 (90.2%) for the Peel and Harvey, respectively. The concentrations in the Peel Inlet in July were almost double those of March 1979. In the Harvey Estuary, they are remarkably similar (16.7 and 16.4 total viable cells per 100 ml). This would seem to indicate that the Harvey is inherently more stable than the Peel. While this may be true to some extent, there is nonetheless a wide range in the counts obtained from the weekly/biweekly monitoring program. This will be discussed in the next section (3.3).

3.2.6 Synopsis

The grid system results can be summarised as follows. In the Peel Inlet, it appears that the eastern section heterocystous cyanobacterial population is dominated by species other than Nodularia spumigena. The western side of the Inlet is more influenced by the Harvey Estuary. For the Harvey Estuary, the southern section had a higher population than the northern half.

Between the two major systems, the Harvey has a greater total heterocystous cyanobacterial population.

Nodularia spumigena is the dominant species.

3.3 REGULAR MONITORING

To assess the overall concentrations, and changes in concentrations and types of cyanobacteria over time, a weekly/biweekly monitoring program was initiated in May 1979. The results of this program up to May 1980 are presented in Figure 3.3.1.1 to 3.3.4.2 and Tables 3.3.1.1 to 3.3.4. Total numbers of cyanobacteria and numbers of Nodularia in surface and bottom waters are shown. Figures and Tables 3.3.1.1–2, 3.3.2.1–2, and 3.3.3. represent the data for individual sampling stations in the Peel Inlet, the Harvey Estuary, and at Mandurah Bridge, respectively. Because certain areas of the system showed similarities with respect to numbers and types (see Section 2), means were calculated (see Tables 3.3.1.1 – 3.3.2.2). Figures 3.3.1.3 and 3.3.2.3 are plots of this data for the southeastern, and northwestern halves of the Peel Inlet, and northern and southern sections of the Harvey Estuary, respectively. Figures 3.3.4.1 and 3.3.4.2 and Table 3.3.4 summarize the data for the two major systems, namely the Peel Inlet and the Harvey Estuary.

The extent of the variation in numbers and types among sites can been seen in the plots of individual stations. For example on July 17 1979, the total count from the surface waters of Station 5 was 214 colonies per 100 ml sample; that same day the corresponding number from Station 3 surface waters was only 12. One hundred percent of the 214 colonies at Station 5 were of the Nostoc type. Station 29, in the Harvey Estuary, also had high concentrations (a total count of 68 colonies per 100 ml),m but 63% were Nodularia spumigena. (Figure 3.3.5).

The variation at one station at different sampling times is also high. For instance, again at Station 5, the number of heterocystous cyanobacteria in a 100 ml water sample ranged from zero on 4.11.79, 18.12.79, 16.01.80, and 09.04.80, to 214 on 17.07.79.

These represent the widest range thus far encountered. Most often the concentrations are less than twenty viable cyanobacteria per 100 ml.

The summary Figures 3.3.1.3 and 3.3.2.3 make the trends in the different areas more clear. In general, the western side of the Peel Inlet has low numbers of cyanobacteria. Nodularia is often present but not necessarily the predominant genus. The maximum mean total count from this area was 25/100 ml on 30.01.80 (18% Nodularia). Maximum numbers do occur at about the same times as in other areas, but the total numbers are usually less than 20.

The eastern side of the Peel shows much greater fluctuations in concentrations. The maximum mean total number recorded so far was 338 at Station 4 on November 21, 1979; only 6.8% of that number were Nodularia. This section of the Peel is the only area dominated by Nostoc species. Nodularia is sometimes present, more often at higher proportions in the bottom waters than in surface waters. Anabaena and Calothrix types are also found here more frequently than in other areas. The presence of Oscillatoria has been discussed in the previous section (3.2). All of these facts indicate that this area presents quite a different environment for the cyanobacteria. Several factors may affect this. Firstly, the influence of the Murray and Serpentine Rivers must be considered. The inflow from these rivers has a higher N:P ratio than does the Harvey River inflow into the south end of the Harvey Inlet (Black and Rosher, 1980). The numbers of cyanobacteria must be examined in relation to the nutrient concentrations and nutrient ratios that have been determined in this study (McComb et al 1980).

This area does not receive the inoculum of Nodularia from the Harvey Estuary which enters the western side of the Peel. However, the fact that Nodularia is often present indicated that the significance of this factor may be negligible. Also, there are large numbers of Nodularia in the sediments (see Section 3.4). These could provide a large inoculum for the overlaying waters. Three of the four stations are quite shallow (4, 5 and 6) and this will invariably influence the type and distribution through the profile by influencing light, temperature, stirring and nutrient distribution.

The Harvey Estuary can be divided into the two sectors indicated in Figures 3.2.2-3 in the previous section, i.e., between Stations 1 and 28. Unlike the grid study results, the northern area, Stations 24, 28, 35, and P58, had consistently higher counts of cyanobacteria than did the southern half. On only one occasion, 21.11.79, was this not the case.

November 21, 1979, was very unusual for the Harvey Estuary in several regards. Only 2.3% of the total population was Nodularia; the other 97.7% consisted of Anabaena. Unicellular blue greens were also present. Only the surface counts were higher in the southern section. The means of the bottom counts from the northern area exceeded those from the south as they did in other weeks. The total numbers from surface samples (southern section) were much greater than from the bottom samples. Though this particular situation did not correspond to the rest of the Harvey Estuary on that day, there was a matching occurrence in the Peel Inlet. There was a large increase in non-Nodularia cyanobacteria in the western half of the Inlet. The mean total surface count was 177.9 (12.9% Nodularia, made up largely of Calothrix and Nostoc.

It would seem then, that one factor or combination of factors, was able to cause an increase in the growth of two similar genera, Nostoc and Anabaena, in quite different areas. More closely related areas, e.g., the two sectors of the Harvey Estuary, did not respond in a similar manner. Also, what caused a large response in one group (Nostoc, Anabaena, Calothrix) did not greatly affect another group (Nodularia). Apart from this exception, the two sectors of the Harvey Estuary have behaved in an analogous manner throughout the survey to this date. As previsouly stated, the numbers in the northern part are higher, usually two to four times.

Except for the date mentioned above, and 17.07.79 (see also Peel Inlet data) Nodularia is the dominant organism in both halves.

Water at Mandurah Bridge (Figure 3.3.3, Table 3.3.3), in general, has lower total numbers of heterocystous cyanobacteria. At times Nodularia made up only a small proportion of the total, for example in July 1979. From November 1979 to May 1980 however, Nodularia spumigena was almost the exclusive species. One of the more important points to note is the lack of fluctuation in the counts from this location. The increase from November 1978 to February 1979, subsequent drop to April 1979 and rise and fall to May 1980, can be taken to represent true changes in population rather than sudden effects of stirring, tides, etc.

3.3.4 Comparison of the Peel Inlet and Harvey Estuary

As with the grid studies, the most interesting comparisons to be made with the monitoring data are those between the Peel Inlet and the Harvey Estuary. Several major points should be made. Firstly, the systems behave similarly in that peaks in total numbers occur at the same times (Figures 3.3.4.1–2, Table 3.3.1.1). Secondly, the numbers of cyanobacteria in the Harvey exceed those in the Peel Inlet.

Nodularia is the dominant cyanobacteria in the Harvey Etuary; it has always been present thus far, with the exception of 14.08.79. Except on rare occasions (see Table 3.3.4), over 80% of the cyanobacterial counts were Nodularia, and on only 17.07.79 and 21.11.79 (as already discussed) did another type predominate. It should be noted that the July data corresponded to the first significant flows of the rivers into the Estuary system. Nodularia are usually present in the Peel Inlet, but in lower concentrations. Major fluctuations are the result of changes in the populations of "other" heterocystous cyanobacteria.

The three major peaks in the Peel Inlet occurred on 17.07.79, 22.08.79, and 21.11.79. Concentrations in the Harvey Estuary increased on those days as well; in addition, cyanobacterial concentrations there were high on 22.05.79, 28.07.79 and from 29.01.80 to 11.03.80.

This survey is continuing.

3.4 DEPTH

The relationship among the surface, bottom and sediment waters and sediments with respect to cyanobacterial concentrations was examined. The results of this initial survey are presented in Table 3.4.1. Viable numbers of total cyanobacteria and Nodularia were determined at six stations: 1, 4, 5, 6, 7 and 8. Sediments from Post 46 (see Figure 3.4.1) were also examined.

Stations 1, 7 and 8 had similar total and Nodularia surface water concentrations. Populations in bottom waters of Station 8 were much greater than at the other two sites (1 and 7). For sediment waters, Station 1 in the Harvey Estuary, had the highest concentrations of both total cyanobacteria and Nodularia. Sediment water was that which overlayed bulked material from three replicate sediment cores. However, Station 1 sediments did not have the highest concentration of cyanobacteria.

This apparent discrepancy may be due to the difficulty in getting equally disturbed sediment samples from which to obtain a sediment water sample.

Stations 4, 5 and 6 and have low Nodularia concentrations in surface water samples, if any were present at all. Station 4 had a high number of non-Nodularia cyanobacteria in surface, but not in bottom waters. Of these stations, Station 4 had the highest total and Nodularia concentrations in the sediment waters but the lowest in the sediments.

But all of the stations had very high concentrations of cyanobacteria, especially Nodularia (a mean of 90.7%), in the sediments.

It appears then, that there is not a direct relation between the numbers and types with depth in the water column and in the sediments. All the surface and bottom concentrations determined for the regular sampling program and the large surveys tend to confirm this lack of correlation.

Very high numbers are present in the sediment water and the sediment. Since many cyanobacteria have the capacity to regulate their position in the water column, numbers and types may reflect in part, the position in the water column where conditions are optimum for that organism. Also, since the numbers in the sediment are so high, and since Nodularia makes up the bulk of the cyanobacteria, the sediments may act as a 'sink' for the water column.

These questions are being pursued further.

3.5 NODULARIA BLOOM

During the period from November 1978 to January 1979, an extensive 'bloom' of Nodularia spumigena occurred in the Harvey Estuary. The overall time course and extent of the bloom was monitored mainly by Secchi depths. Fluorimetry, chlorophyll a concentrations, direct cell counts, nitrogen fixation rates, and nutrient concentrations were monitored and related to Secchi depths. A list of the dates and analyses conducted is presented in Table 3.5. Figure 3.5 is a map of the estuarine system with the sample locations plotted. Note that these are not those used for the large surveys and regular sampling program.

3.5.1 Secchi Depths

The results of the Secchi depth surveys are presented in Table 3.5.1 and Figures 3.5.1a – f. Figure 3.5.1.2, containing the Secchi depth data for three dates when there was no bloom (7.8.79, 21.11.79 and 16.01.80), is included for comparison.

The Secchi depth is the depth at which a white disc with defined characteristics can no longer be seen when lowered into the water column. It is, therefore, essentially a measure of the transparency of the water column. Since the turbidity of the water during the bloom was almost totally the result of the presence of Nodularia, it can also be taken to represent the density of the bloom.

Secchi depth and turbidity are inversely related, therefore the data in the Figures has been plotted as the inverse of Secchi depths.

The most obvious point is that the bloom was contained almost entirely in the Harvey Estuary. There was a slight increase in the water turbidity in the Peel Inlet on 30.11.78, probably due to a flow from the Harvey into the Peel. The Nodularia did not appear to grow in the Peel Inlet and the major accumulation in the Peel was that area between the Harvey Estuary and the Mandurah Channel. These observations were confirmed by other analyses.

Within the Harvey, the highest bloom density was on the eastern side on 23.11.78. The density gradually decreased after 30.11.78 to the last of the Secchi depth surveys, 08.01.79. Even at this stage water turbidities were often higher than those the following year. Of the three dates shown in Figure 3.5.1.2, the turbidities in November 1979 most closely resembled the 1978 values.

3.5.2 Secchi depth, fluorometry and chlorophyll a concentrations; 23.11.78.

On 23.11.78, both Secchi depths and fluorometry measurements for chlorophyll a concentrations were taken. Secchi depths, their inverse, and chlorophyll a concentrations are listed in Table 3.5.2.1. Both $(\text{Secchi depth})^{-1}$ and chlorophyll a are plotted in Figure 3.5.2.1. Table 3.5.2.2 contains the data for the standard curve (Figure 3.5.2.2) used to calculate chlorophyll a concentrations from fluorometer readings. The correlation between the two parameters is very high; $r^2 = 0.9958$. As can be seen from the map, Figure 3.5.2.1, the correlation with Secchi depth $^{-1}$ is also good. This data is plotted in Figure 3.5.2.3; the r^2 value is 0.86. This indicates that the turbidity in the estuarine water was closely related to living, photosynthetic biomass present.

3.5.3 Acetylene reduction, vegetative cell and heterocyst concentrations; 17.11.78.

One of the most significant aspects of a bloom of this type of organism is its ability to transform atmospheric nitrogen into a form usable by the rest of the biota in the estuarine system, thereby enriching it with respect to nitrogen. Since the same enzyme, nitrogenase, performs both the N_2 to NH_3 and the C_2H_2 (acetylene) to C_2H_4 (ethylene) conversions, acetylene reduction can be used to estimate the nitrogen fixing potential of a system.

On 17.11.78, a survey of the acetylene reduction activity over the bloom area was conducted. Direct microscopic counts of filaments, cells and heterocysts were also made. Correlations among these were calculated. The data for cell concentrations and acetylene reduction activities in the water are plotted in Figure 3.5.3.1. Table 3.5.3.1 contains the information as well as the heterocyst concentrations and cell to heterocyst ratios, and acetylene reduction activities in relation to cell and heterocyst numbers.

Though there appears to be a definite positive correlation between cell concentrations and acetylene reduction in the water, there is a lot of variation. The linear regression is shown in Figure 3.5.3.2; the r^2 value of 0.48 does not indicate a good fit.

Examination of Figure 3.5.3.2 reveals two distinct areas in the Harvey Estuary. With the one exception of Site 15, all the sampling locations south of Station PB1 had low acetylene reduction activity to cell concentration ratios; the northern stations had high ratios. That is, the acetylene reduction activity per cell was lower in the southern end than in the northern part. In Figure 3.5.3.2, the ratios of the northern sites are above the line of linear regression; all the southern sites (except Station 15) fall below. This grouping can also be very clearly seen in the relationship between cell numbers and the inverse of heterocyst acetylene reduction activities (Figures 3.5.3.3).

It should be recalled also, that this dividing line is the same as that which seems to occur in the weekly monitoring program and the large surveys.

When the acetylene reduction activity per heterocyst is plotted against heterocyst concentration, the curve tends towards a rectangular hyperbolic function. This is shown in Figure 3.5.3.4. The inverse of such a function should yield a straight line (Figure 3.5.3.5). The accuracy of acetylene reduction data below 0.2 nmoles/ml/hr is questionable. These low activity stations (Peel Inlet stations) have not been included in the calculation. Station 25 data has also been omitted; because of its very high cell concentrations, and concomitant photosynthesis, oxygen levels were almost certainly inhibitory to the oxygen sensitive nitrogenase enzyme. The r^2 value for the resulting data is 0.76. Omitting these sites, the r^2 value for the linear regression between total cell concentrations and the inverse of acetylene reduction activity per heterocyst is 0.68 (Figure 3.5.3.3).

This analysis of data indicates that acetylene reduction by heterocysts more closely related to heterocyst concentrations than to cell concentrations. Very generally then, in the Harvey Estuary, the higher the heterocyst concentrations, the lower the activity of each heterocyst. This suggests that high fixation rates in a population of heterocystous cyanobacteria then, can be the result of increased heterocyst concentration (N_2 reduction/heterocyst/unit time).

It has already been shown that the acetylene reduction activity was greatest in the Harvey Estuary. To determine if there was any trend in the cell to heterocyst ratios over the estuary system, these were plotted on the map (Figure 3.5.3.6). As can be seen, the cell to heterocyst ratio is higher in the Peel Inlet. When these data are graphed (i.e., concentration of heterocyst against concentration of vegetative cells), the points fall into two groups: the Peel Inlet and the Harvey Estuary. The linear regression equations for these two groupings are plotted in Figure 3.5.3.7. The slopes for the two systems are distinctly different and the r^2 values for both are quite high.

3.5.4 Depth profiles : acetylene reduction, cell and nutrient concentrations

Thus far, only surface waters have been discussed. On 30.11.78, the water column at Station 20 was examined at 0, 0.5, 1.0, and 1.5 metres. Acetylene reductions activities, cell concentrations, pigment and nutrient concentrations were determined. The results are presented in Figures 3.5.4.1 – 4 and Tables 3.5.4.1 –2. Depth profiles of chlorophyll, and nutrient concentrations at Station 20, chlorophyll concentrations at Station 11, and acetylene reduction activities and nutrient concentrations at Station 25 on 23.11.78 were examined as well. The results are shown in Table 3.5.4.3. They are similar from the two days; the 30.11.78 data will be discussed.

The maximum cell concentration occurred at 0.5 m while the maximum heterocyst concentration was at the surface (Figure 3.5.4.1). Maximum chlorophyll and phaeophytin concentrations were also found at 0.5 m. The chlorophyll to cell ratio, however, was slightly lower at 0.5 m than at the surface (Figure 3.5.4.2). Further down the profile, the chlorophyll concentration per cell markedly increased. This likely reflects an increased requirement for chlorophyll to trap energy under light limited conditions. The Secchi depth here was 0.27 m (see Table 3.5.1).

Acetylene reduction activities are presented in Figure 3.5.4.3. Samples were incubated both in situ and on the surface (on-board the boat). Maximum activities were recorded for the surface water samples (Figure 3.5.4.3). Samples from 0.5 m and below showed lower activities whether incubated on the surface or in situ, however, their activities decreased with depth. This decrease emphasises the difference between potential and actual nitrogen fixation activity. The pattern of decline in activity with incubation depth holds true in relation to both cell and heterocyst numbers. With surface incubation though, the lowest activity was recorded for 0.5 m depth samples. The acetylene reduction per cell (nitrogen fixation capacity) for these samples appears to be less.

The nutrient nitrogen and phosphorus analyses are presented in Figure 3.5.4.4. Nitrate and nitrite nitrogen concentration is low but almost triple with depth (4 to 11 ug/L). The increase in ammonia nitrogen is from 42 to 71 ug/L (Table 3.5.4.2). Total nitrogen is maximum at the surface and drops by 20% to 1.5 m. Organic and soluble nitrogen concentrations per vegetative cell and per heterocyst are also shown in Figure 3.5.4.4. The organic and soluble nitrogen concentrations per heterocyst increase with depth. The vegetative cell concentrations of both nitrogen forms increase sharply from 0.5 to 1.0 m. From 1.0 to 1.5 m there is a drop in nitrogen per cell while the soluble nitrogen per cell remains constant. For phosphorus, the orthophosphate is very stable to 1.0 m and then decreases at 1.5 m. On the other hand, total phosphorus changes little from 0.5 m. The value for surface organic phosphorus is very low considering cell and nitrogen concentrations there, and the accuracy of these results must therefore be suspect. On a per cell basis, both total nitrogen and total phosphorus were maximum at 1.0 m.

3.5.5 Surface water nutrient concentrations and ratios, and chlorophyll a; 23.11.78

On 23.11.78, besides chlorophyll a concentrations and Secchi depths, nitrogen and phosphorus in surface waters were also analyzed. Nutrient concentrations and ratios are listed in Table 3.5.5. The nitrogen and phosphorus concentrations are ploted on maps of the estuary in Figures 3.5.5. 1a – b. The relationships between concentrations of total nitrogen and of total phosphorus with chlorophyll a are plotted in Figure 3.5.5.1. From the Figures 3.5.5. 1a – b, it can be seen that the nutrients have a similar distribution, chlorophyll a and cell concentrations.

Summaries of the data for the Peel and the Harvey are given in Table 3.5.5. For soluble nutrients, the concentrations in the Harvey Estuary were about two and four times those in the Peel Inlet. Of the soluble nitrogen compounds however, nitrate plus nitrite nitrogen was higher in the Peel than the Harvey. The chlorophyll a ratio of the Harvey to the Peel was 6.1; the total phosphorus concentration and total nitrogen concentration ratios between the two systems were 7.0 and 8.1, respectively. The graphs of the relation between nutrient and chlorophyll concentrations indicate that they are strongly related. From

visual assessment of these graphs, it appears that there is a slight lag in both cases. For phosphorus, there also appears to be a levelling off of the curve after about 80 ug/L.

In all cases in the Harvey Estuary, the total N:P ratio was very high: 36.2 to 147.8. The means were 45.6 in the Peel Inlet and 53.4 in the Harvey Estuary. Normally accepted N:P ratios range from 10–20:1. Soluble N:P ratios were also high, but there was a greater difference between the two systems: 26.0 and 12.9 in the Harvey and Peel respectively. This would correspond to a greater productivity by the Harvey population. Nutrients are further discussed in Section 3.5.6.

3.5.6 Nutrient concentrations over time; Stations PB1 and PB2, October, 1978 to February, 1979.

The effect which the 1978 – 79 Nodularia bloom had on the Peel–Harvey Estuarine system can be assessed in terms of the changes in nutrient (nitrogen and phosphorus) concentrations and their resulting ratios.

Chlorophyll a, nitrogen, and phosphorus concentrations at Station PB1 from 03.10.78 to 13.02.79 are shown in Figure 3.5.6.1.1 for comparison, the same parameters for Station PB2 are plotted in Figure 3.5.6.1.2. Figures 3.5.6.2.1 – 2 represent the changes in nitrogen to phosphorus ratios (solubles and totals) over the same time period. The data are listed in Tables 3.5.6.1 – 2.

As measured by chlorophyll a, the peak of the bloom occurred on 29.11.78 (Figure 3.5.6.1.1). A small second peak occurred late in December. The organic nitrogen concentrations reflect the main peak as does the total phosphorus. Soluble phosphates were very high at that time, though maximum soluble phosphate concentrations occurred the previous week.

The plots of nitrogen (soluble and total) concentrations at Station PB1 (Figure 3.5.6.1.1) clearly illustrate the events which occurred in the water column after the main bloom. Organic nitrogen (and chlorophyll) concentrations decreased as the bloom dissipated. After total nitrogen declined, ammonia nitrogen increased to a maximum on 23.01.79. This is a natural decomposition process. When ammonia declined the nitrate–nitrite nitrogen increased as a result of nitrification.

As previously indicated, the total phosphorus is maximum at the same time as organic nitrogen and chlorophyll a. In October 1978, there was an elevated total phosphorus level in the Harvey Estuary. This was the result of an increased input from the Harvey River; the peak total phosphorus in the river water occurred in September (Black and Rosher, 1980). The phosphorus concentrations in the estuary water column then fell and rose again to almost the same concentration, during the bloom. This flow of phosphorus into the Estuary may have been, to a large extent, responsible for the bloom initiation. Also in this regard, it is worth noting that the 1977 – 1978 (October 1977 to September 1978) flow of the Harvey River contributed 20% of the nitrogen and 60% of the phosphorus in 37% of the flow. The corresponding 1978 – 1979 contribution was 57% nitrogen and 79% phosphorus to nitrogen ratio would favour a nitrogen fixing organism.

There is a third rise in total phosphorus in January (Figure 3.5.6.1.1), after the second smaller chlorophyll concentration rise. This may have resulted from dying phytoplankton.

Except for phosphorus, the corresponding graphs for Station PB2 indicate very little changes (Figures 3.5.6.1.2). In other words, the influence of the bloom did not significantly extend past the Harvey entrance into the Peel Inlet. The first flush of phosphorus did affect the entire estuary system, as shown by the peaks in total and soluble phosphorus at Station PB2, but conditions which allowed the Nodularia to proliferate in the Harvey Estuary must not have prevailed in the Peel Inlet.

Surface and bottom nutrient ratios are plotted for Stations PB1 and PB2 in Figures 3.5.6.2.1 - 2. The surface N:P (total) ratio sharply increased on 29.11.78 as well. The Nodularia then, through nitrogen fixation, was increasing the nitrogen level in the water. The ratio of soluble N:P did not alter significantly until after the bloom when a sharp increase was related to nitrate + nitrite, and ammonium nitrogen concentrations upon the collapse of the bloom.

There was little change in the total N:P ratios at Station PB2. However, there was an increase in the soluble N:P ratio concomitant with that at Station BP1.

In other words nutrients incorporated into the system appear to have been redistributed into nearby areas during bloom decline. Similar increases in nutrients or nutrient ratios did not occur at farther removed sampling stations, e.g., Station 4.

3.5.7 Calculation of the Nitrogen Contribution

The ultimate effect of a phytoplankton bloom must be its input into the system in which it occurs.

The closest estimate of the nitrogen added through dinitrogen fixation by the Nodularia bloom is that based on the amount of nitrogen contained in the bloom itself. Using the total nitrogen in the water at the peak of the bloom (30.11.79), and subtracting the river inputs and the maximum levels of nitrogen in the Harvey waters just before the bloom, the nitrogen which must have been incorporated into the bloom was 309 tonnes (Figures 3.5.7). This calculation does not take into account any sediment contribution of nitrogen or loss from the Harvey waters to the Peel Inlet and the ocean prior to the peak of the bloom. Both are probably small relative to the overall nitrogen contribution by the bloom.

Several other methods could be used to calculate bloom nitrogen contributions. One is based on *in situ* acetylene reduction rates and another on heterocyst numbers and average acetylene reduction rates per heterocyst. Both methods suffer from their dependence on assumptions regarding the acetylene reduction activities at the time of measurement relative to the maximum reduction rates. It is quite probable that the time of measurement (in this study, early afternoon), while usually optimum for photosynthesis, was not the time of maximum nitrogenase activity. Total nitrogen, however, is based on a measureable product rather than on a potential rate of product formation.

Three hundred and nine tonnes is similar in magnitude to the nitrogen added to the system by the Harvey River in 1977 - 1978 or 1978 - 1979 (see Black and Rosher, 1980).

4 OTHER ANAYLSES

What must now be examined are the factors limiting or stimulating the growth of the cyanobacteria in the Peel–Harvey Estuary. Two nutrients, magnesium and iron, have been suggested as limiting in some cases.

To gain some appreciation of their concentrations in the system, water samples taken on two days were analysed by High Resolution Mass Spectrometry, HRMS (W. Simmonds, University of Western Australia, pers.com.) (Table 4).

Though these analyses do not estimate biological availability of these nutrients, they do show that : a) the magnesium concentrations may have increased from October to May, b) there is no significant difference between the two systems with respect to concentrations, and c) they are not likely to be limiting anyway.

5 PERSPECTIVES AND FURTHER WORK

The role of the heterocystous cyanobacteria through nitrogen fixation is shown in Figure 5.

Though the cyanobacteria are not always in bloom proportions, they are always present in the Peel–Harvey Estuary. The types and concentrations are being examined with respect to seasonal and spatial fluctuations.

What must now be examined is the role, under controlled conditions, of nutritional (especially nitrogen, phosphorus, and salt concentrations) and non-nutritional (pH, temperature, light) factors in the regulation of growth of and nitrogen fixation by the major types, and in particular, Nodularia spumigena.

6 ADDENDUM

Since the time of writing this report, two larger Nodularia blooms have occurred, one from October 1980 to February 1981, and the second from October 1981 to March 1982. These will not be discussed in the present report, but will be reported separately. However, a list of parameters examined during the two blooms is presented in Table 5. The calculations of the nitrogen inputs by the two blooms are presented with the 1978 – 1979 calculation in Table 3.5.7. The calculated overall inputs were 308.8 T, 434.6 T, and 713.4 T nitrogen for 1978 – 1979, 1980 – 1981, and 1981 – 1982, respectively.

REFERENCES

Allen, M.M. 1968 Simple conditions for growth of unicellular blue-green algae on plates. J. Phycol. 4:1–4

Atkins, R.P. and McComb, A.J. 1978 DCE/UWA Nutrient Analysis Facility, Botany Department, University of Western Australia, Annual Report No.1, 1978

Bayley, I.A.E. and Williams W.D. 1966 Chemical and biological studies on some saline lakes of south-east Australia. Aust. J. mar. Freswat. Res. 17: 177–228

Black, R.E. and Rosher, J.E. 1980 Hydrology and meterology of the Peel Inlet and Harvey Estuary DCE Technical Report, June 1980

Chiffings, A.W. 1979 Cockburn Sound Study. Technical Report on Nutrient Enrichment and Phytoplankton Report No.3. Department of Conservation and Environment, Western Australia. July 1979

Congdon, R.A. 1979 Hydrology, nutrient loading and phytoplankton in Lake Joondalup. DCE, Western Australia, Bulletin No 67

El-Nawawy, A.S. and Hamdi, Y.A. 1975 Research on blue-green algae in Egypt, 1958–1972 in I.B.P.6. Nitrgoen fixation by free living micro-organisms. W.D.P. Stewart (ed.) Cambridge University Press, Cambridge, 1975

Finlayson, M. and McComb, A.J. 1978 Nitrogen fixation wetlands of southwestern Australia. Search 9:98–99

Francis, G. 1878 Posionous Australian lake. Nature, 18:11–12

Fogg, G.E. 1978 Nitrogen fixation in the oceans in Environmental Role of Nitrogen-fixing Blue-green Algae and Asymbiotic Bacteria. U. Granhall (ed.) Swedish Natural Science Research Council, Sweden, 1976

Granhall, U. 1975 Nitrogen fixation by blue-green algae in temperate soils, in Nitrogen fixation by free-living micro-organisms. W.D.P. Stewart (ed.). Cambridge University Press, Cambridge 1975

Horne, A.J. 1977 Nitrogen fixation – a review of this phenomenon as a polluting process. Progress in Water Technology 8 (4/5):359–372

Horne, A.J. 1978 Nitrogen fixation in eutrophic lakes, in Water Pollution Microbiology. R.Mitchell (ed.). John Wiley & Sons, Inc., New York, 1978

Hughes, E.O., Gorham, P.R., and Zehnder, A. 1958 Toxicity of a unialgal culture of Microsystics aeruginosa. Can. J. Microbiol. 4:225–236

Jansson, B.-O., 1978 The Baltic – a systems analysis of semi-enclosed sea, in Advances in Oceanography. H. Charnock and G. Deacon (eds.) Plenum Press, New York 1978

Kenneally, K.F. 1973 An occurrence of the planktonic blue-green alga, Oscillatoria erythraea, at Cottesloe. The Western Australian Naturalist 12:168

Nordin, R.N. and Stein, J.R. 1980 Taxonomic revision of Nodularia (Cyanophyceae/Cyanobacteria). Can. J. Bot. 58:1211–1224

Ostrom, B. 1976 Fertilization of the Baltic by nitrogen fixation in the blue-green alga Nodularia spumigena. Remot Sens. Environ. 4:305-310

Renaut, J., Sasson, A., Pearson, H.W. and Stewart, W.D.P. 1975 Nitrogen-fixing algae in Morocco, in Nitrogen fixation by free-living micro-organisms W.D.P. Stewart (ed.) Cambridge University Press, Cambridge, 1975

Rippingale, R. 1975 Progress report on Peel/Harvey Inlets to Metropolitan Water Supply Sewerage and Drainage Board, March, 1975

Simmonds, W. Department of Soil Science and Plant Nutrition, University of Western Australia, 1980 (pers. comm.)

Smith, G.G. 1972 A red tide of Trichodesmium in coastal waters of Western Australia. The West Australian Naturalist 12:81-83

Stewart, W.D.P. 1965 Nitrogen turnover in marine and brackish habitats. 1. Nitrogen fixation. Ann. Bot. 29:229-239

Stewart, W.D.P. 1975 Biological cycling of nitrogen in intertidal and supralittoral marine environments, in Proc. 9th Europ. mar. biol. Symp. H. Barnes (ed.) Aberdeen University Press, Scotland 1975

Ulbricht, K.A. and Schmidt, D. 1977 Massenauftreten mariner Blaualgen in der Ostee auf satellitenaufnahmen erkannt. DFVLR Nachrichten 22:913-915

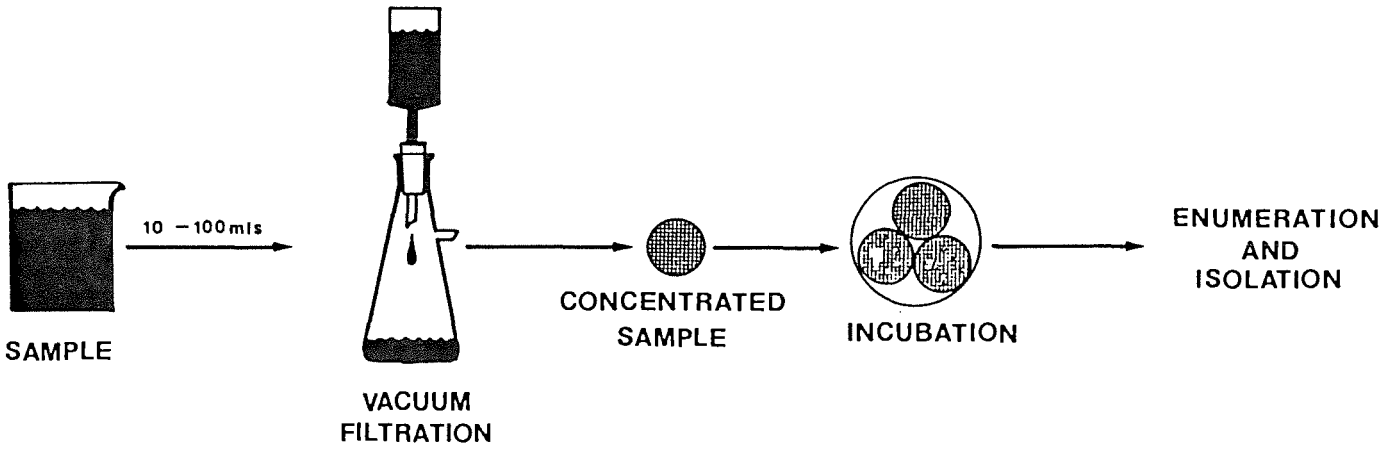


Figure 2. Enumeration and isolation technique

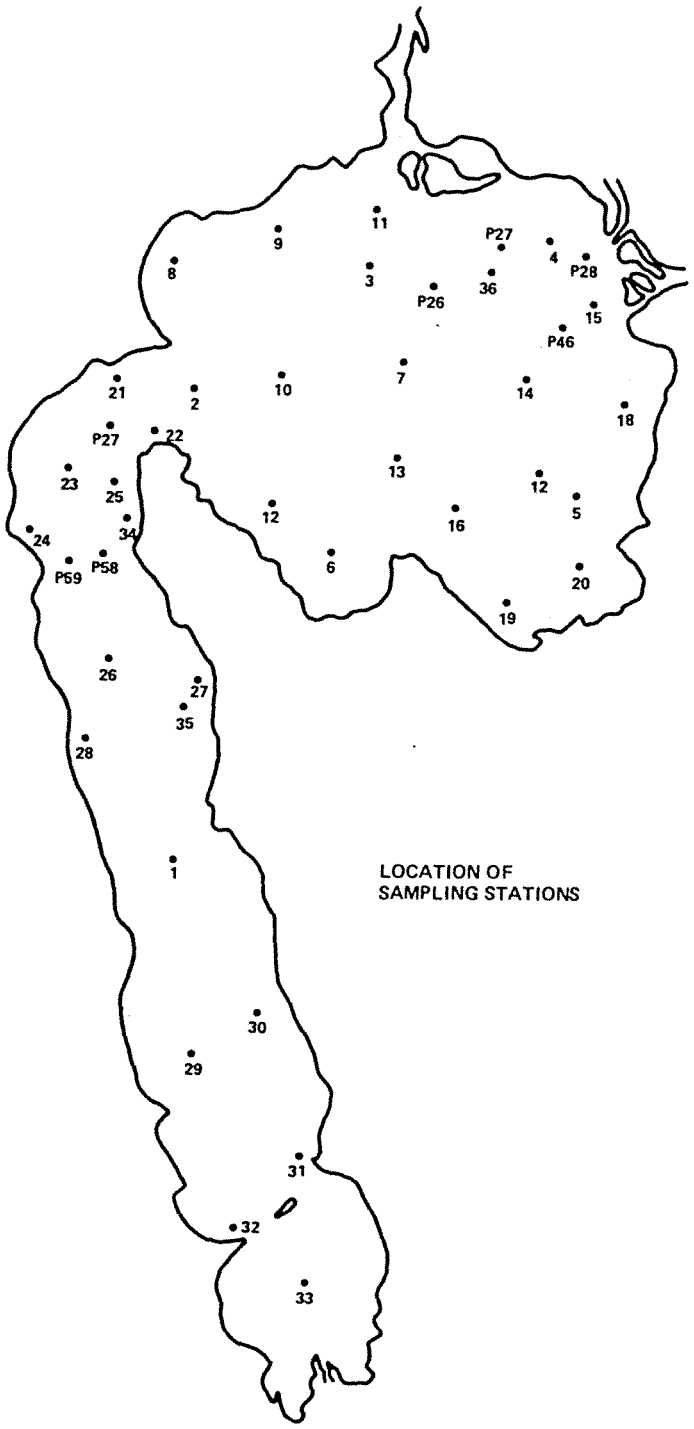


Figure 3.2.1 Location of sampling stations

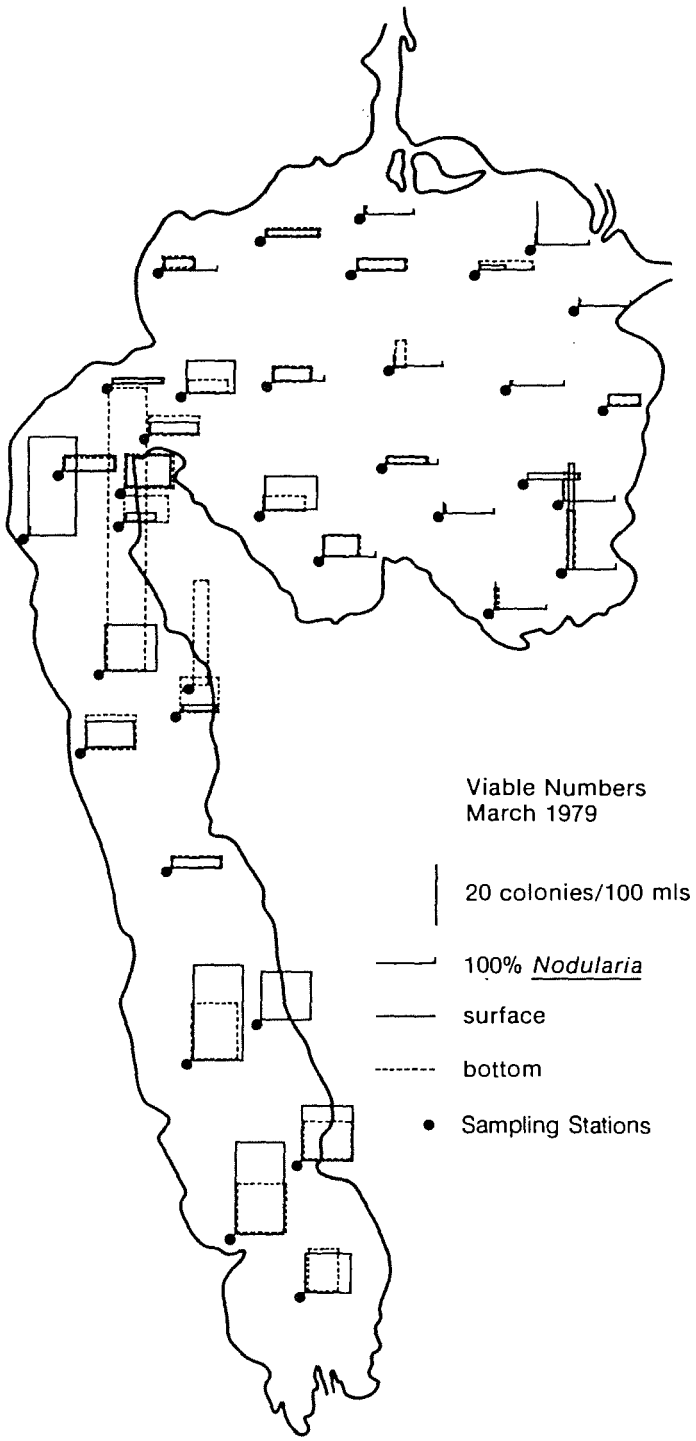


Figure 3.2.2 Total numbers of cyanobacteria, and percentage of Nodularia; Grid study, March 1979

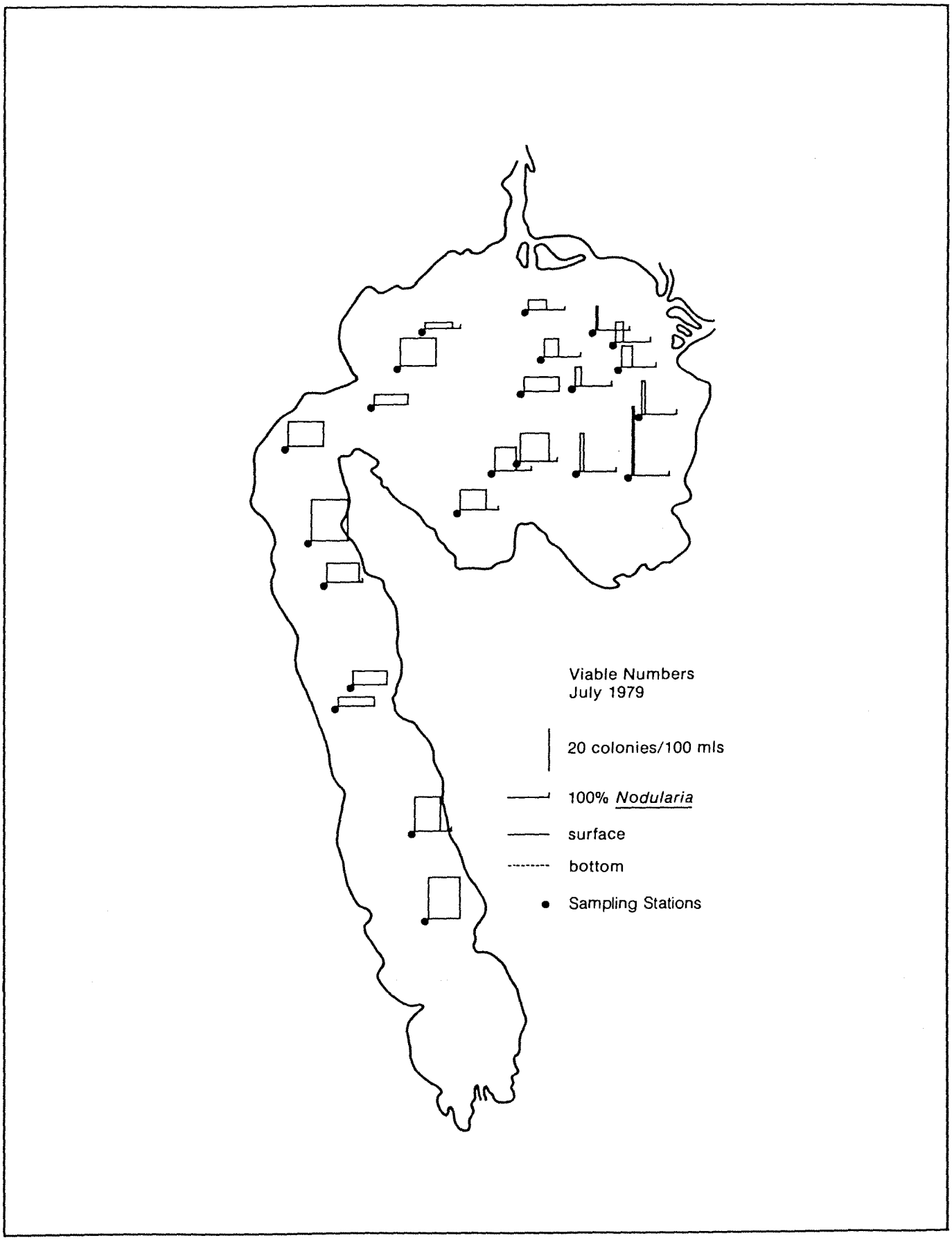


Figure 3.2.3 Total numbers of cyanobacteria, and percentage of Nodularia; Grid study, July 1979

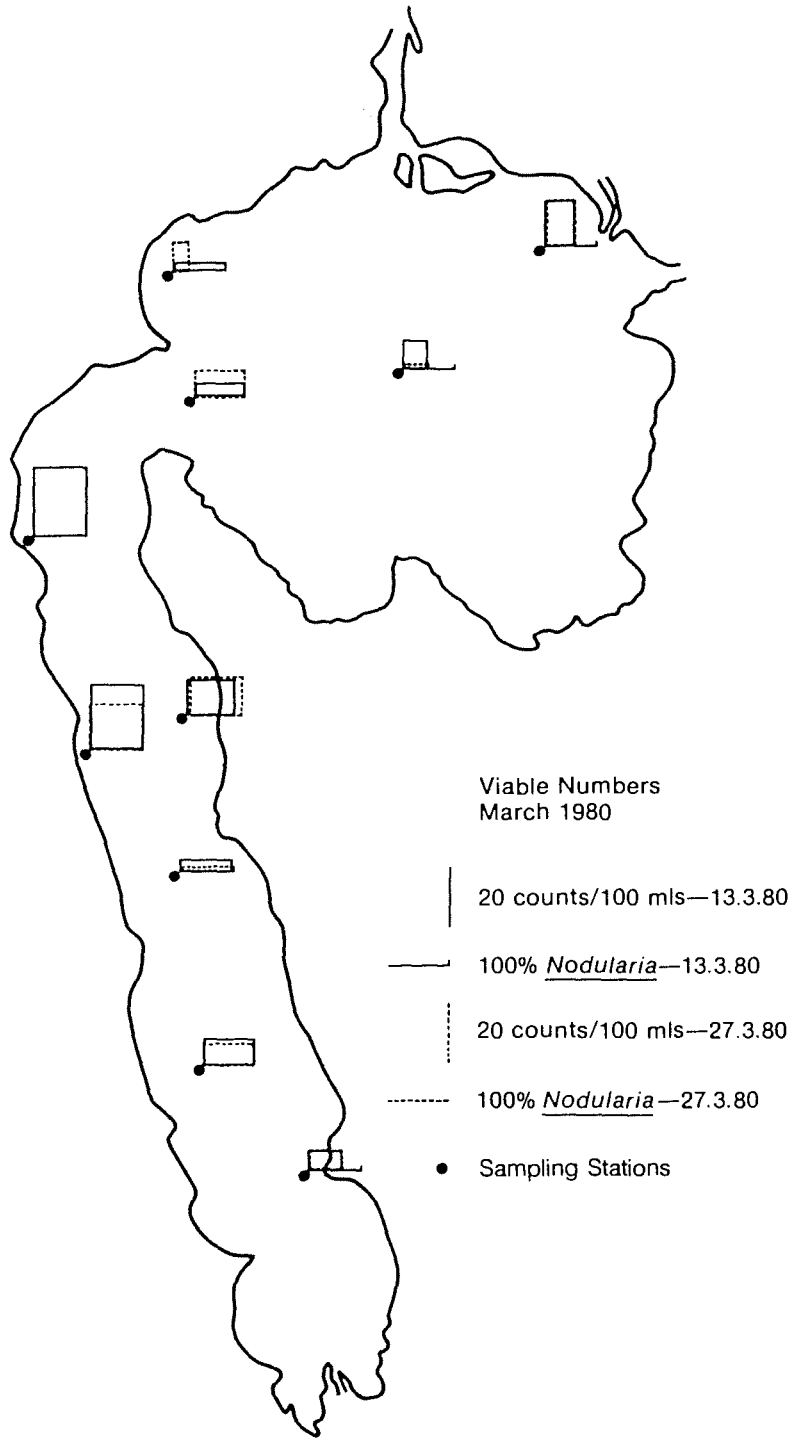


Figure 3.2.4 Total numbers of cyanobacteria, and percentage of Nodularia; March 1980

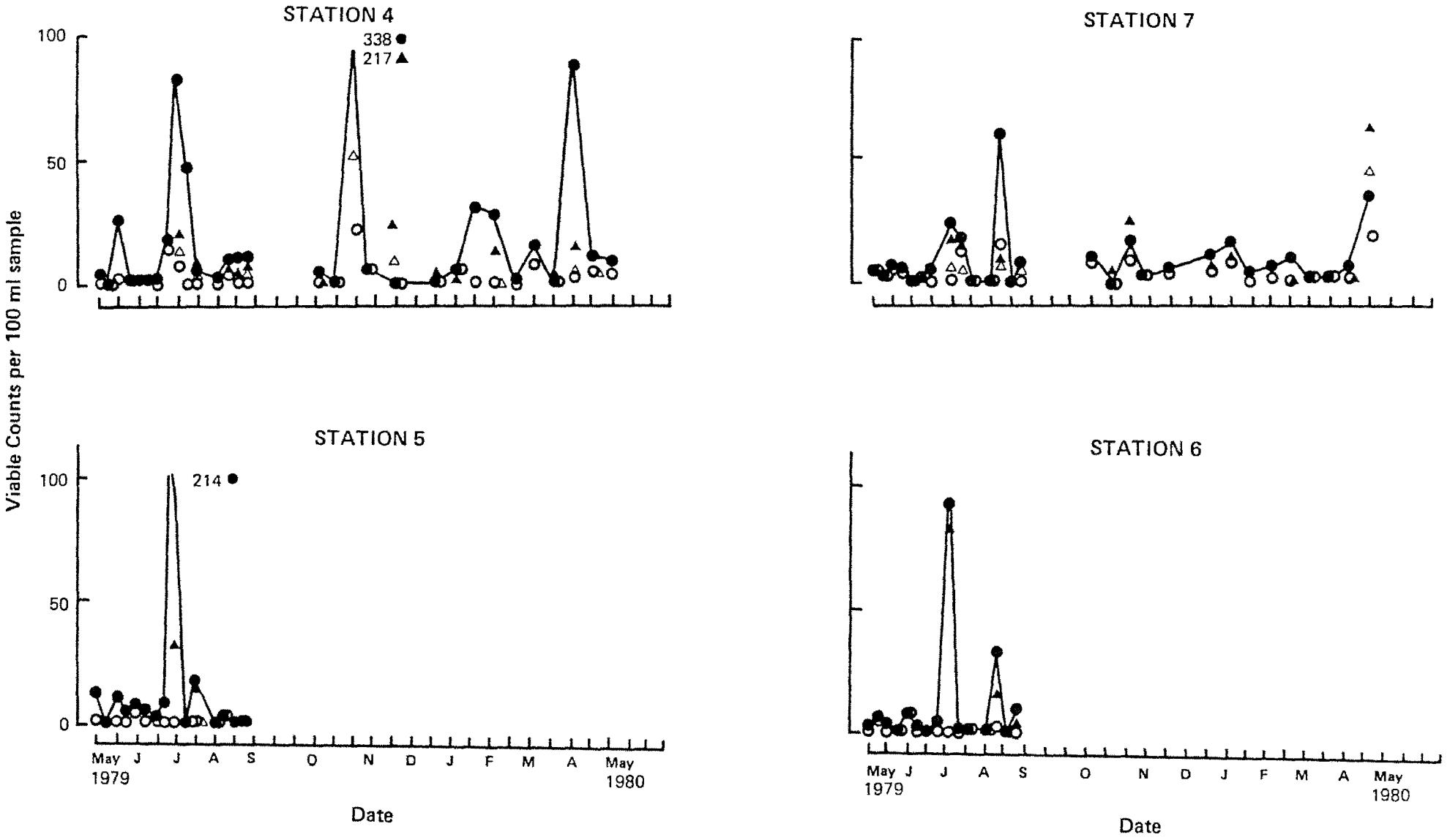


Figure 3.3.1.1 Weekly/Biweekly monitoring, Stations 4, 5, 6, 7

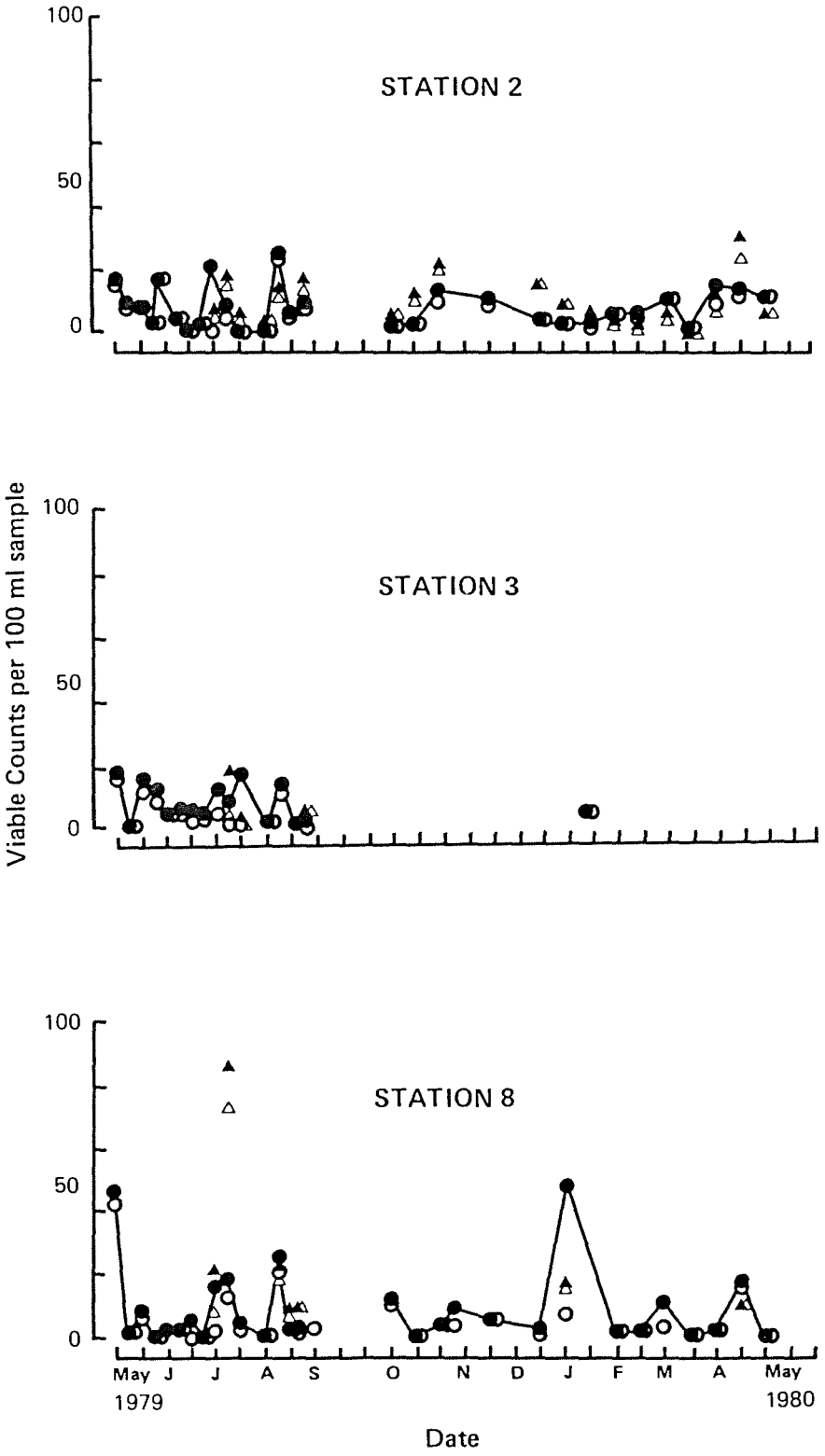


Figure 3.3.1.2 Weekly/Biweekly monitoring, Stations 2, 3, 8

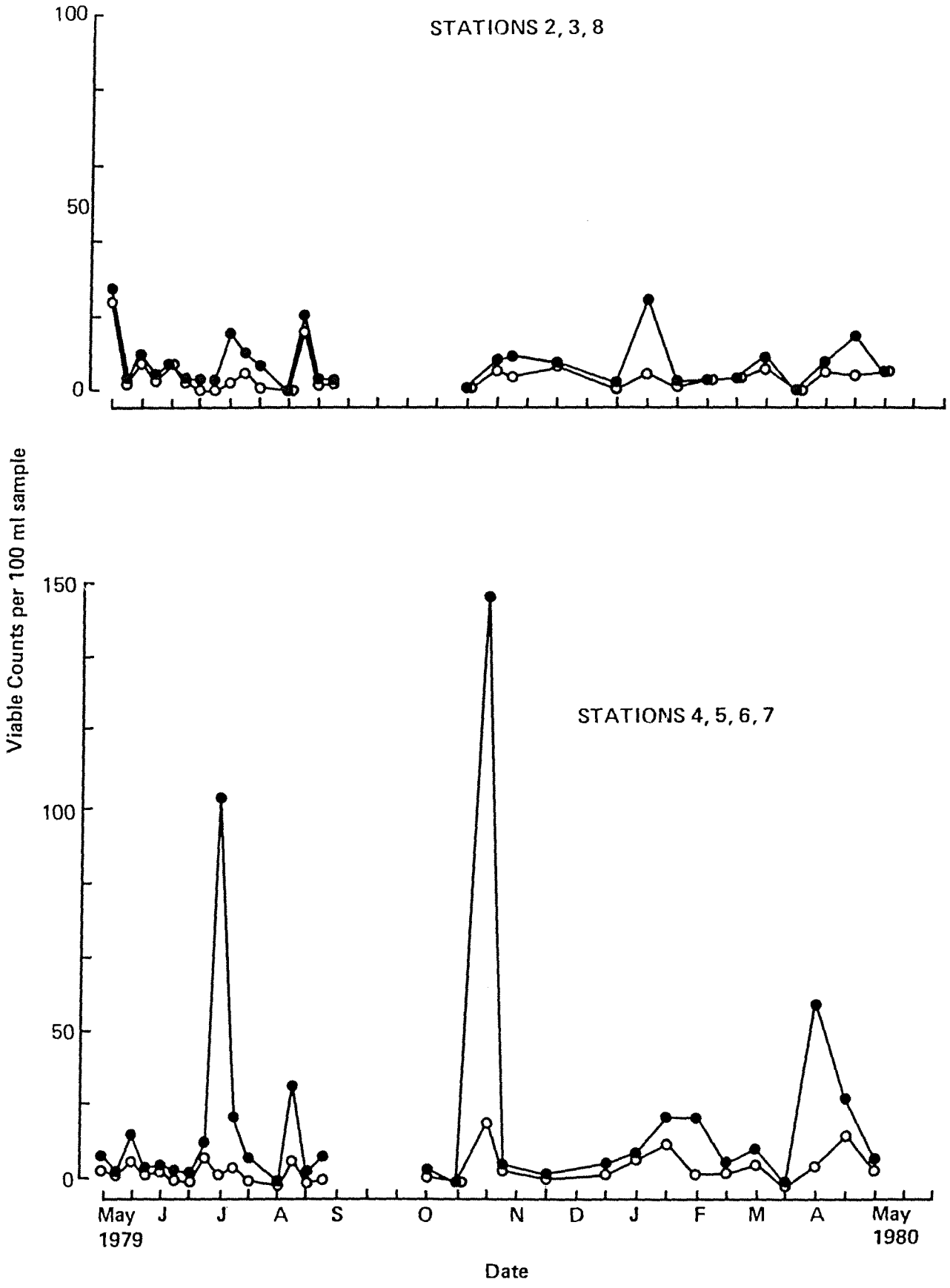


Figure 3.3.1.3 Weekly/Biweekly monitoring; summaries of Stations 2, 3, 8 and 4, 5, 6, 7

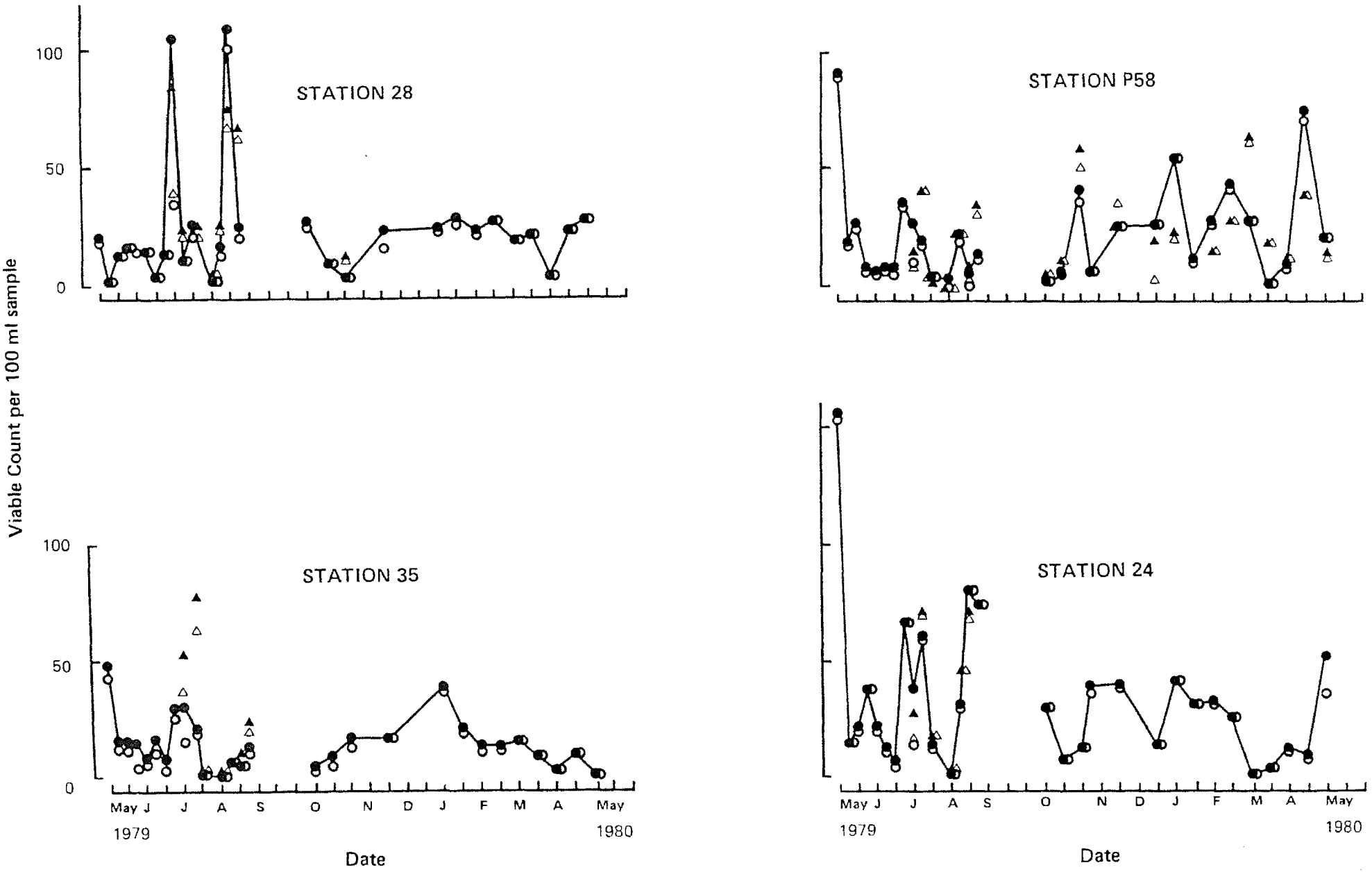


Figure 3.3.2.1 Weekly/Biweekly monitoring; Stations P58, 24, 28, 35

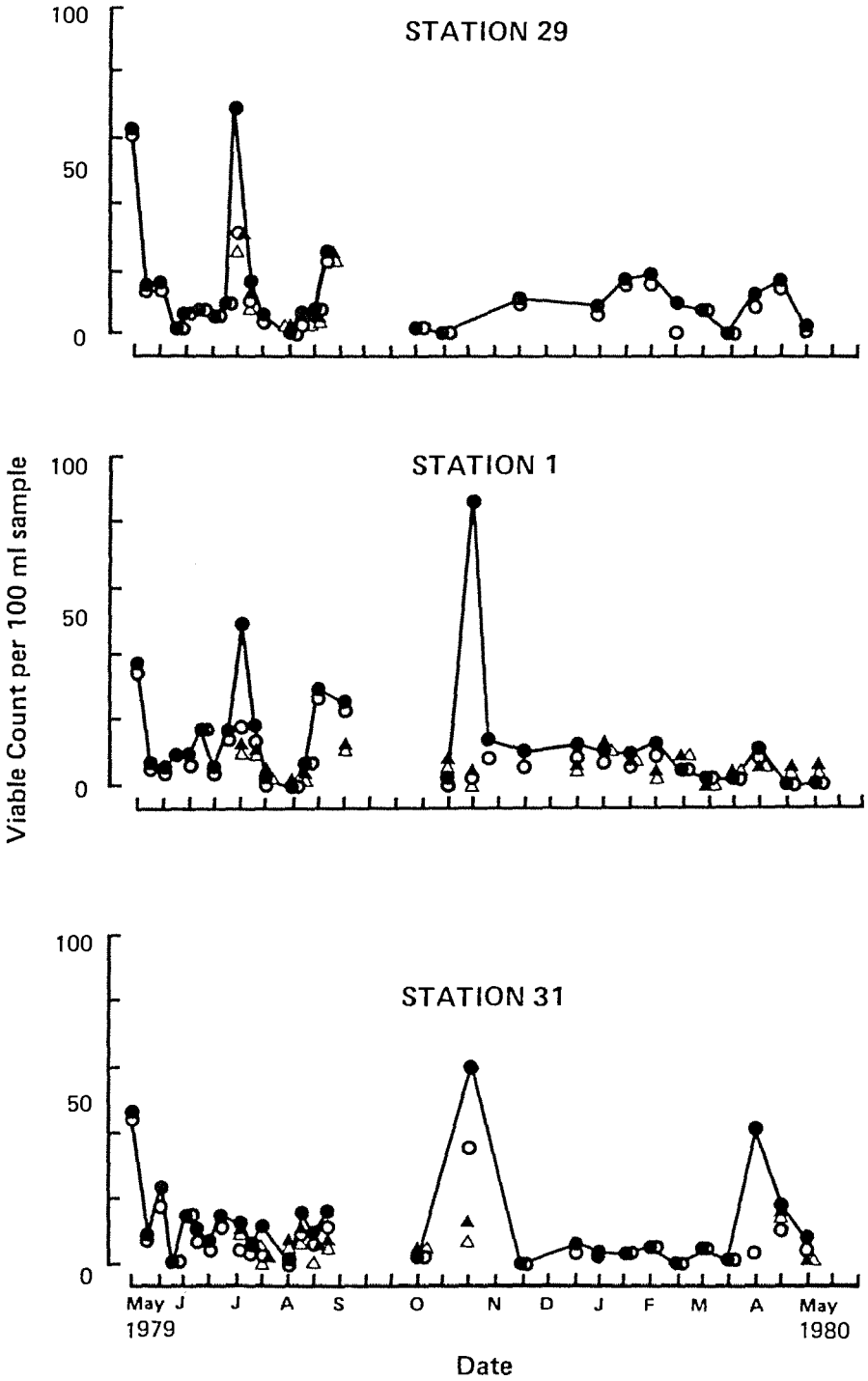


Figure 3.3.2.2 Weekly/Biweekly monitoring; Stations 29, 1, 31

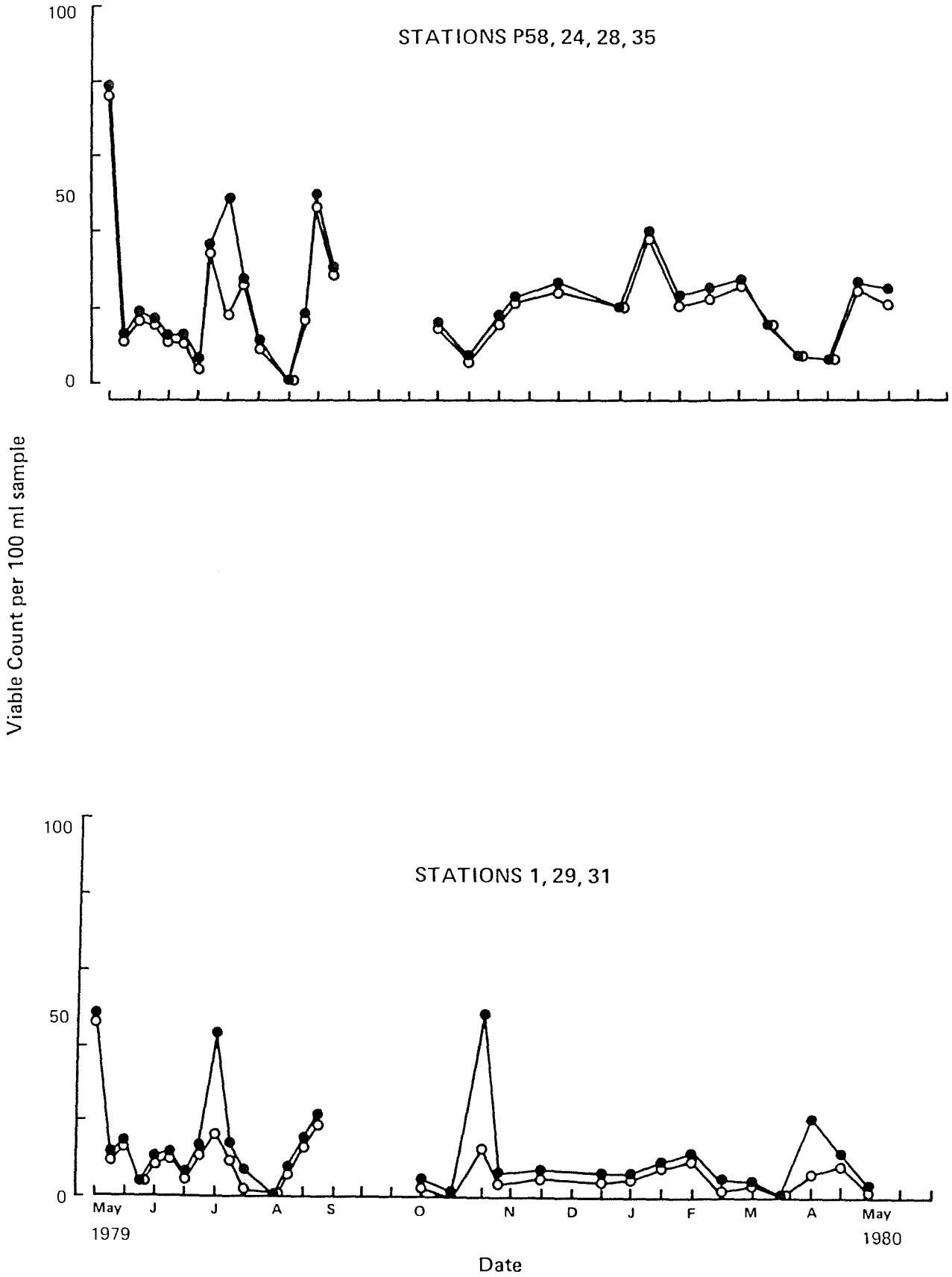


Figure 3.3.2.3 Weekly/Biweekly monitoring; summaries of Stations 24, 28, P58, 35, and 1, 29, 31

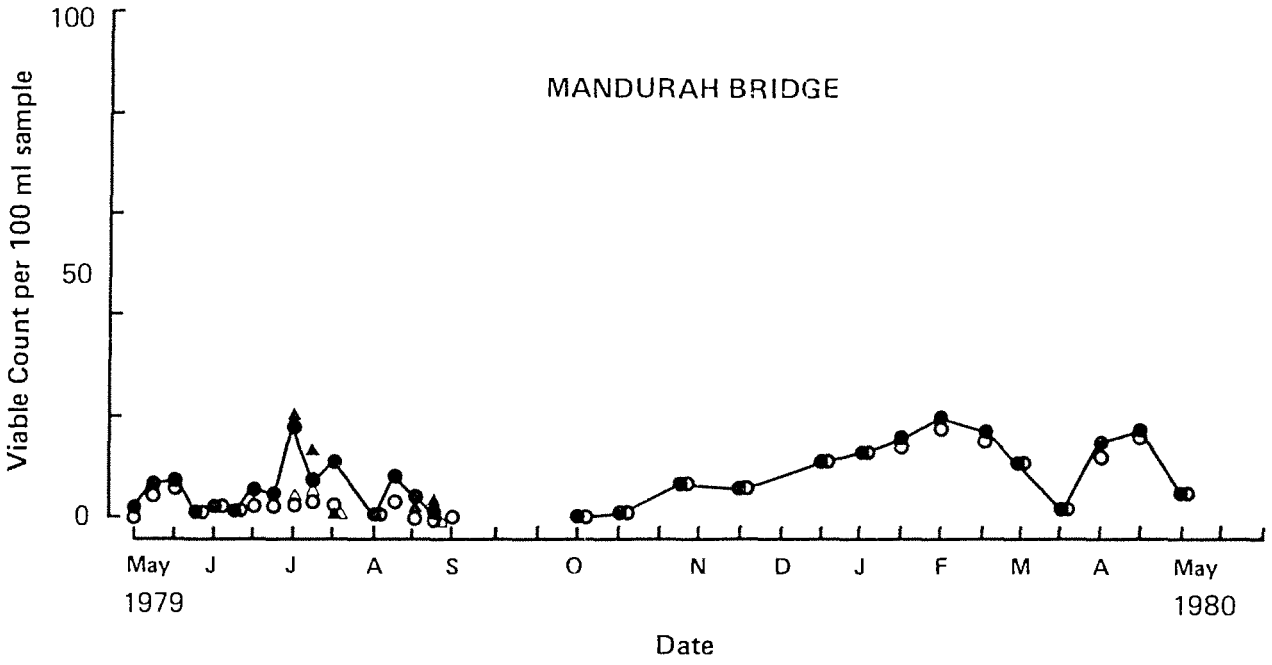


Figure 3.3.3 Weekly/Biweekly monitoring; Mandurah Bridge

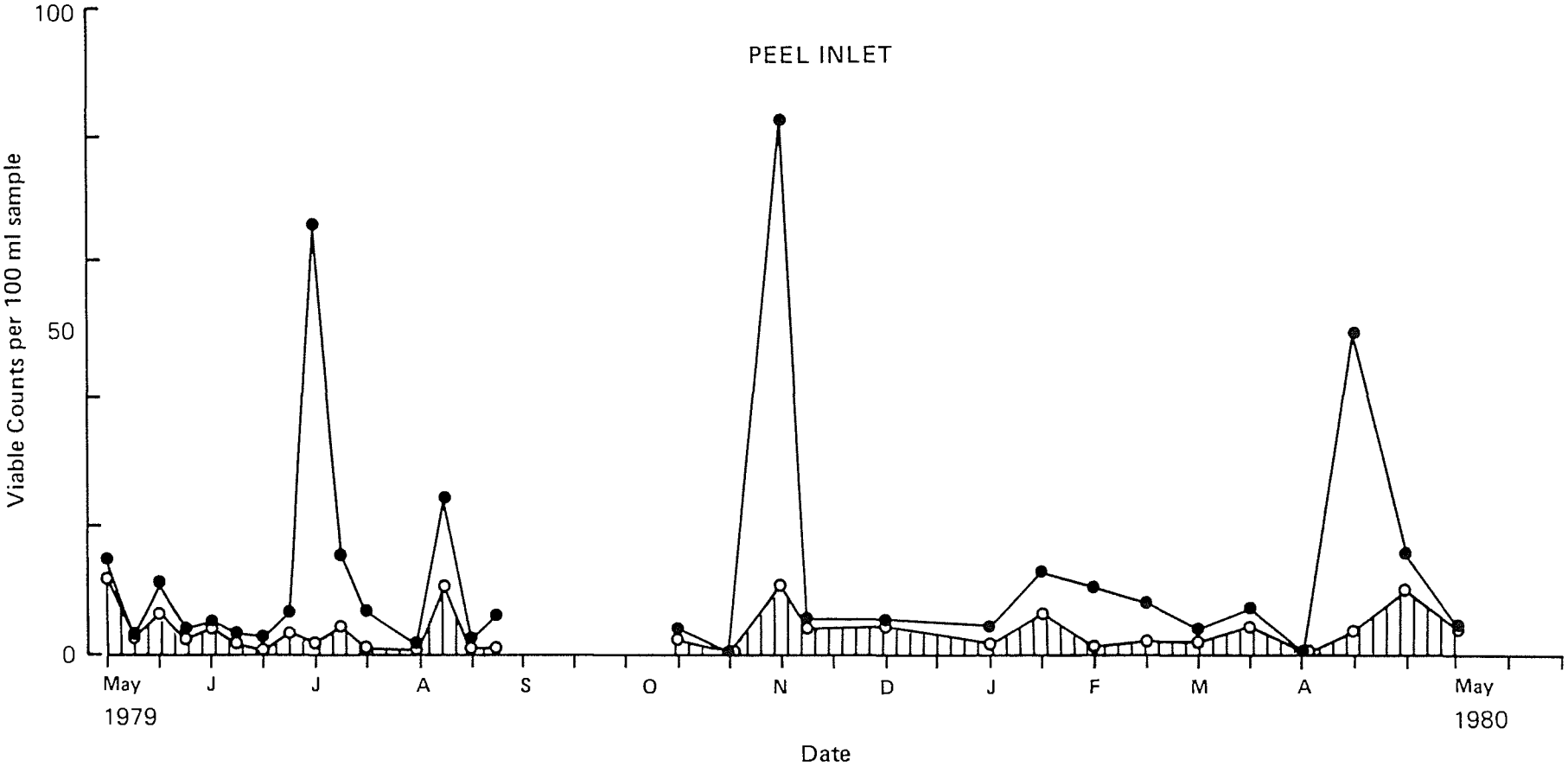


Figure 3.3.4.1 Weekly/Biweekly monitoring; summary of the Peel Inlet

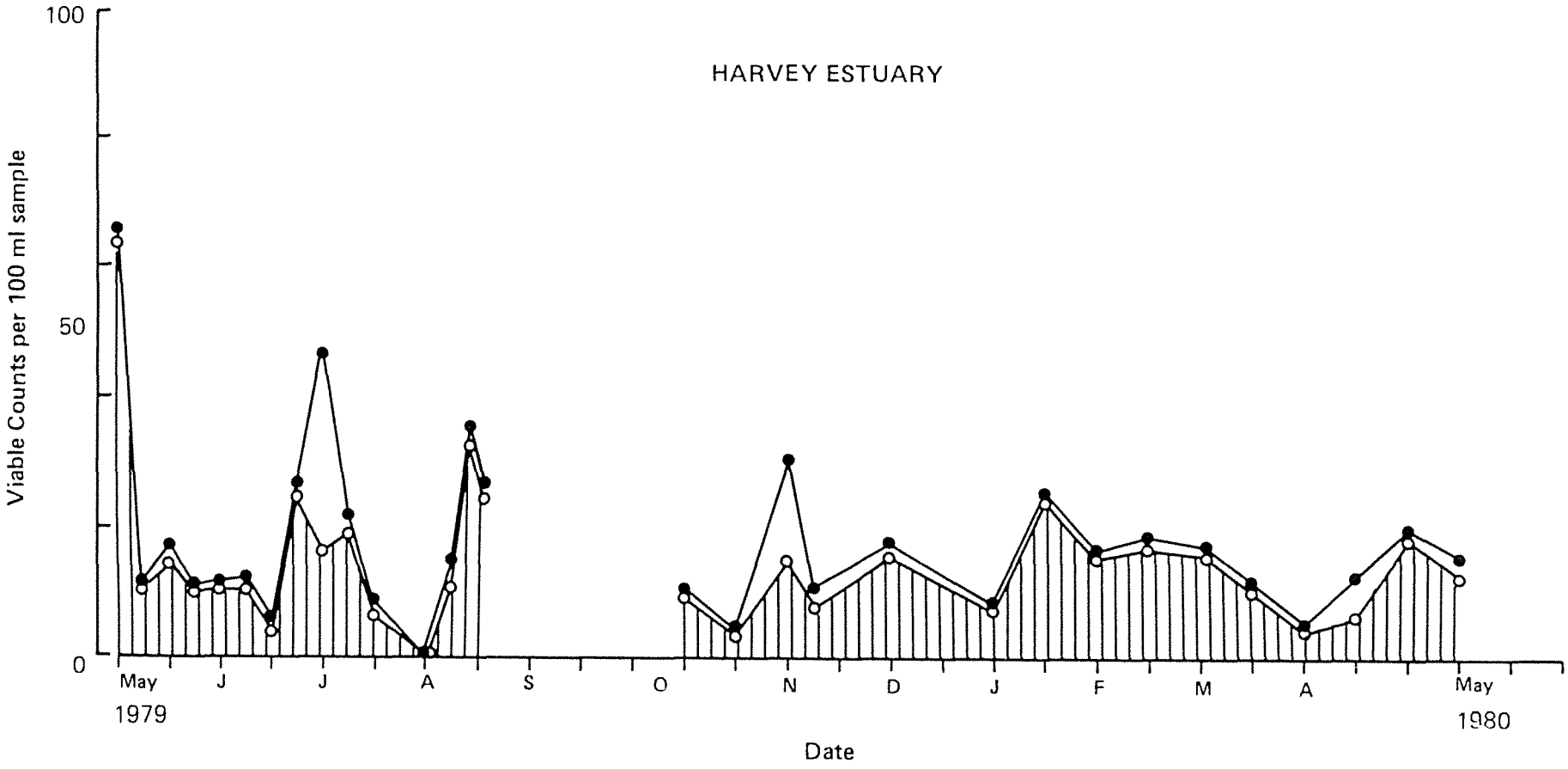


Figure 3.3.4.2 Weekly/Biweekly monitoring; summary of the Harvey Estuary

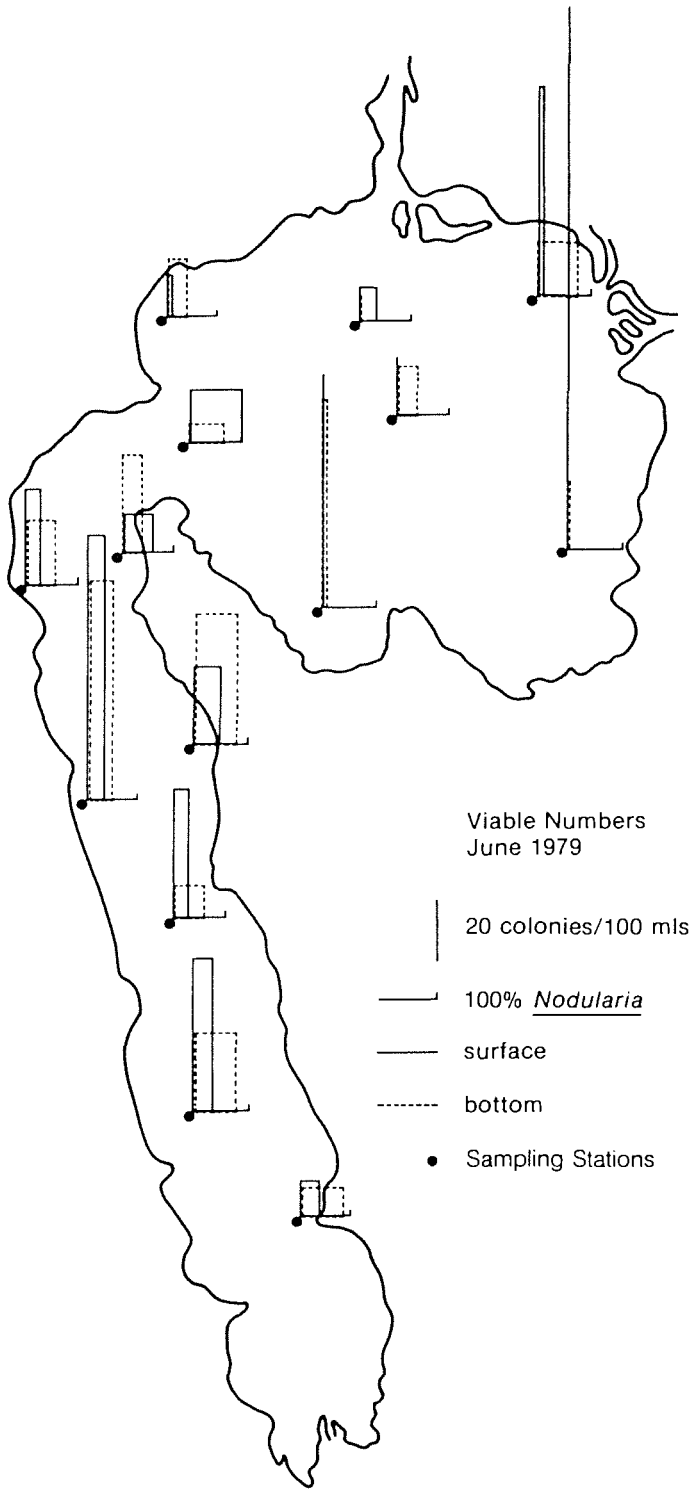


Figure 3.3.5 Total numbers oc cyanobacteria, and percentage of Nodularia; June 17, 1979

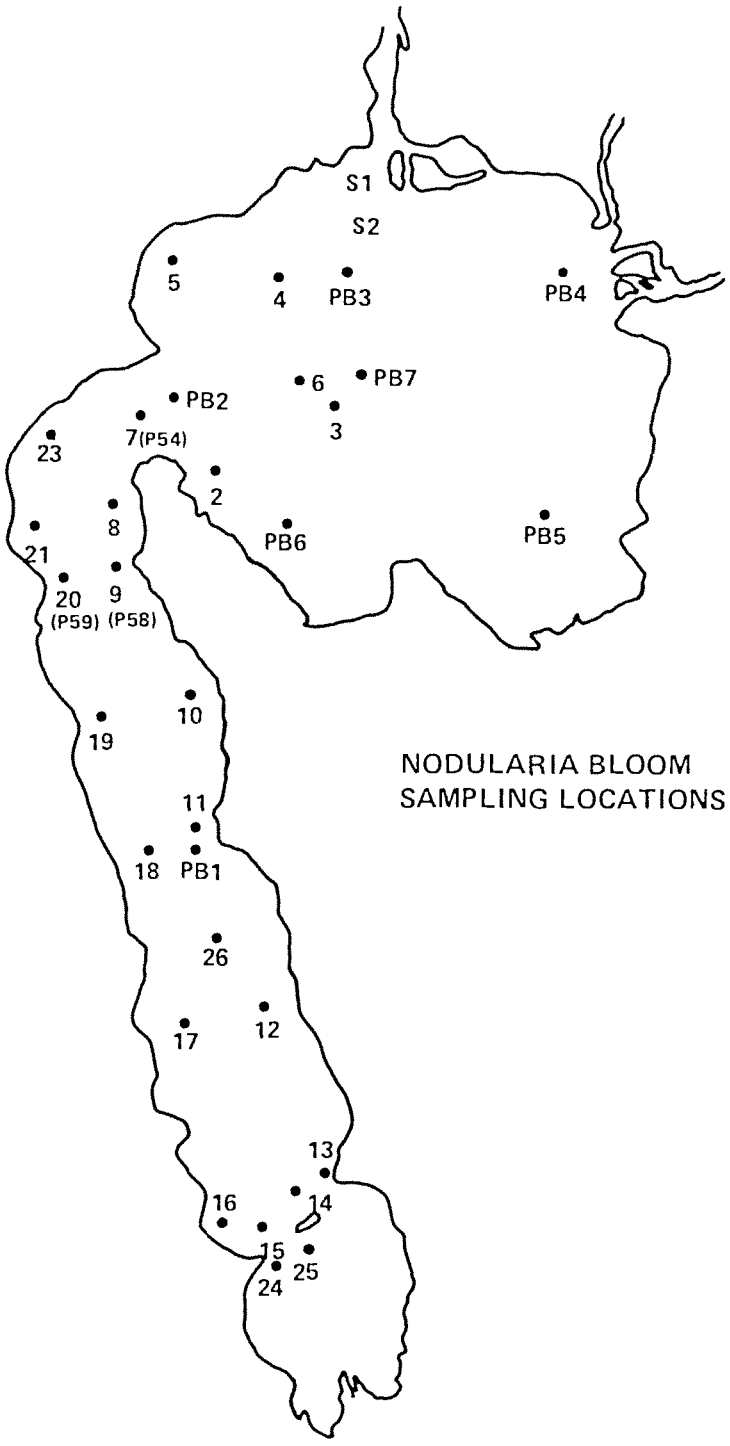
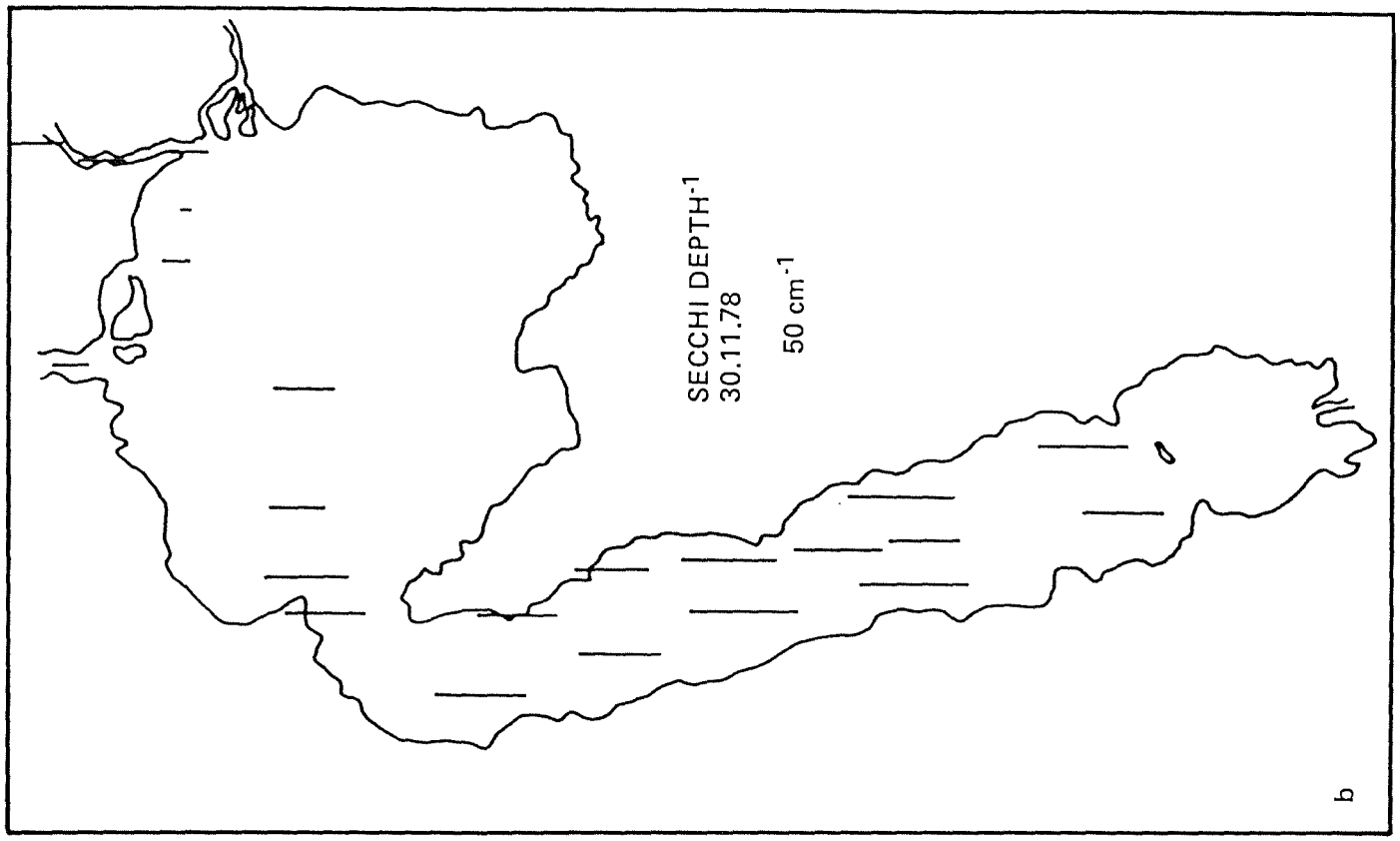


Figure 3.5 Nodularia Bloom; Sampling site locations



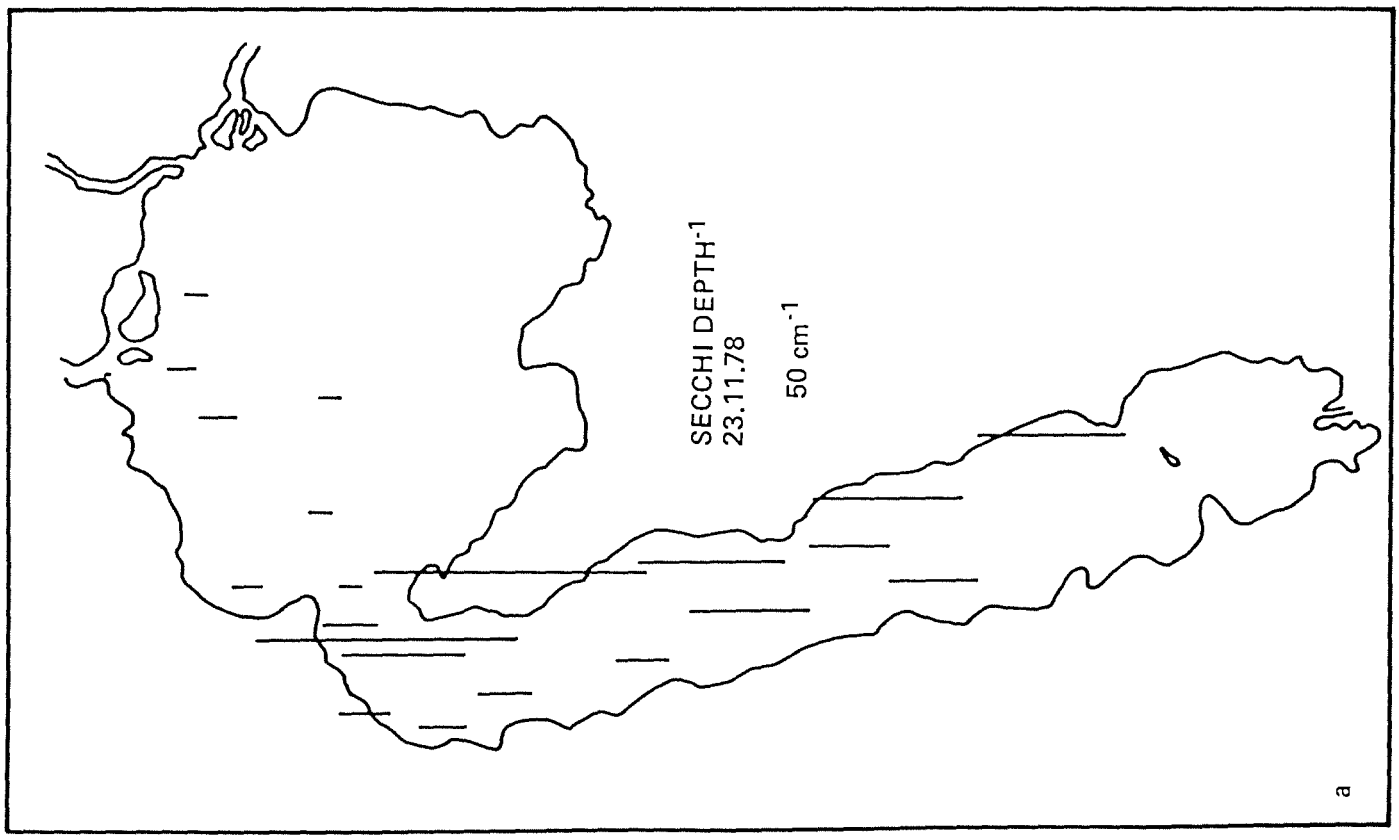
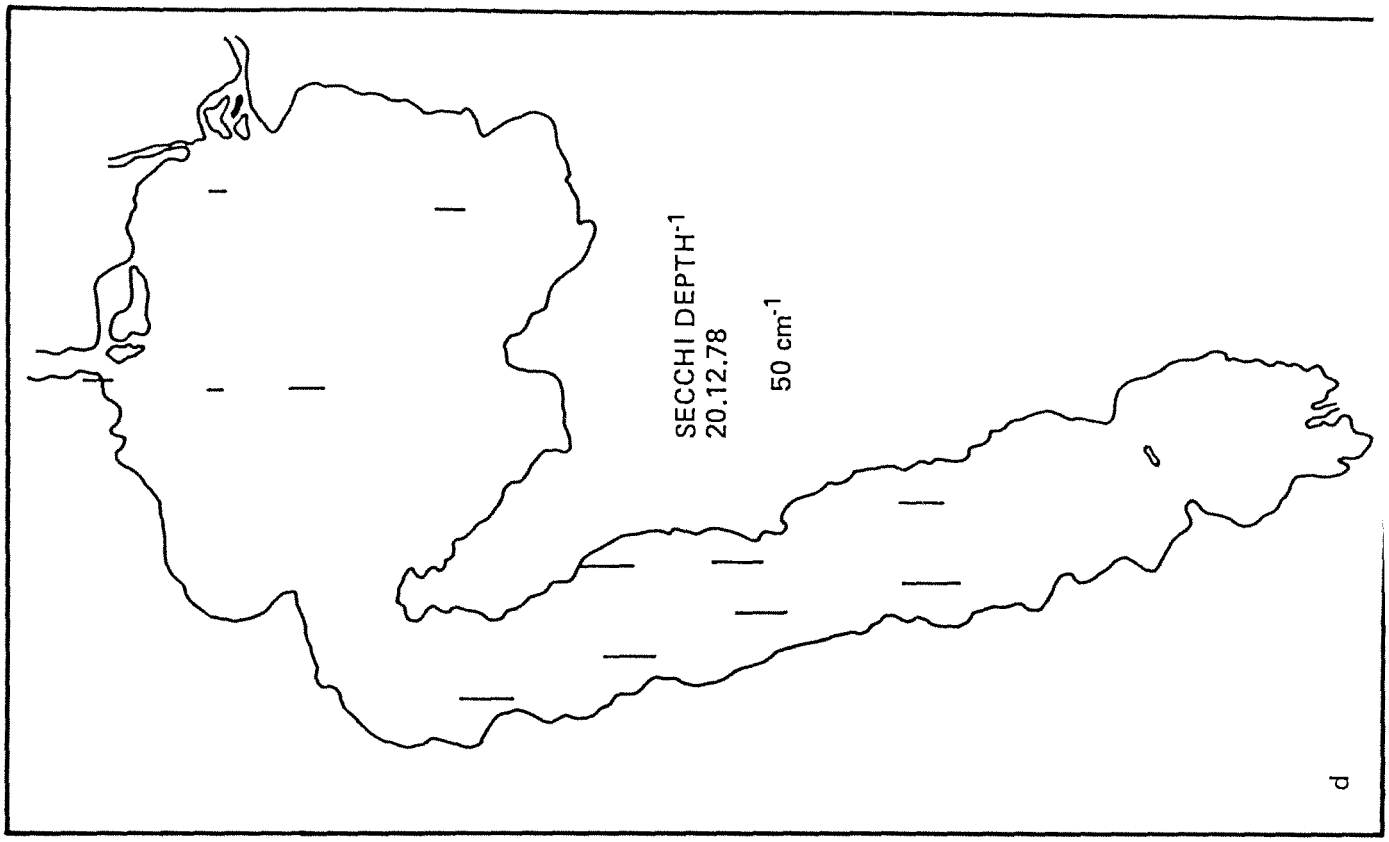


Figure 3.5.1.1 Nodularia Bloom; Secchi depths, November 1978 to January 1979



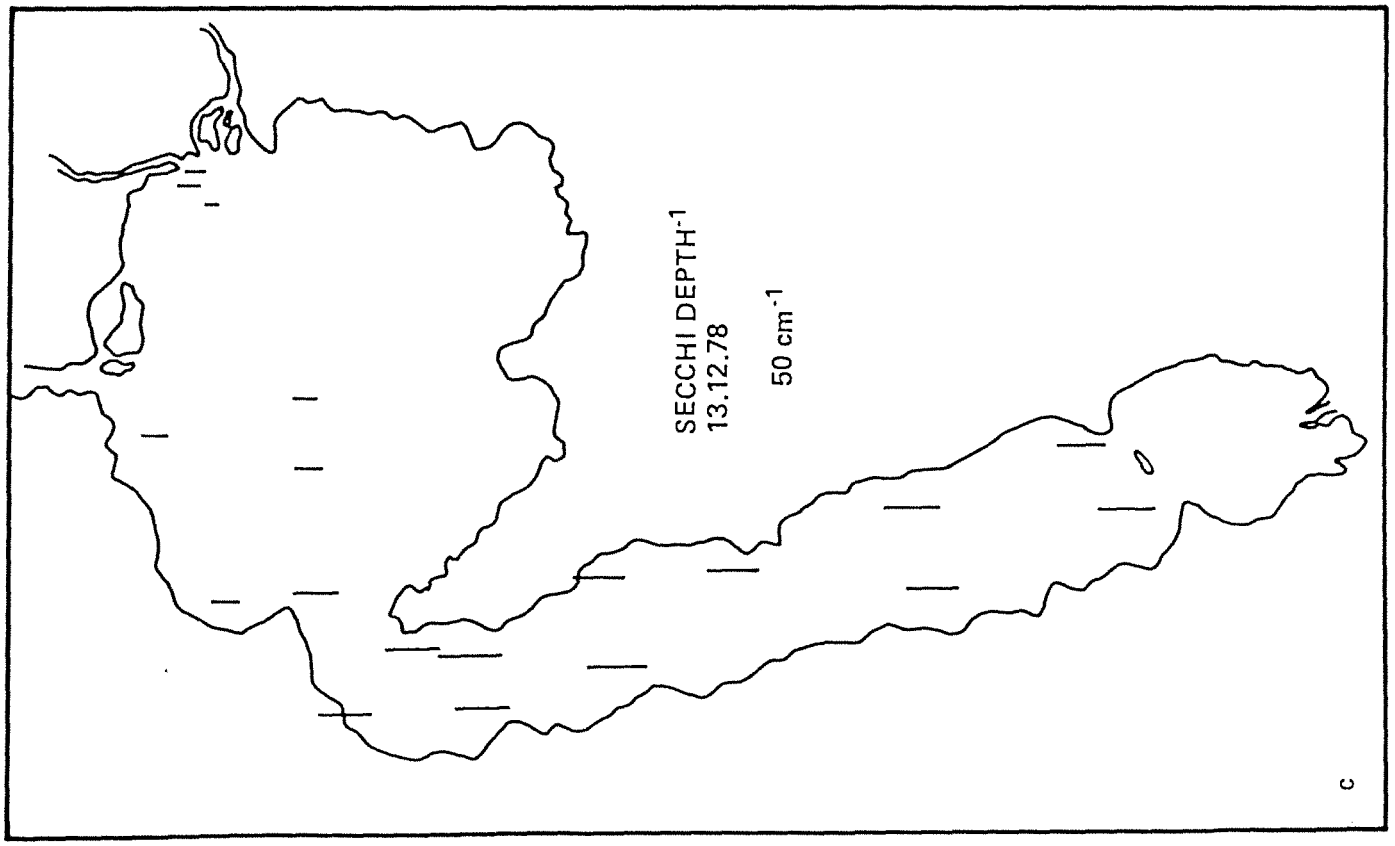
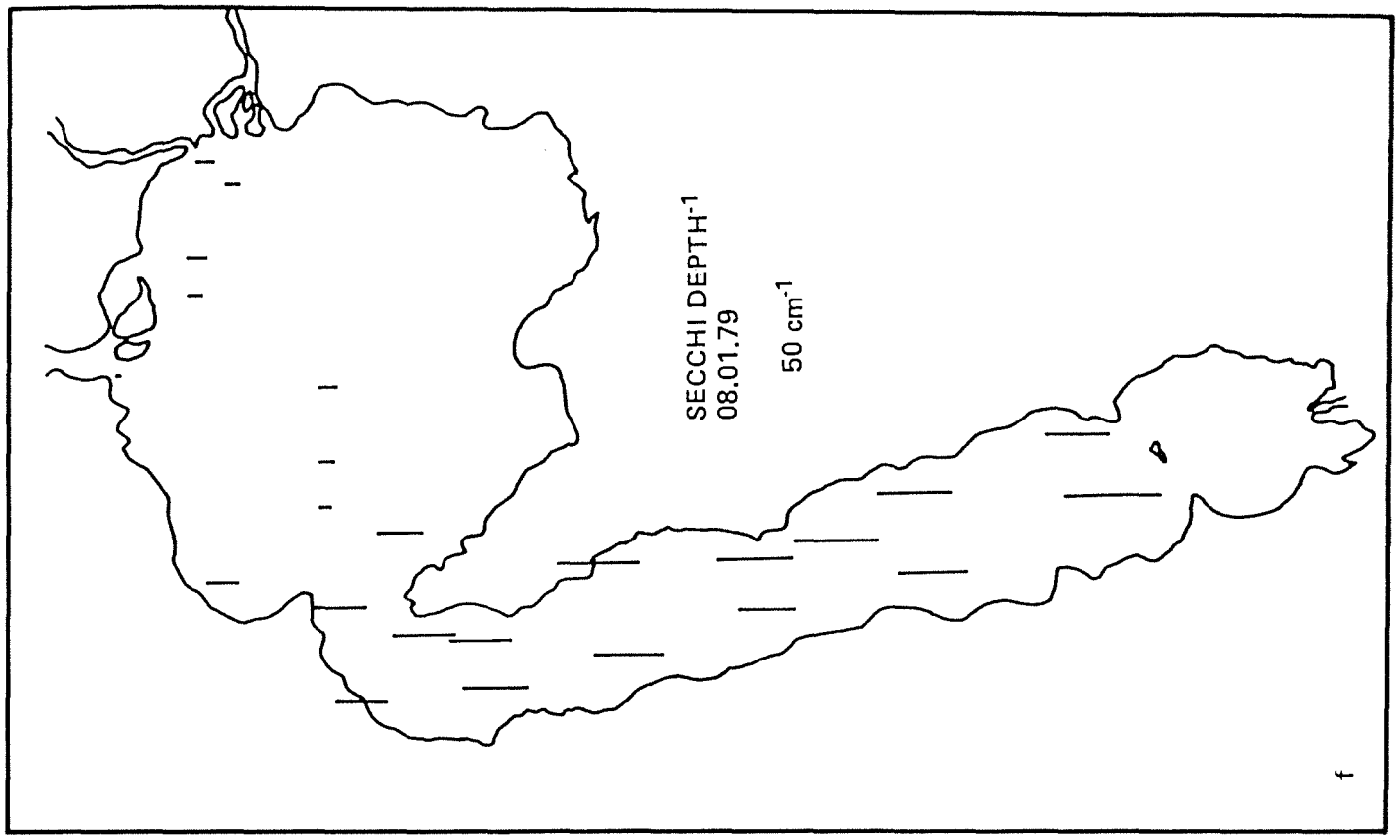


Figure 3.5.1.1 Nodularia Bloom; Secchi depths, November 1978 to January 1979



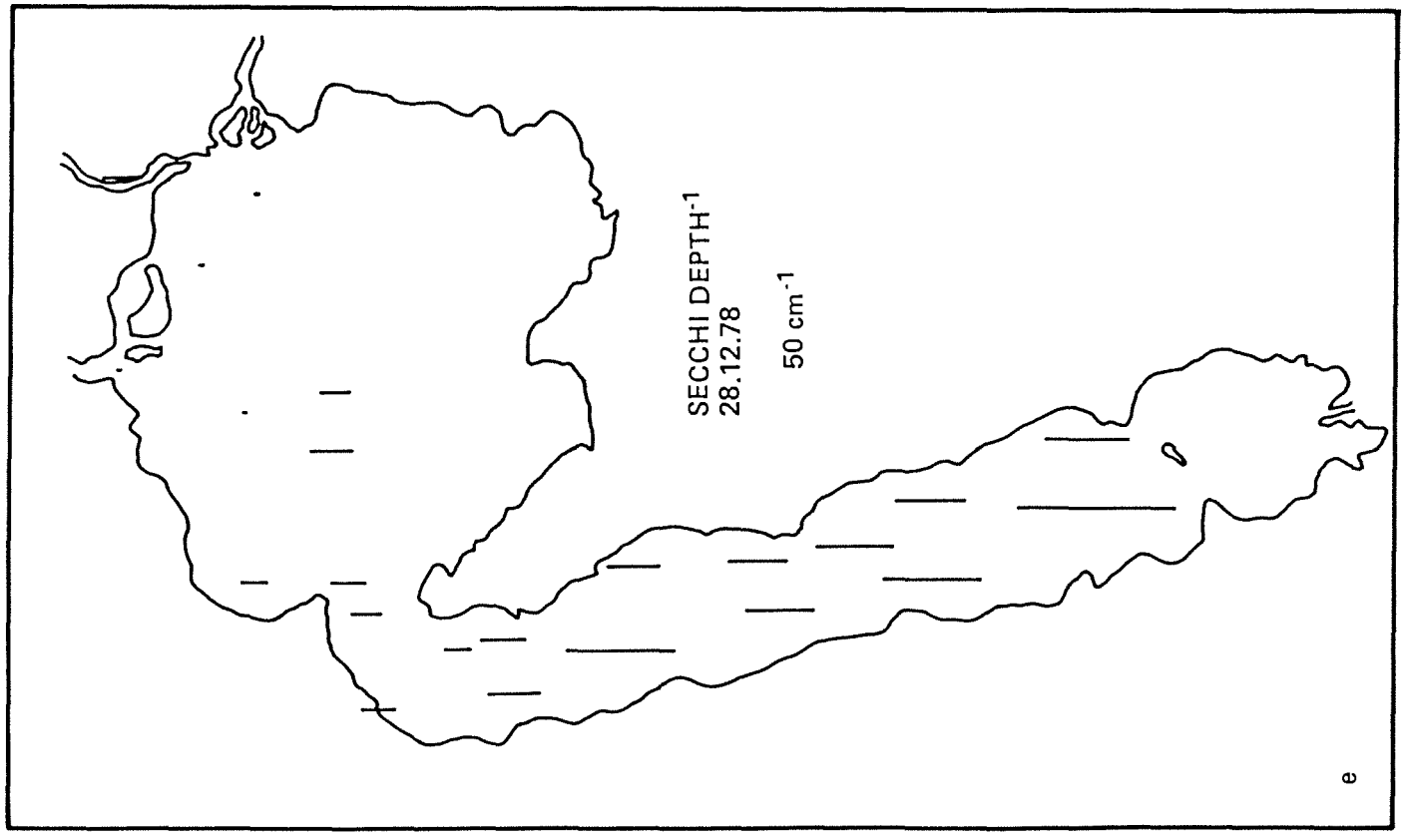


Figure 3.5.1.1 Nodularia Bloom; Secchi depths, November 1978 to January 1979

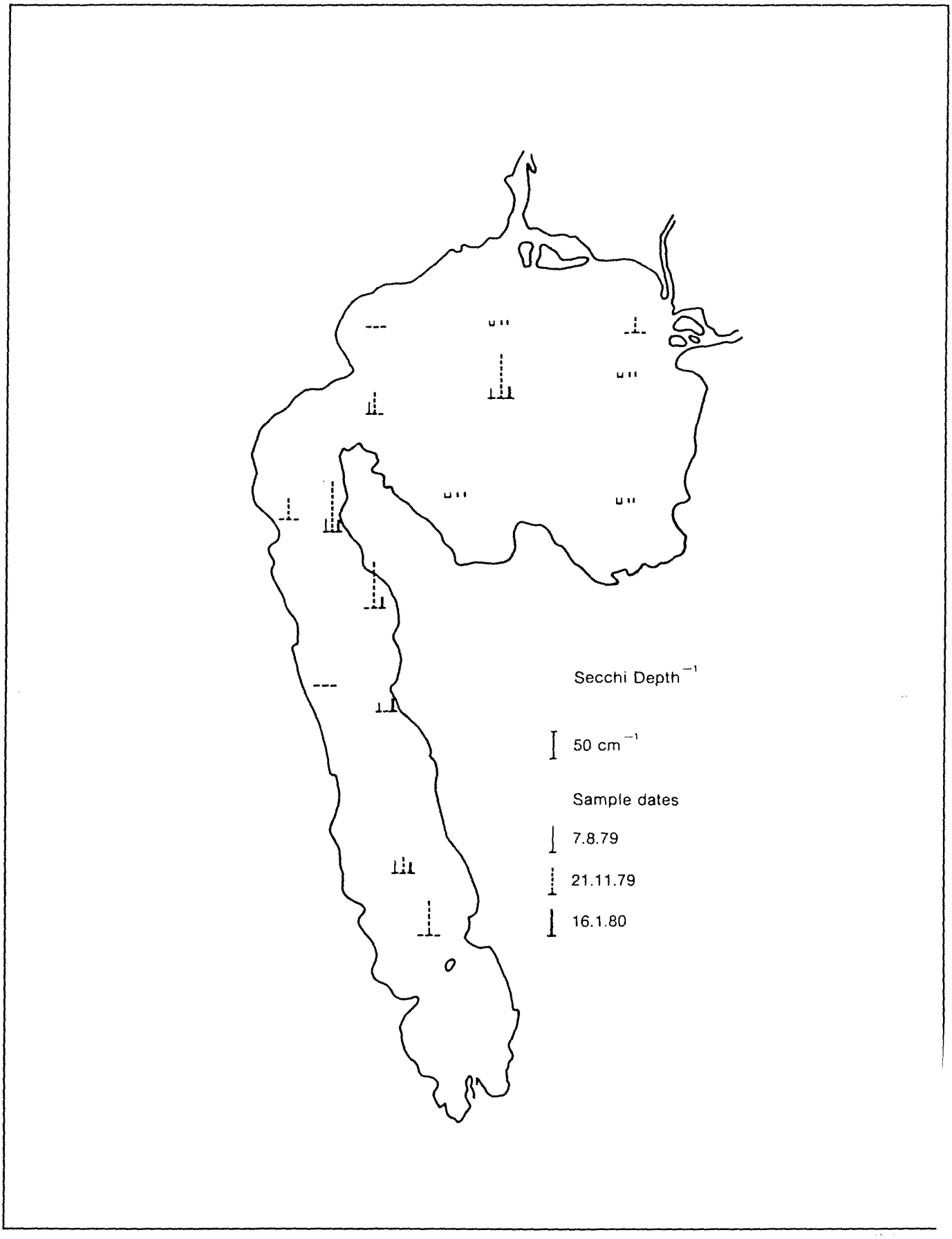


Figure 3.5.1.2 Nodularia Bloom; Secchi depths, 7.8.79, 21.11.79, and 16.01.80

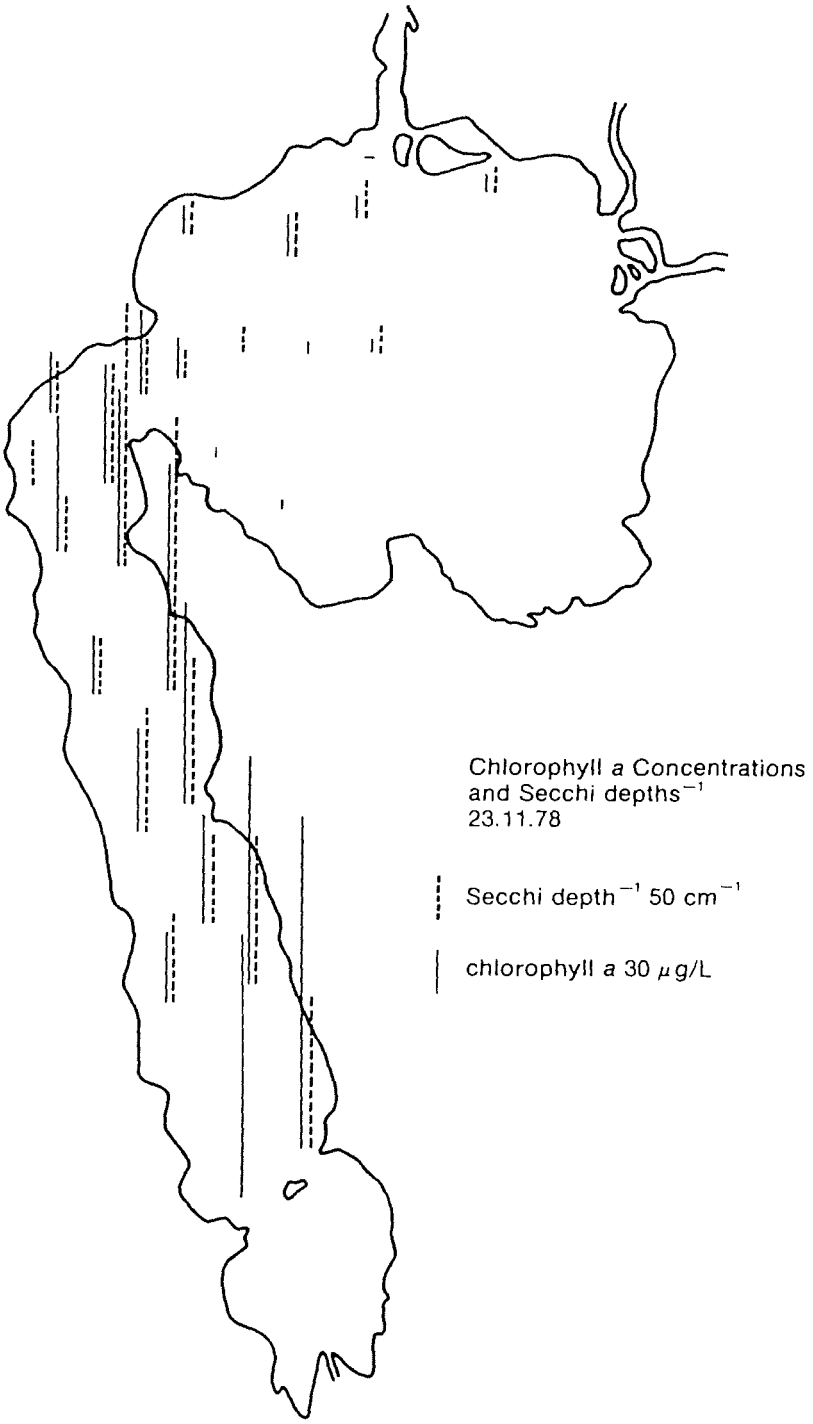


Figure 3.5.2.1 Map of secchi depth^{-1} and chlorophyll concentrations 23.11.78

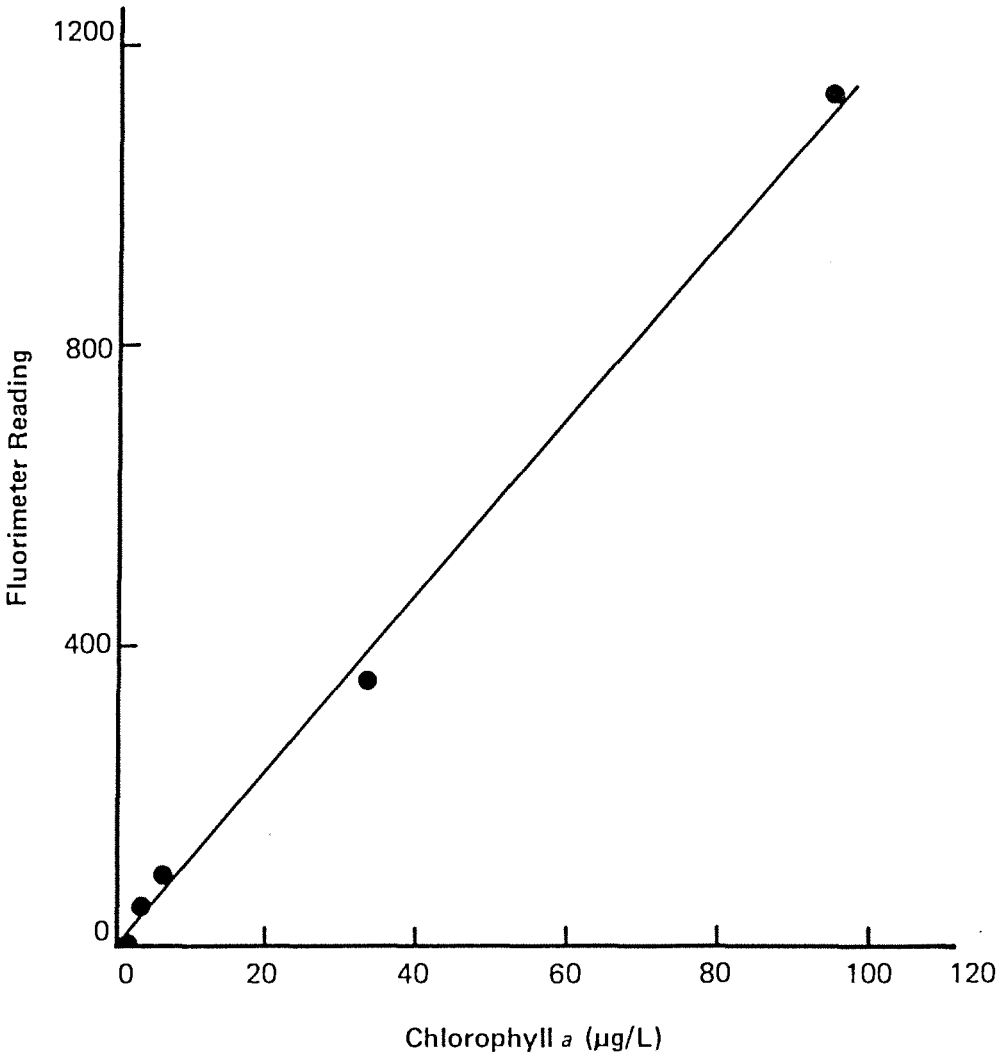


Figure 3.5.2.2 Standard curve for determining chlorophyll a from fluorometer readings

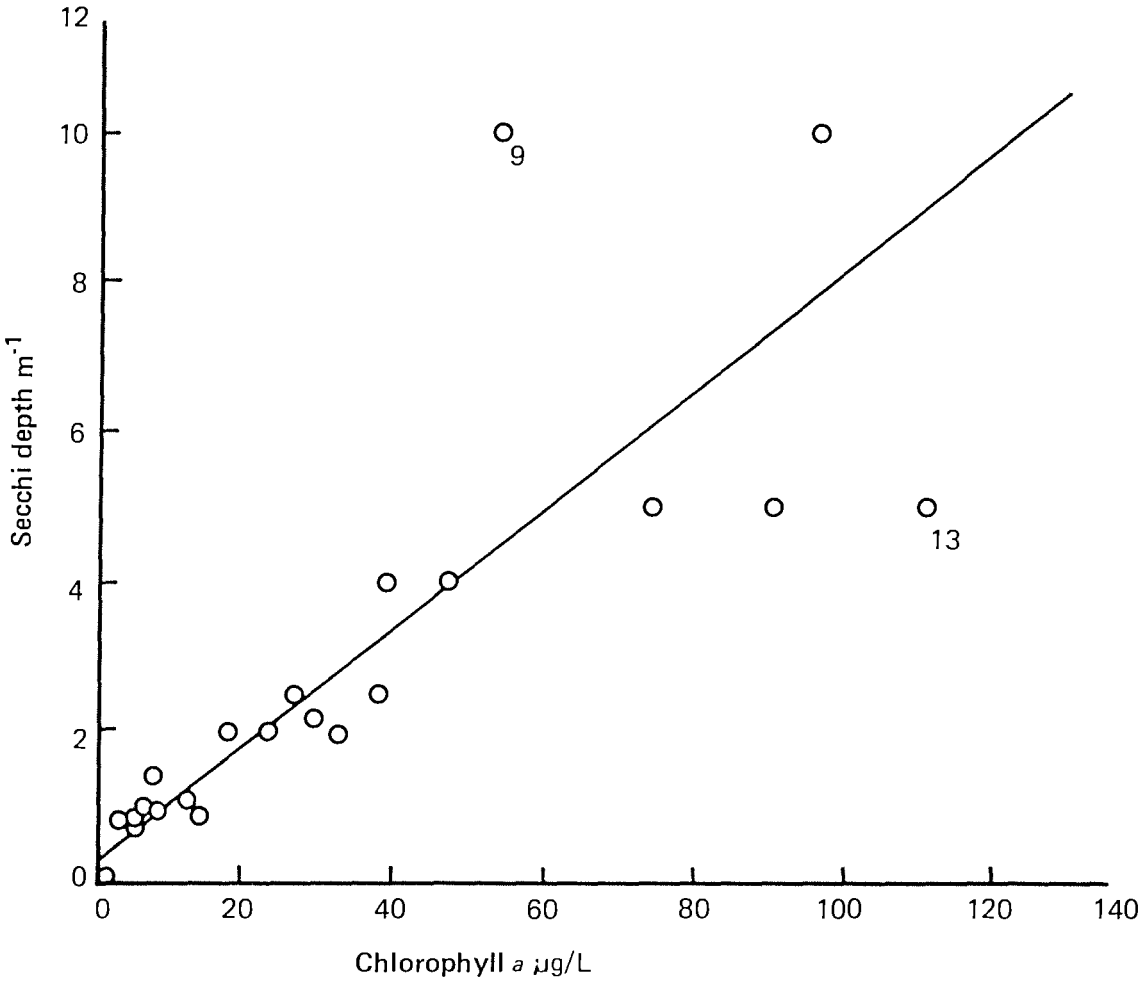


Figure 3.5.2.3 Graph of secchi depth^{-1} versus chlorophyll a 23.11.78

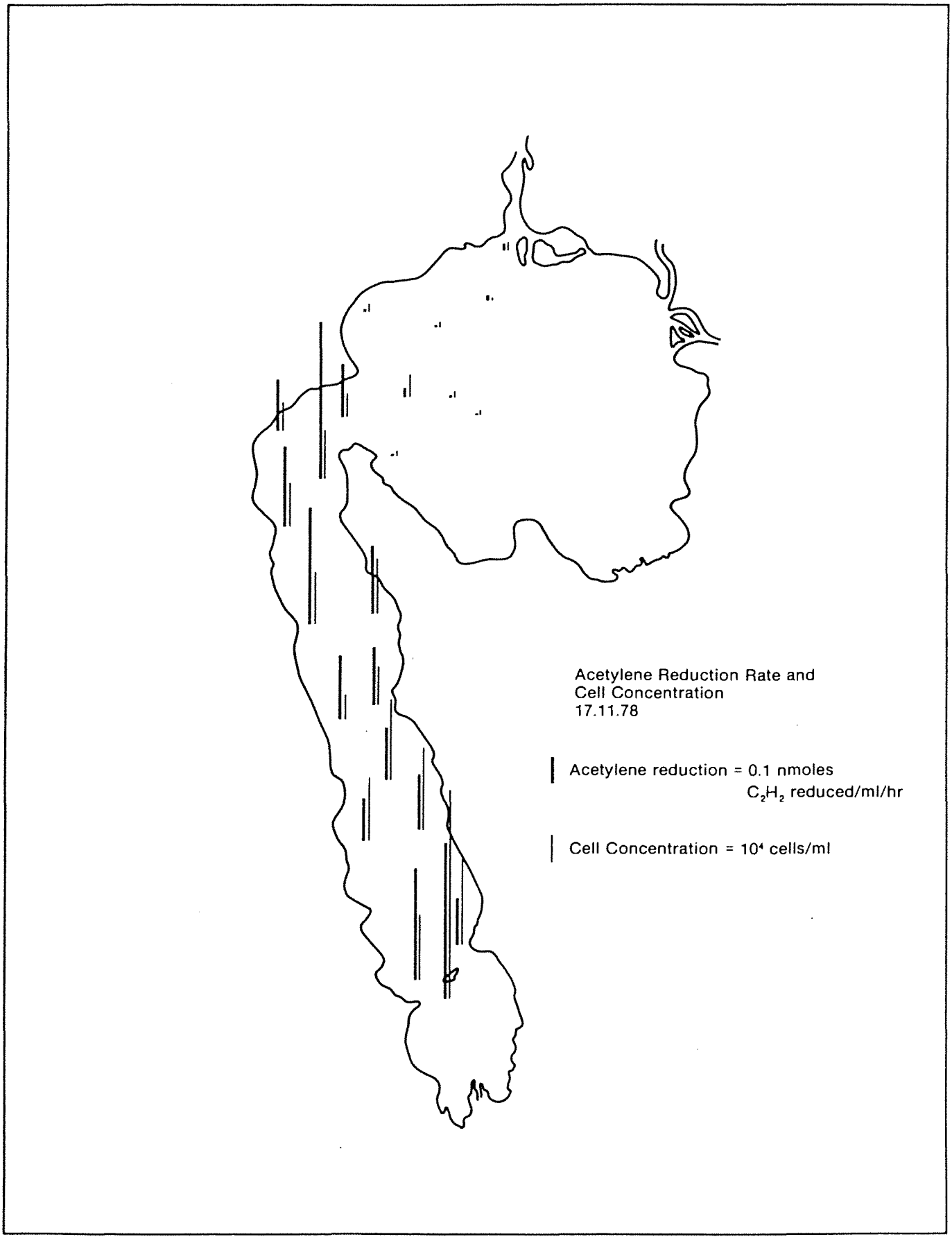


Figure 3.5.3.1 Map of acetylene reduction activity and cell concentration; 17.11.78

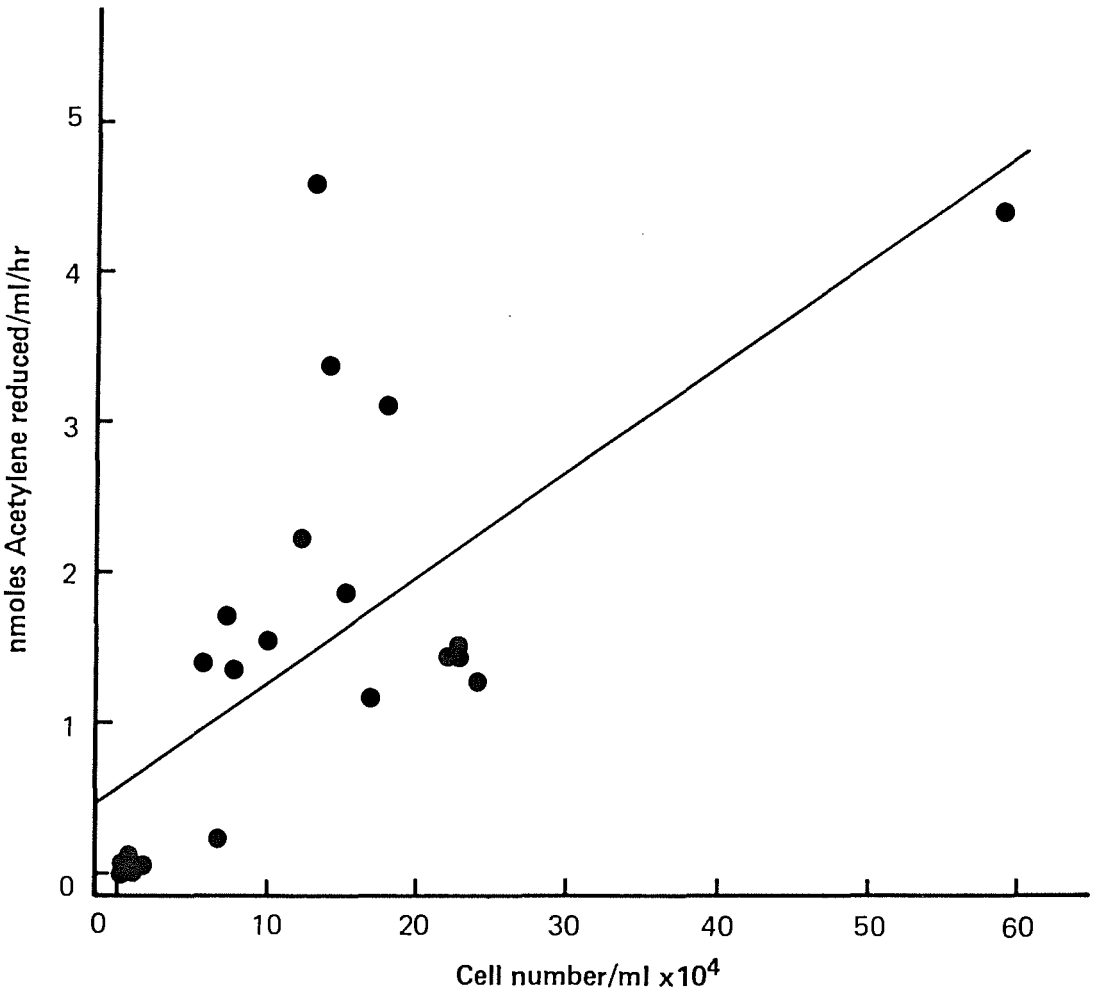


Figure 3.5.3.2 Graph of acetylene reduction activity and cell concentration; 17.11.78

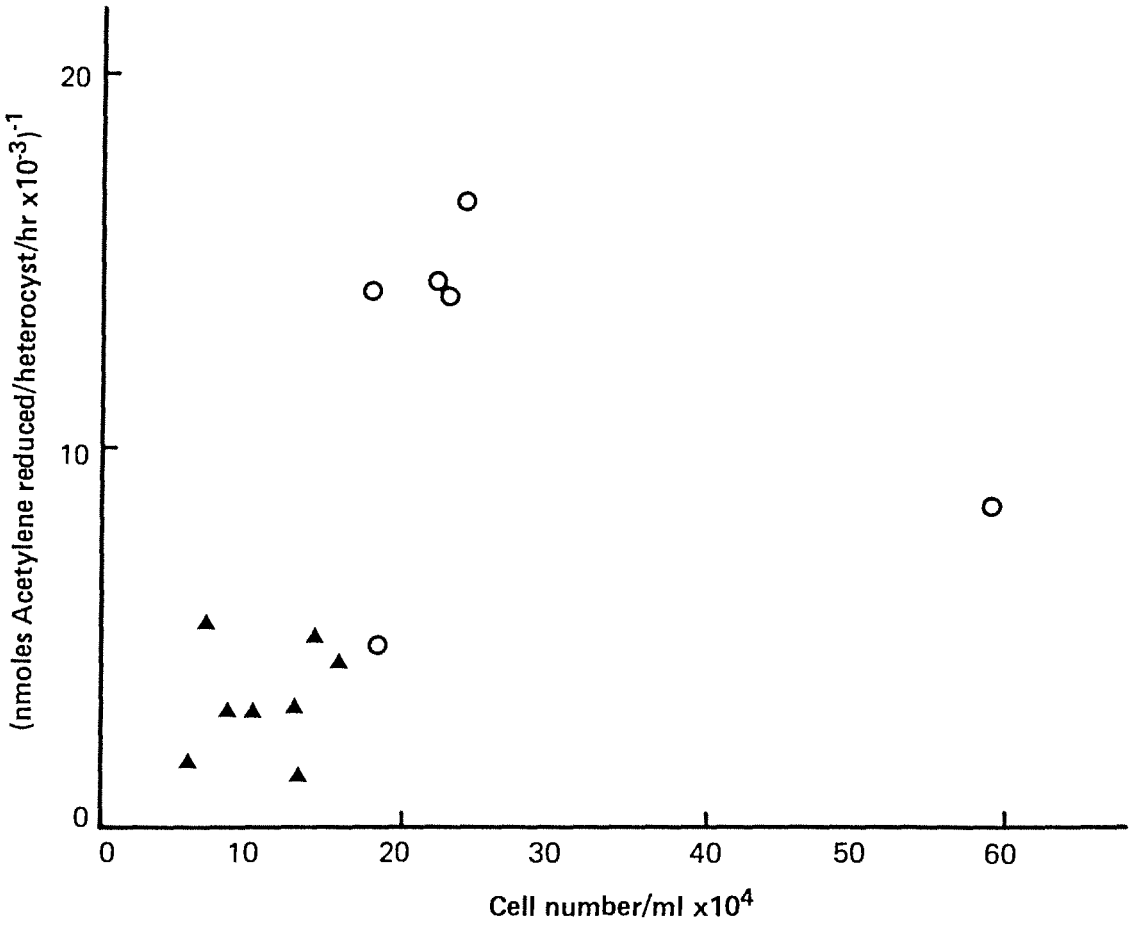


Figure 3.5.3.3 Graph of heterocyst acetylene reduction activity^{-1} versus cell concentration

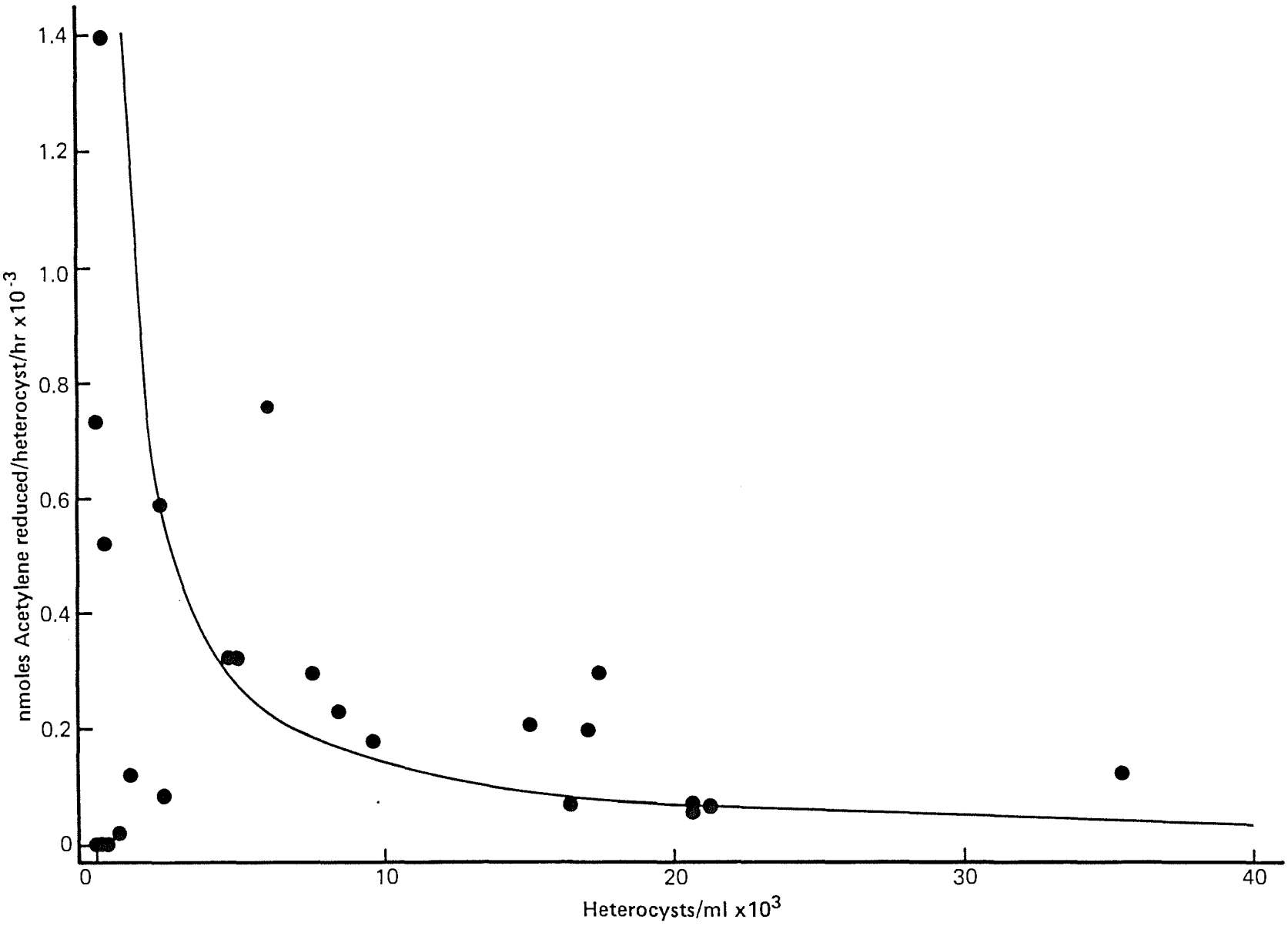


Figure 3.5.3.4 Graph of acetylene reduction activity versus heterocyst concentration; 17.11.78

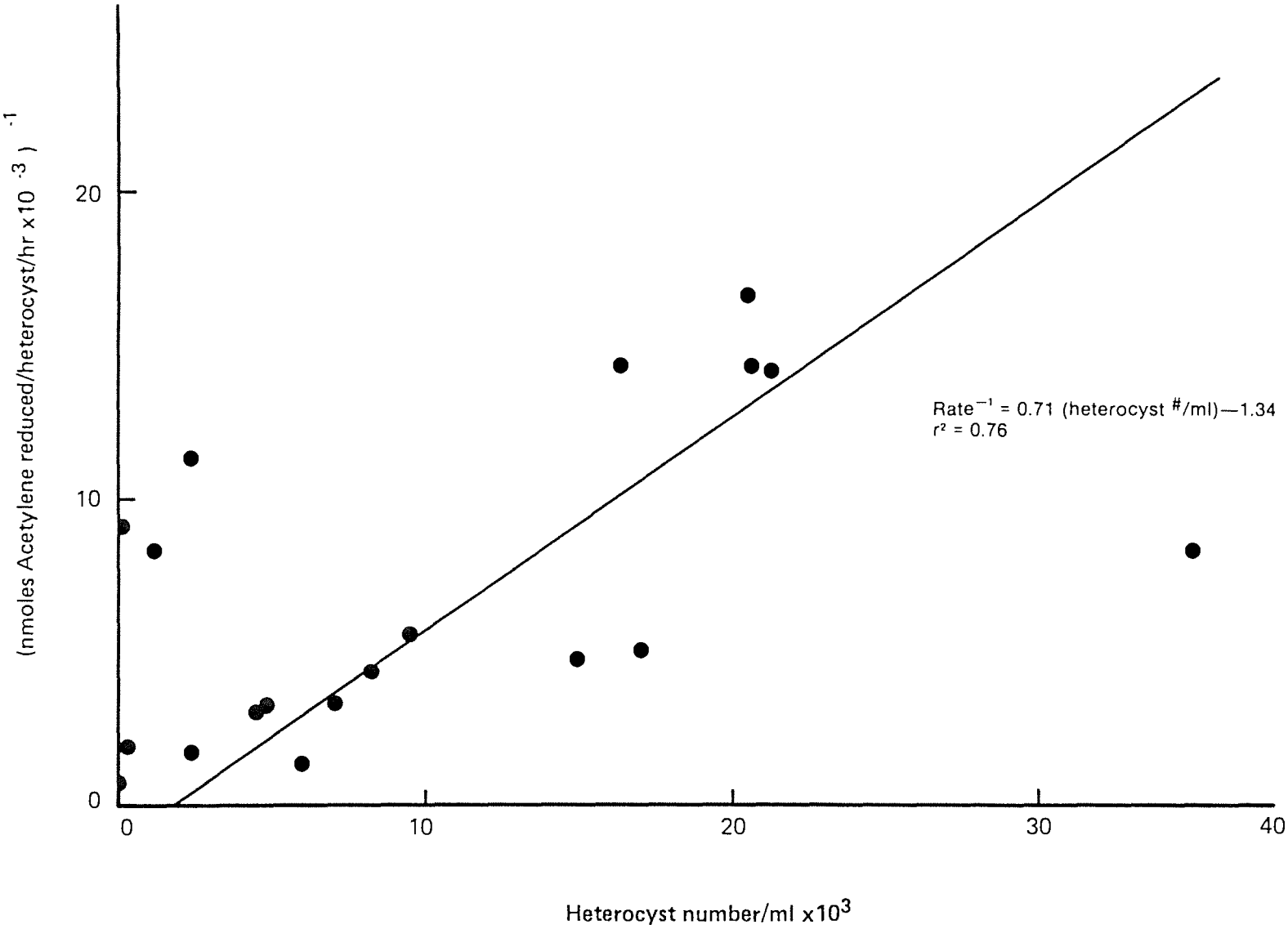


Figure 3.5.3.5 Graph of heterocyst acetylene reduction activity^{-1} versus heterocyst concentration; 17.11.78

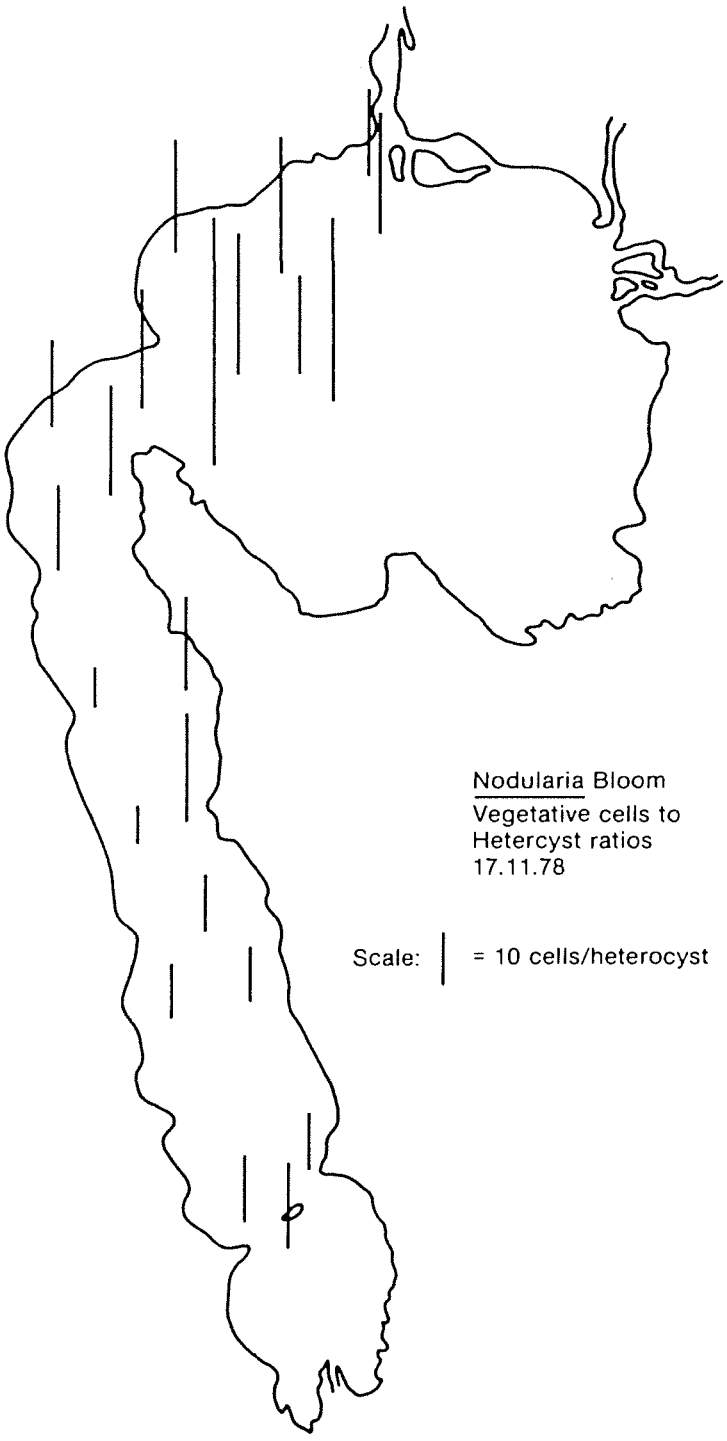


Figure 3.5.3.6 Map of cell to heterocyst ratios; 17.11.78

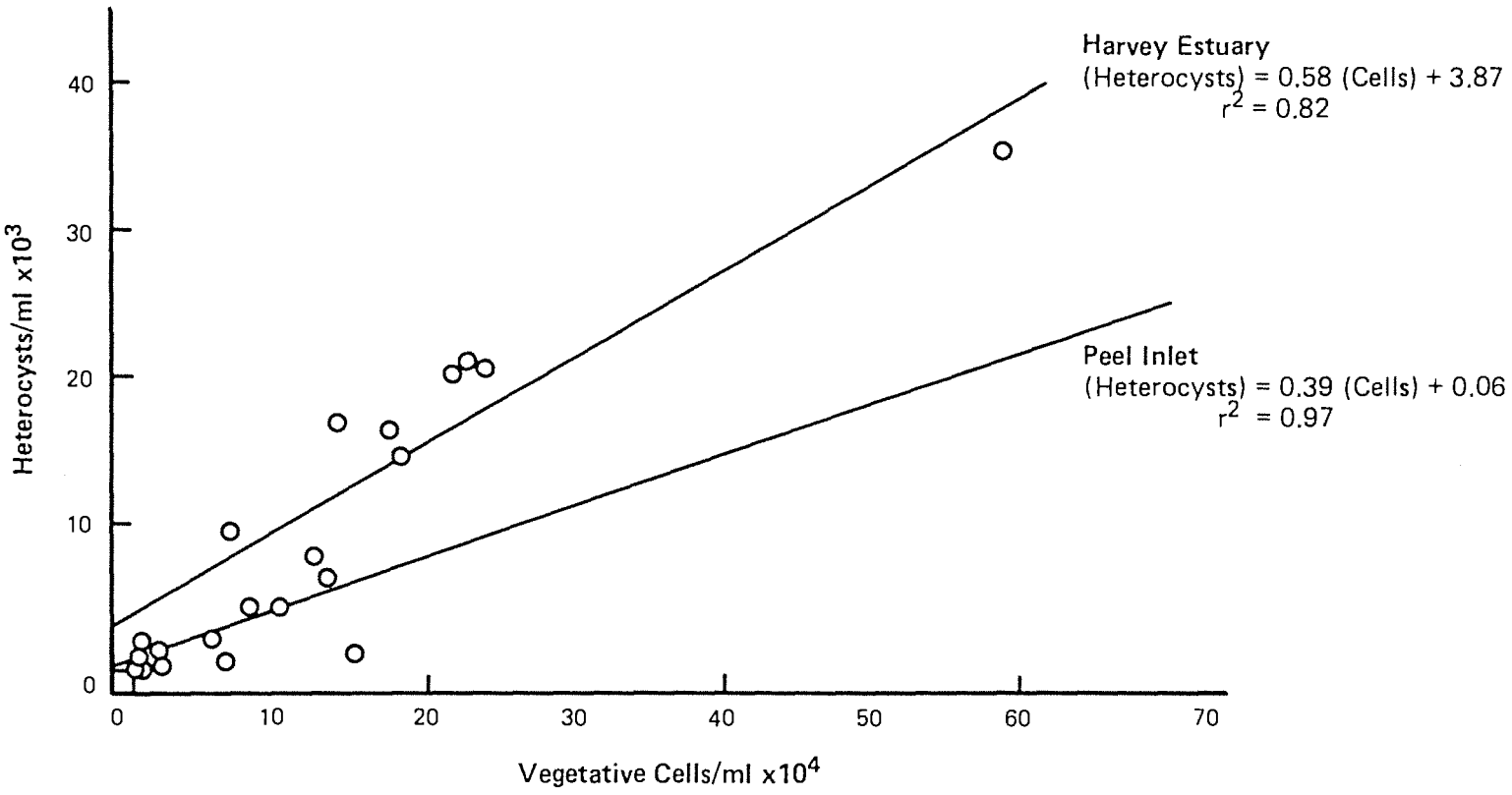


Figure 3.5.3.7 Graph of cell to heterocyst ratios; 17.11.78

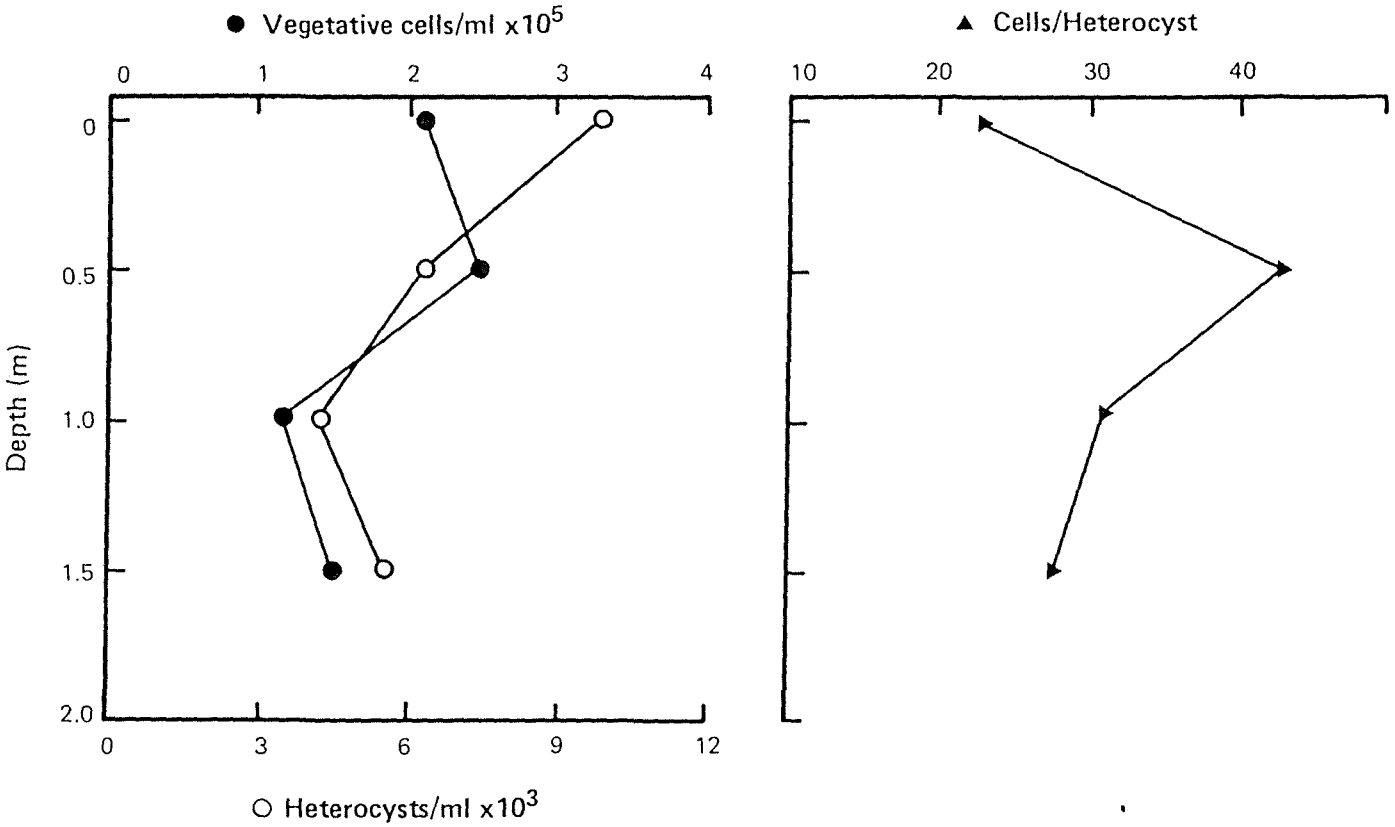


Figure 3.5.4.1 Cell and heterocyst concentrations and ratios; depth profiles at Station 20, 30.11.78

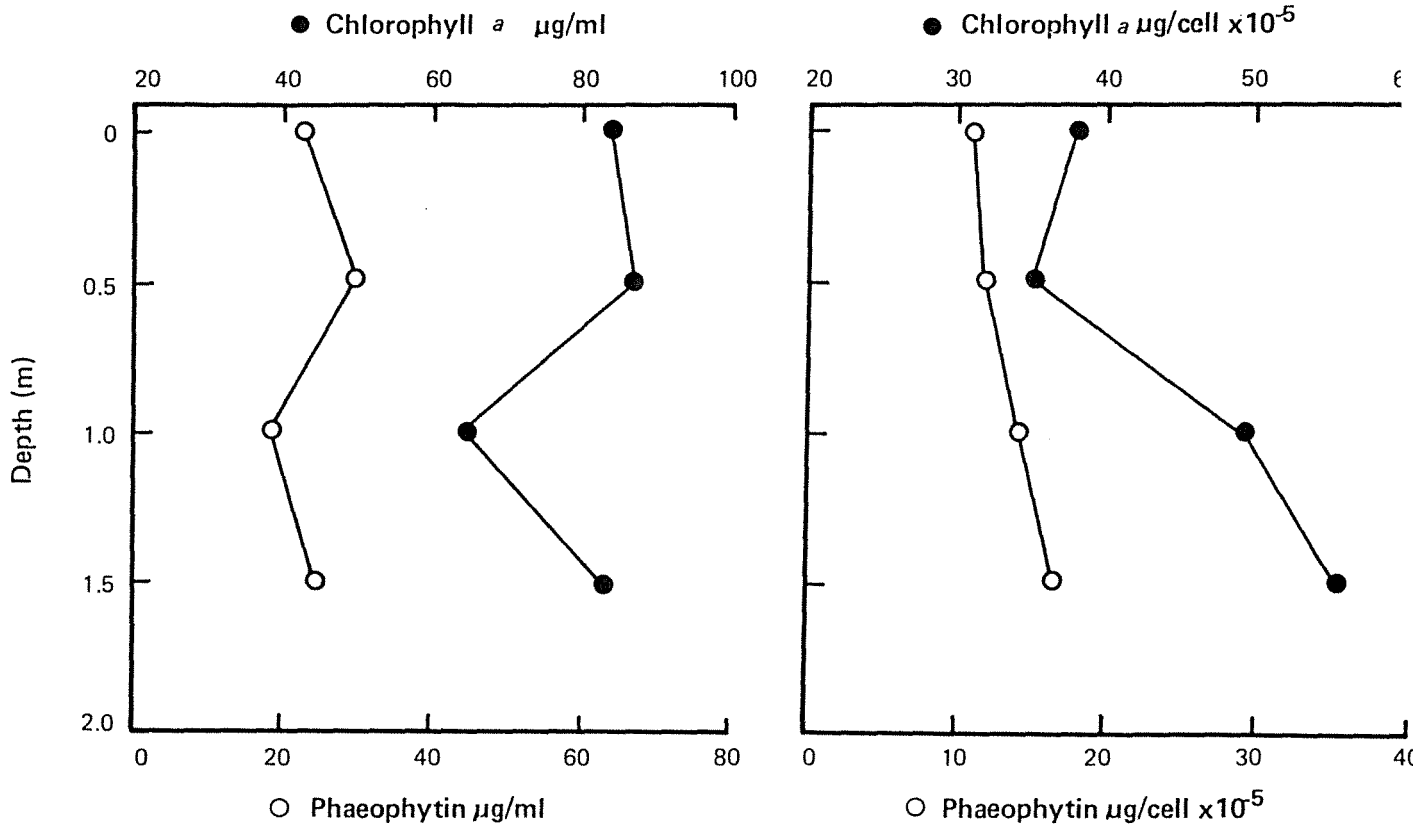


Figure 3.5.4.2 Chlorophyll and phaeophytin concentrations on a volume and cell basis; depth profiles, Station 20

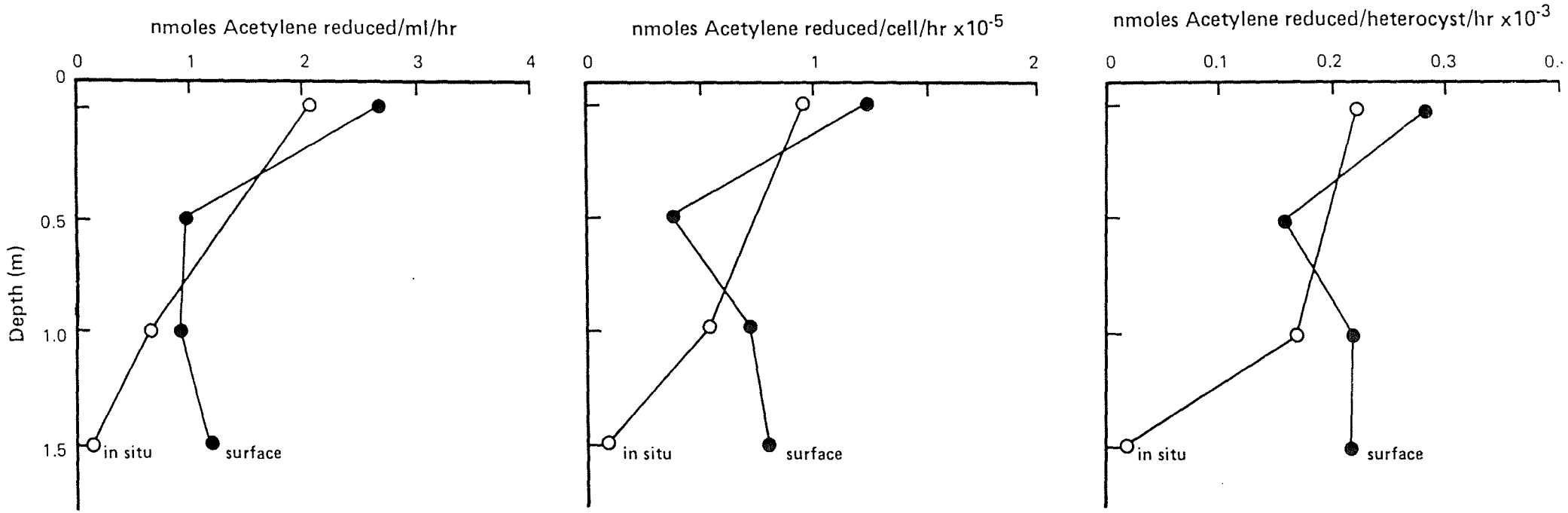


Figure 3.5.4.3 Acetylene reduction rates; depth profiles at Station 20; 30.11.78

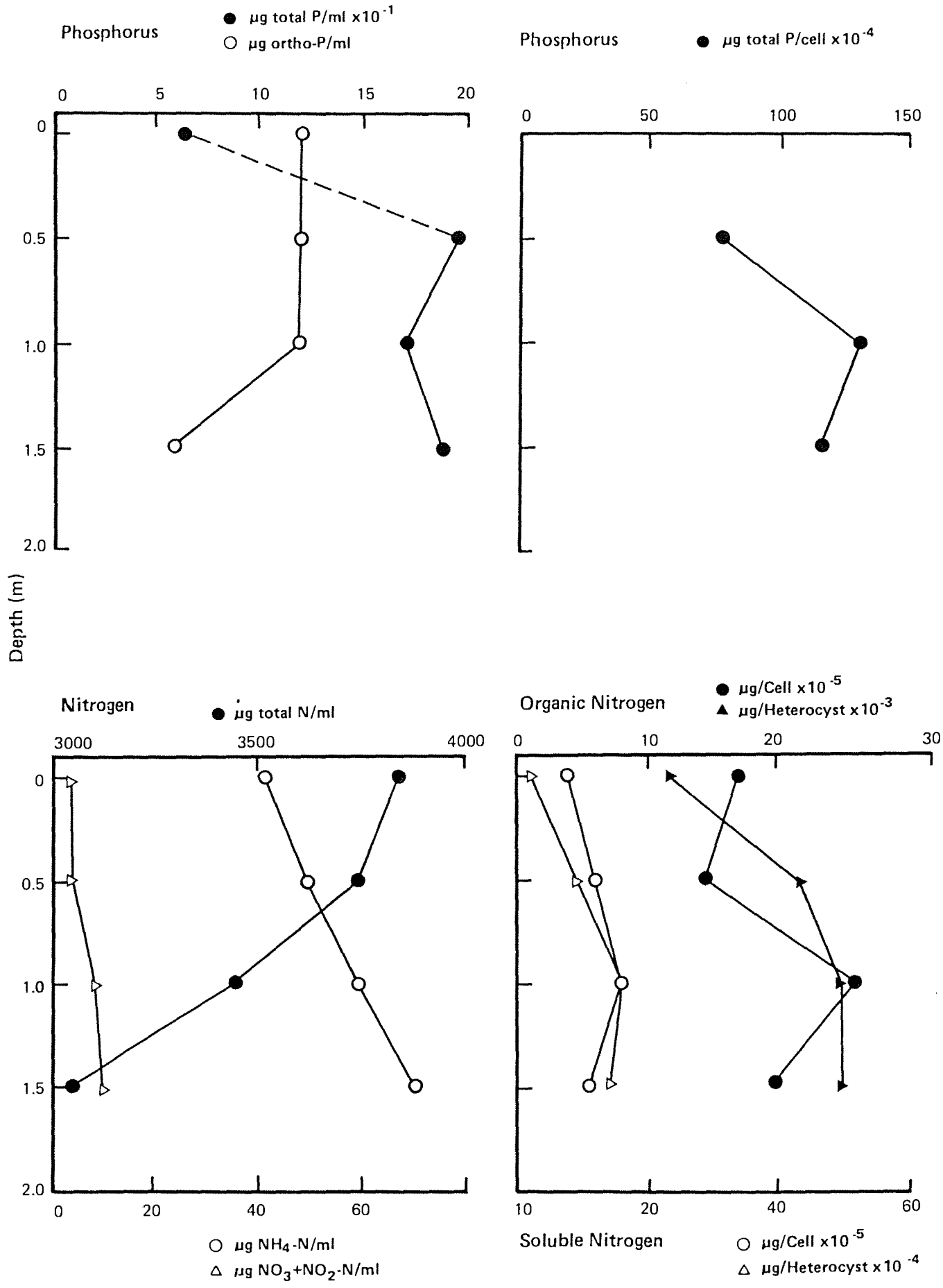
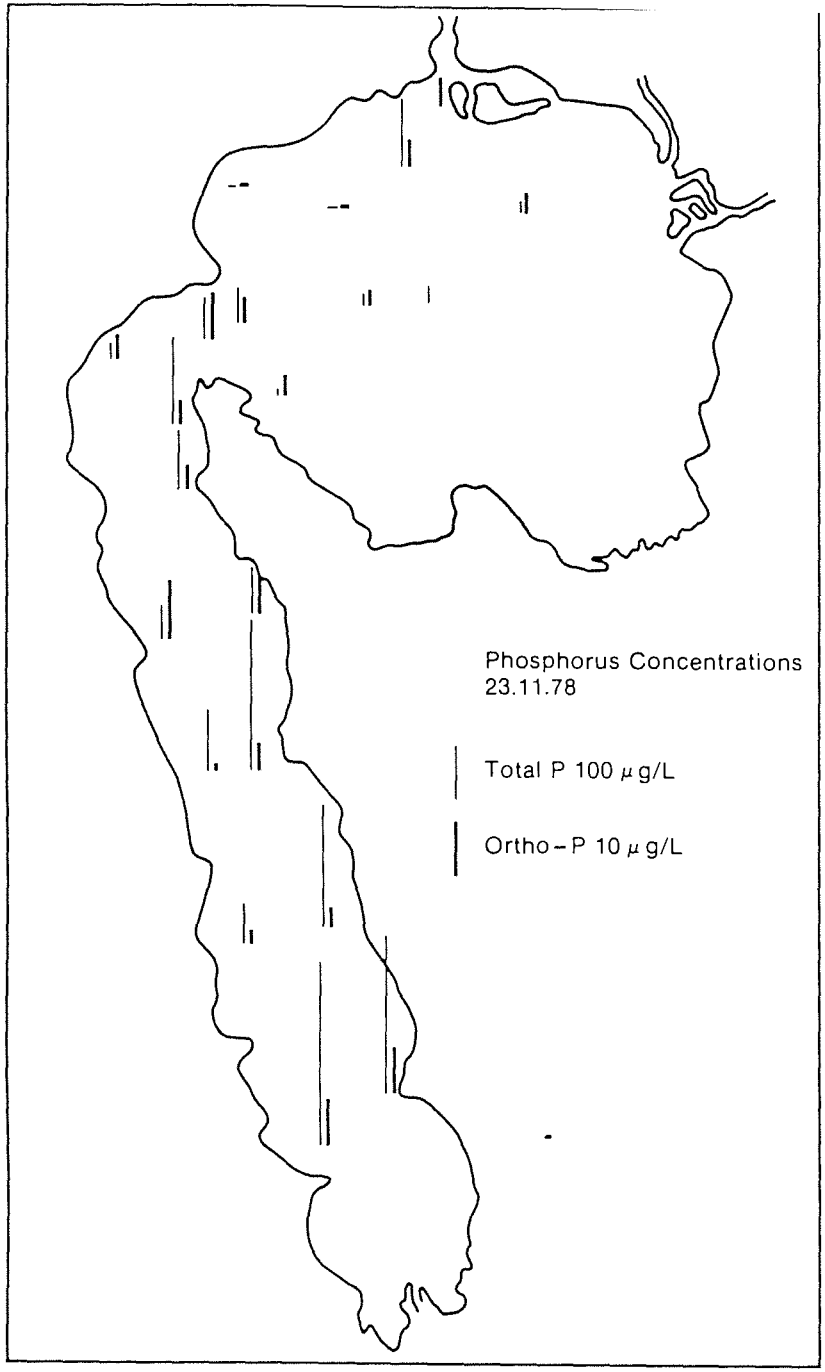


Figure 3.5.4.4 Nutrient concentrations; depth profiles at Station 20; 30.11.78



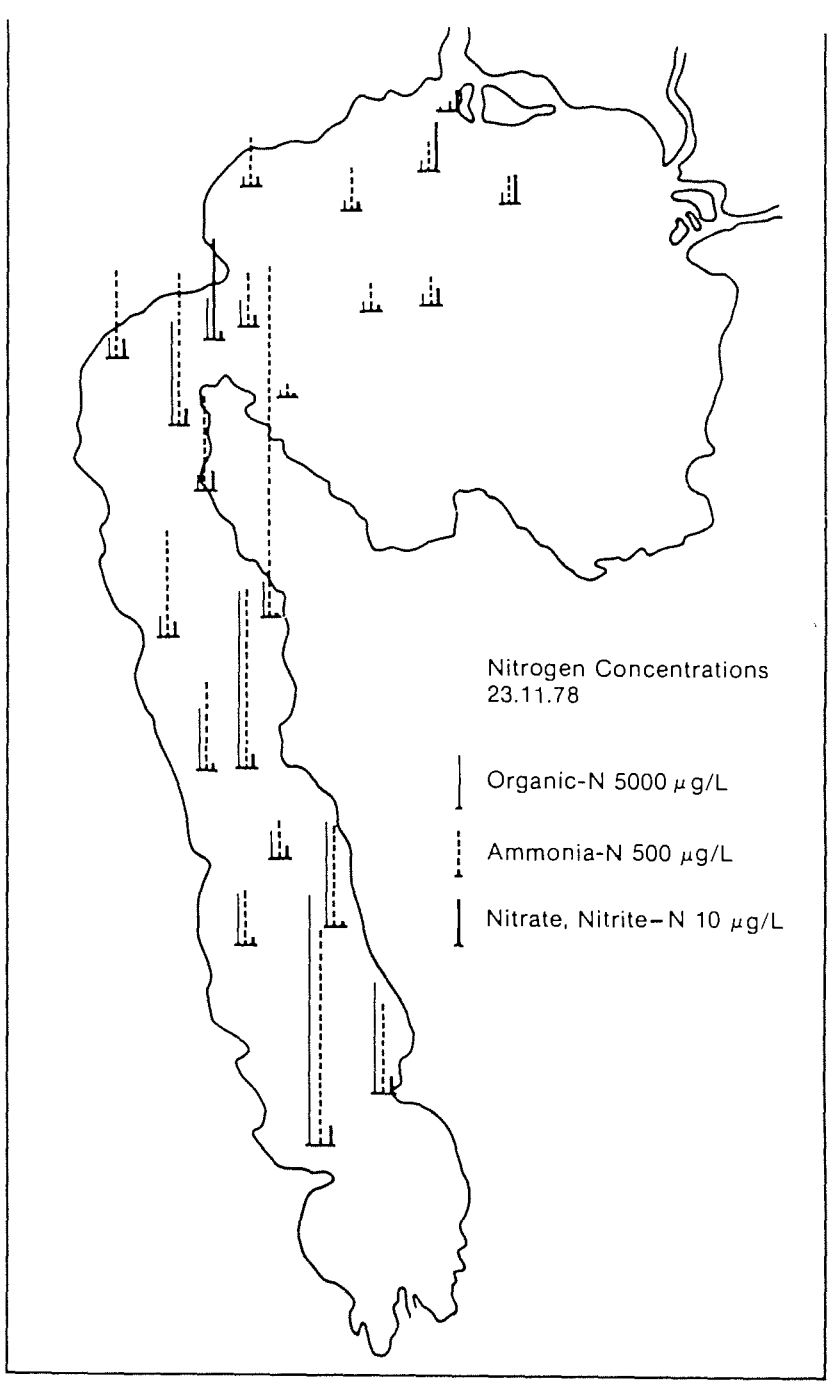
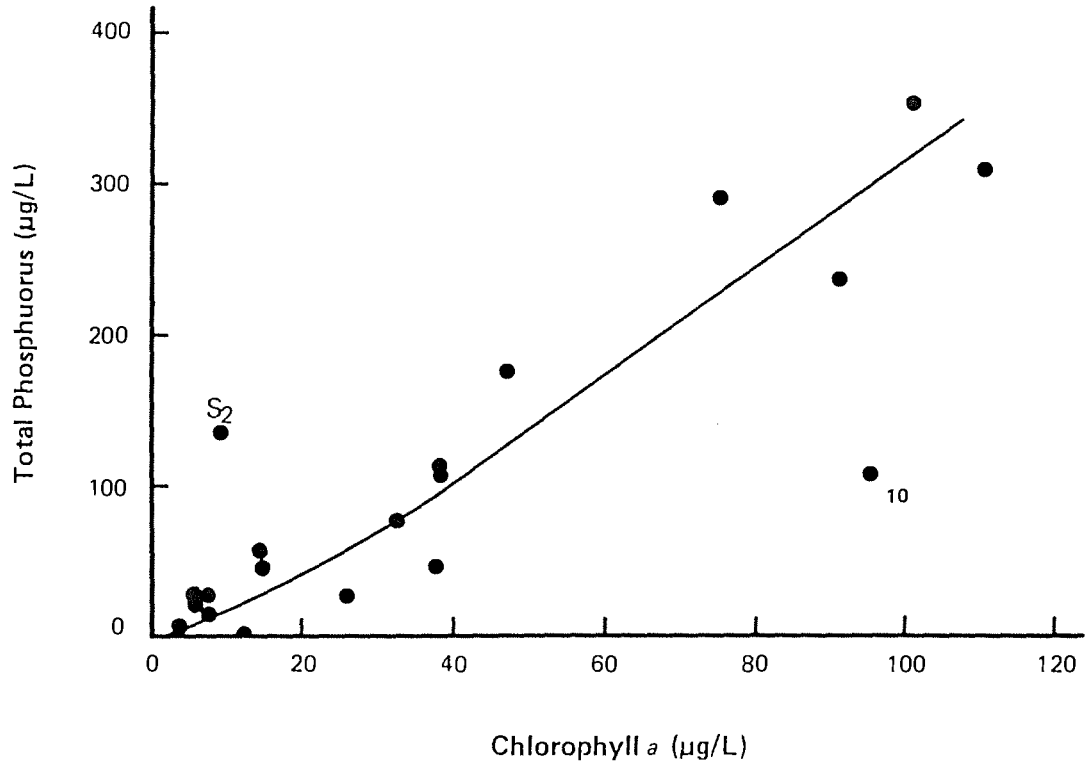


Figure 3.5.5.1a,b Maps of nitrogen and phosphorus concentrations in surface waters; 23.11.78



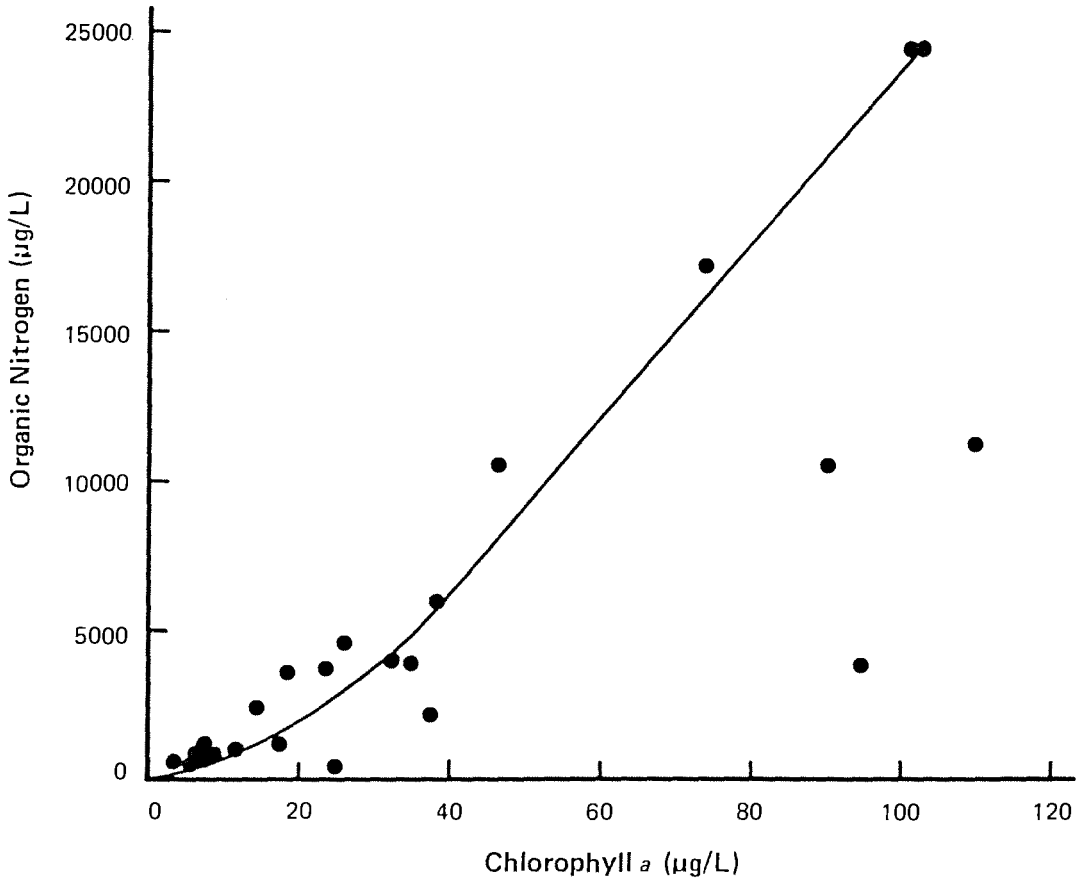


Figure 3.5.5.2 Graphs of nitrogen and phosphorus concentrations versus chlorophyll a concentrations; 23.11.78

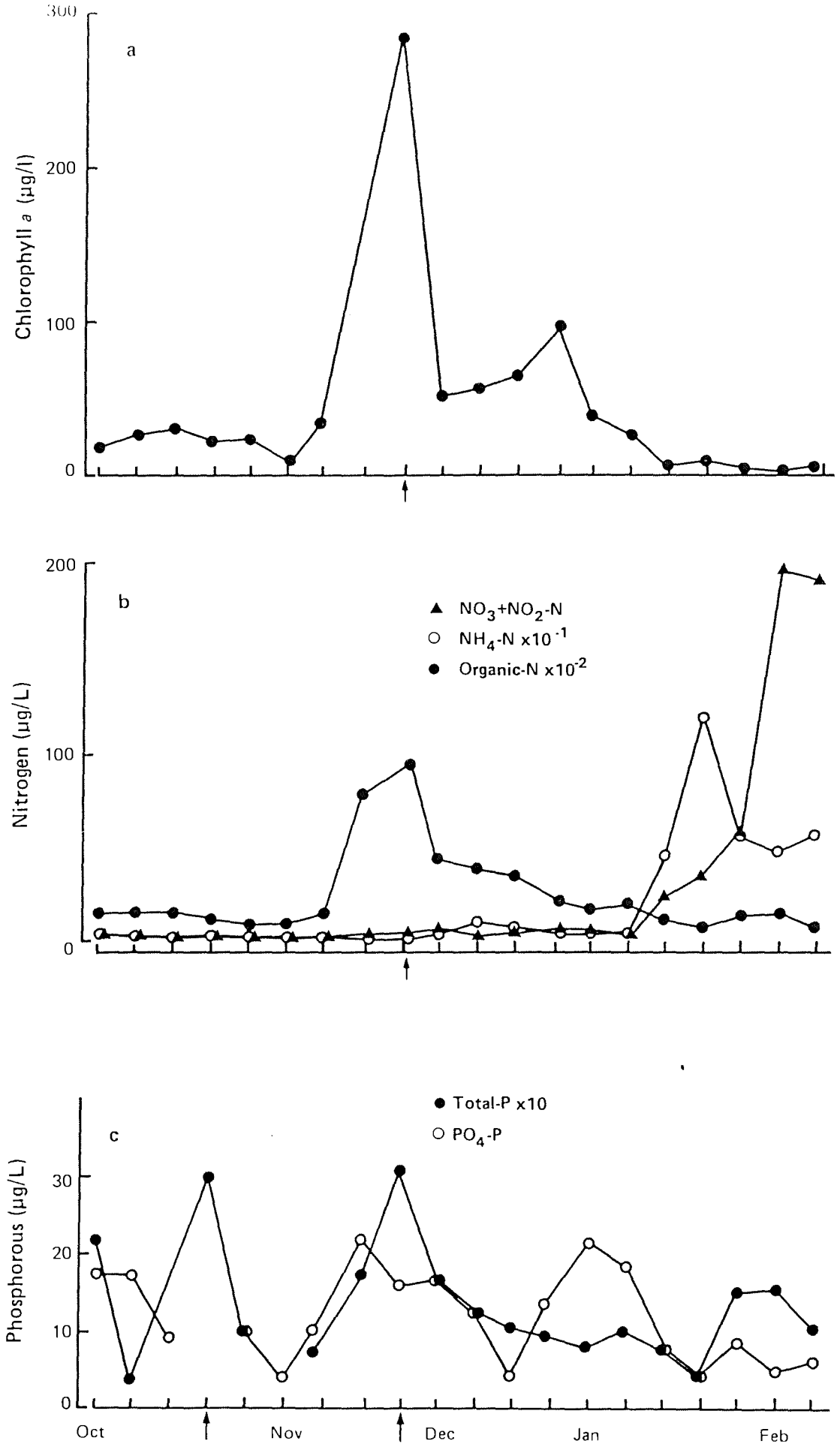


Figure 3.5.6.1.1 Graphs of chlorophyll a, nitrogen and phosphorus concentrations at Station PB1; October 1978 to February 1979

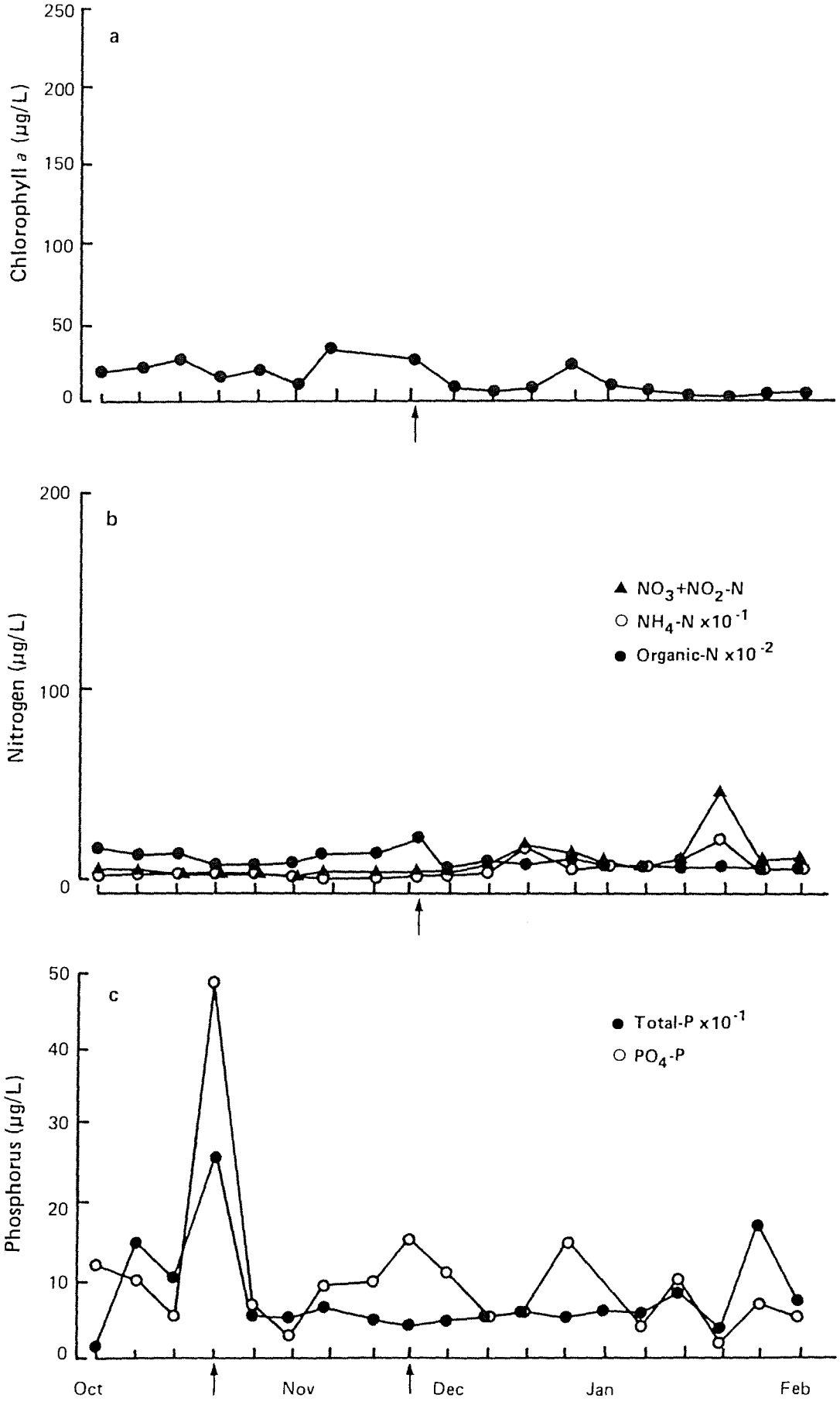


Figure 3.5.6.1.2 Graphs of chlorophyll a, nitrogen and phosphorus concentrations at Station PB2; October 1978 to February 1979

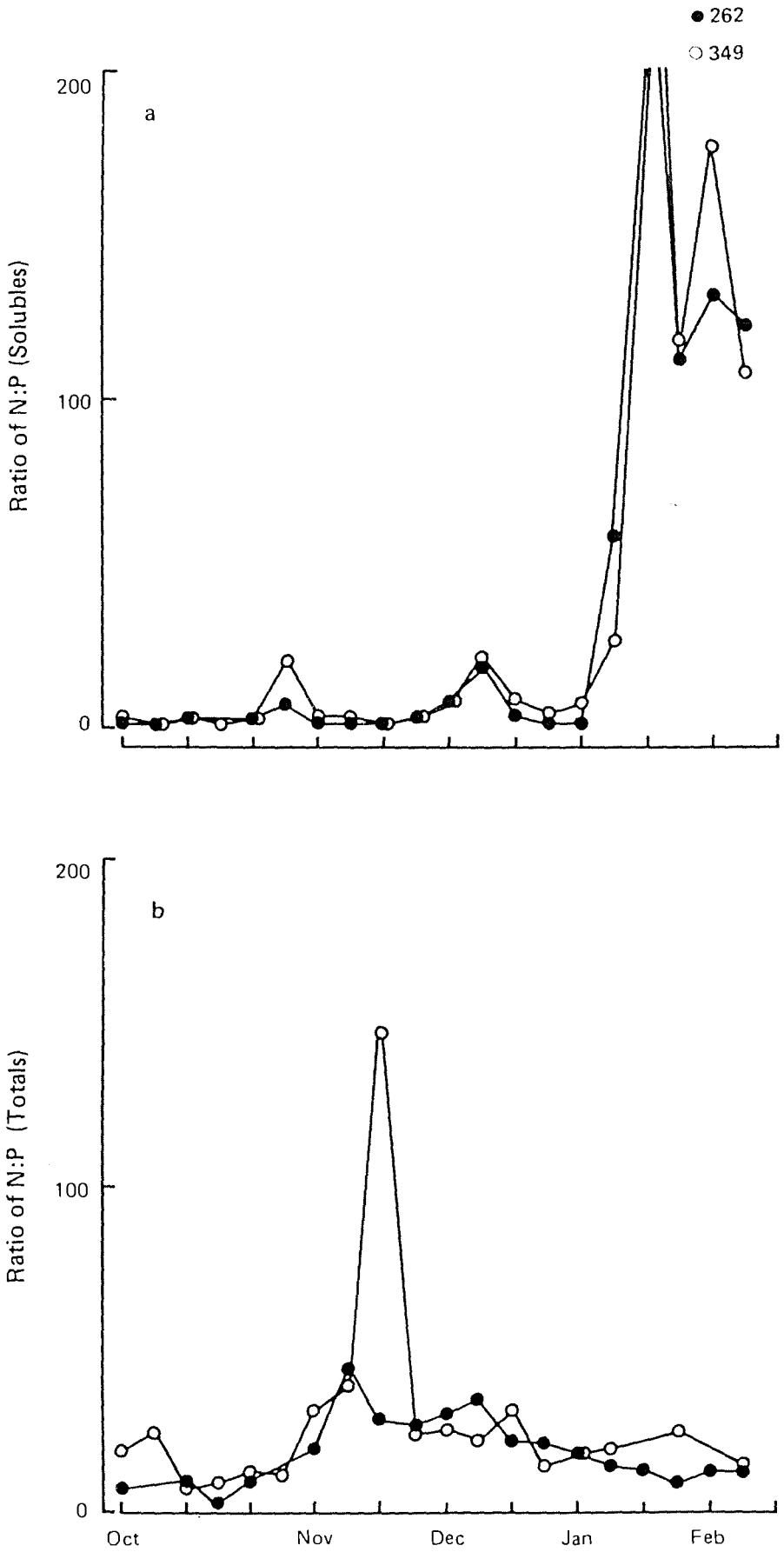


Figure 3.5.6.2.1 Graphs of soluble and total nutrient ratios; Station PB1, October 1978 to February 1979

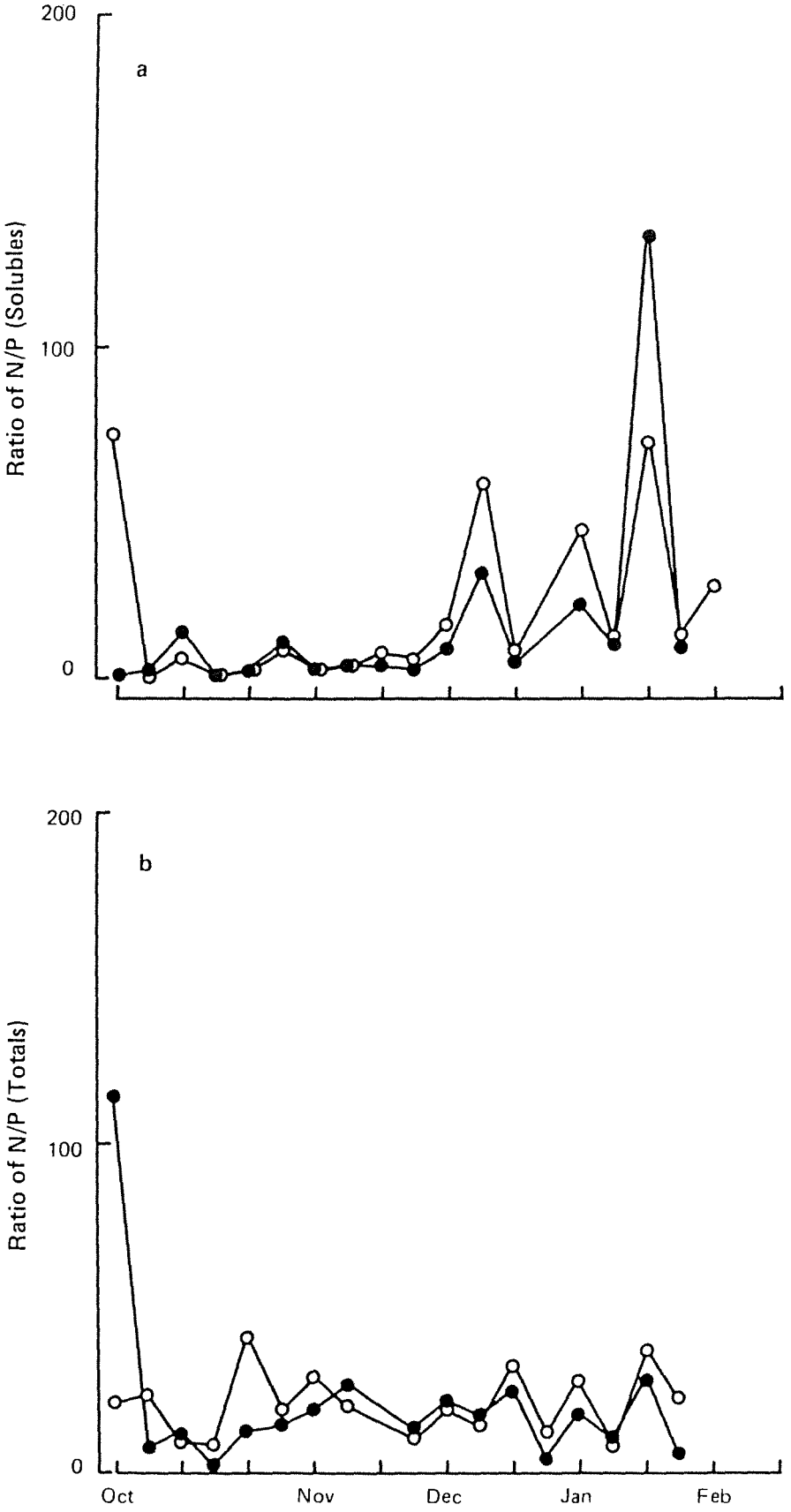


Figure 3.5.6.2.2 Graphs of soluble and total nutrient ratios; Station PB2, October 1978 to February 1979

	1978-79	1980-81	1981-82
Maximum surface organic N conc.			
Harvey (Station 1)	9225 ug/L	9164 ug/L	16261 ug/L
Peel (Station 4)	--	4342 "	2658 "
Depth to which bloom occurs at maximum concentrations	0.75 m	0.75 m	0.75 m
Volume through which bloom occurs			
Harvey	4.2×10^{10} L	4.2×10^{10} L	4.2×10^{10} L
Peel	--	4.6×10^{10} L	4.6×10^{10} L
Organic nitrogen in water at the peak of the bloom:			
Harvey	387.5 T	384.9 T	682.9 T
Peel	--	199.7 T	123.5 T
Total	387.5 T	584.6 T	806.4 T
River input			
November loading	3.7 T	?	?
Nitrogen concentration in water prior to blooms			
Harvey	1999 ug/L (75 T)	2377 ug/L (89 T)	(54 T)
Peel	--	1638 ug/L (61 T)	(39 T)
Total	75 T	150 T	93 T
Nitrogen contribution by the *Nodularia* blooms	308.8 T	434.6 T	713.4 T

Figure 3.5.7 Calculation of the nitrogen fixation capacity of the Nodularia spumigena bloom; November 1978 to January 1979

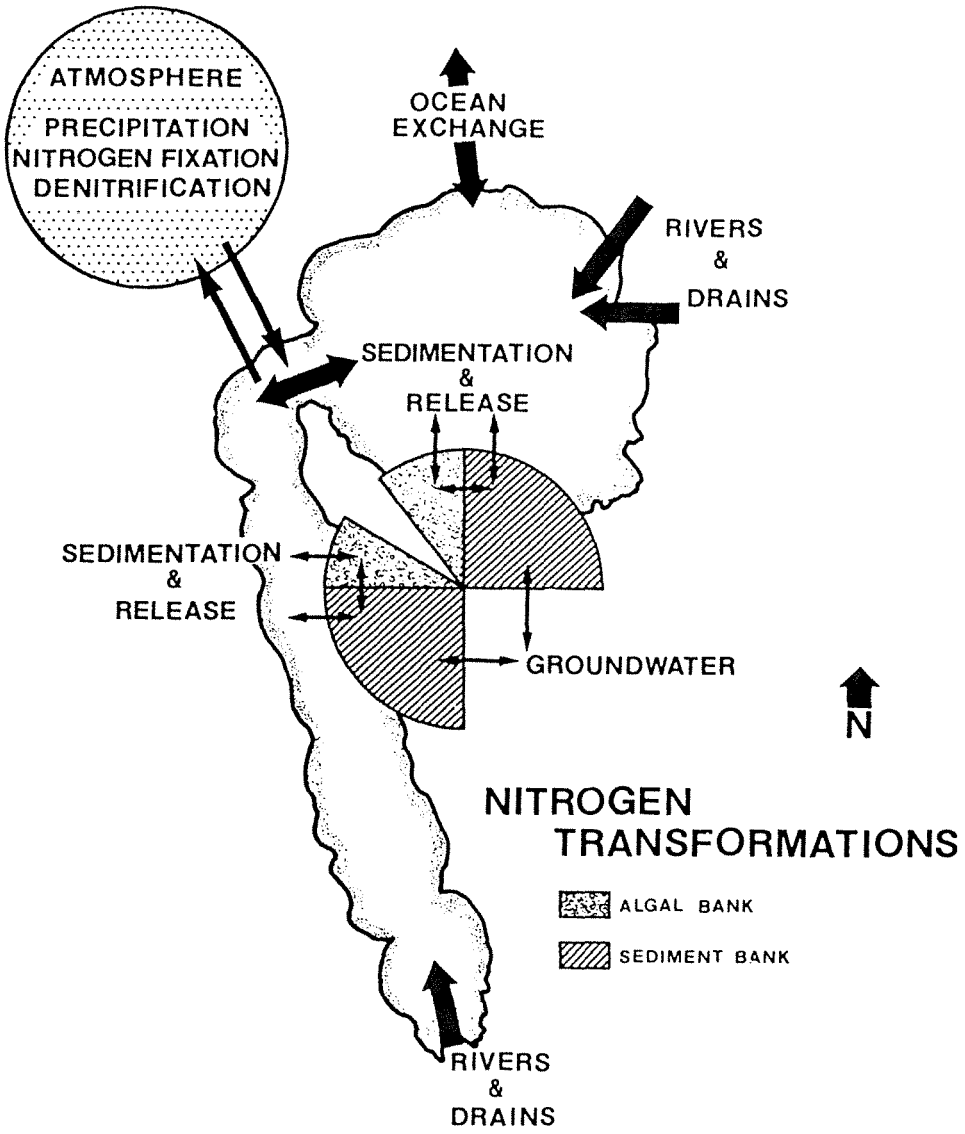


Figure 4 Nitrogen Transformations

Table 2.1 Composition of growth and isolation media for cyanobacteria

Nutrient	Modified BG11 medium[a]	fsP medium[b]
Macronutrients	g/L	g/L
K_2HPO_4	0.039	0.0195
$MgSO_4.7H_2O$	0.075	0.0375
$CaCl_2.2H_2O$	0.0268	0.0134
Citric Acid	0.006	0.0030
EDTA	0.001	0.0005
$NaHCO_3$	0.020	0.0100
$FeC_6H_5O_7.5H_2O$	0.006	0.0030
Micronutrients (A5)	mg/L	mg/L
H_3BO_3	2.86	1.43
$ZnSO_4.7H_2O$	0.356	0.178
$Na_2MoO_4.2H_2O$	0.4214	0.2107
$CuSO_4$	0.0710	0.0355
$CoCl_2.6H_2O$	0.0394	0.0197
$MnSO_4.H_2O$	1.78	0.890
Glass distilled water	1L	-
Filter sterilized estuary water	-	1L
For solid media Bacto Agar	10g/L	10g/L

[a] Modified from Hughes, Gorham and Zehnder, 1958.

[b] "Filter-sterilized Peel"-based medium.
Filter sterilization was accomplished using a 0.20μ mesh membrane filter, and was used rather than heat sterilization in order to avoid the possible formation of toxic compounds when estuary water was heated. BG11 nutrients could be autoclaved.

[c] Double strength agar (in glass distilled water) was sterilized (autoclaved) separately and then mixed with sterile double strength nutrient solution; again, this was to avoid the formation of toxic compounds (see Allen 1968)

Table 2.2 : Taxonomic Reference List

Desichakary, T.V. 1959 Cyanophyta. Academic Press, New York

Geitler, L. 1932 Cyanophyceae. Akademische Verlagsgellschaft m. b. H. Leipzig. Johnson Reprint Corp., New York, 1971

Prescott, G.W. 1962 Algae of the Western Great Lakes Area. Wm. C. Brown Co., Publishers. Dubuque, Iowa

[a]Rippka, R., Deurelles, J., Waterbury, J.B., Herdman M. and Stainier, R.Y. 1979. Generic assignments, strain histories and properties of pure cultures of cyanobacteria. J. Gen. Micro. 111: 1-61

see also

Bourelley, P. 1970 Les Algues d'Eau Douce. Initiation a la Systematique. Tome III. Les algues blues et rouges. Les Eugleniens, Peridiniens et Cryptomonadines. Editions N. Boubee & Cie, 3 Place Saint-Andre-des-Arts, Paris - VI[e]

Chapman, V.J. 1954 The marine algae of New Zealand. J. Linn. Soc. Botany, 55:333-502

Drouet, F. and Dailey, W.A. 1956 A revision of the coccoid myxophyceae. Butler University Botanical Studies. Vol.12. J.E. Potzger (ed.). Dept. of Botany, Butler University, Indianna, 1956

[a]Krantz, T. and Bold, H.C. 1969 Phycological Studies IX. Morphological and taxonomic studies of Nostoc and Anabaena in culture. University of Texas Publications, No. 6924

[a] Especially useful for Cyanobacteria in culture.

Table 3.1.1 The frequency of primary isolation of cyanobacteria from the Peel-Harvey Estuarine waters according to the organism group and sampling location from eighteen sampling dates, [a] 1978-80.

Station Location	*Nodularia spumigena* coarse	*Nodularia spumigena* fine	*Nodularia Harveyana*	*Nostoc* carneum-Linkia group	*Nostoc* punctiforme group	*Nostoc* others	*Anabaena*	*Calothrix*	Oscillatoriaceae	LPP groups	Unicellular	TOTAL
Mandurah Bridge	✓	✓		10	1	2	2	2	1	✓	3	21
2	✓	✓		15	1	4	3	3	0	✓	9	35
3	✓			11	0	4	1	0	0	✓	1	17
4	✓			22	2	5	7	7	2	✓	4	49
5	✓	✓		11	2	4	2	0	2	✓	3	24
6	✓	✓		10	0	3	-	0	0	-	1	14
7	✓	✓		14	1	2	4	1	0	-	10	32
8	✓	✓		8	2	1	1	3	0	-	1	16
1	✓	✓		11	0	0	4	3	0	✓	7	25
P58	✓	✓		3	0	2	2	3	0	✓	6	16
24	✓	✓		4	0	2	1	2	1	✓	6	16
28	✓	✓		3	0	0	7	1	1	✓	6	18
29	✓	✓	1	11	1	3	5	1	1	-	6	28
31	✓	✓	1	14	2	6	4	0	1	✓	8	35
35	✓	✓		14	1	0	1	0	0	✓	9	25
Total				161	13	38	44	26	9		80	371

← HETEROCYSTOUS FILAMENTOUS → ← NON-HETEROCYST. FILAMENTOUS → ← UNI-CELL-ULAR →

a. Note that this not a listing of all the primary isolation data; on other occasions the groupings used were *Nodularia* and "Others".

b. "Coarse" and "fine" *Nodularia spumigena* are defined as having average filament widths of greater than or equal to 10 μ and less than 9 μ, respectively. The difference is descernable in colonies under 16X magnification.

The colonial habit of *N. Harveyana* closely resembles that of *Anabaena* species, and therefore, has previously been listed under the latter category.

c. The groupings used are each composed of several types and the numbers shown are cumulative, thus the frequencies sometimes appear to be over 100%.

d. LPP groups usually occur as contaminents in other cyanobacterial colonies.

e. ✓ indicates very high frequencies of primary isolations.

Table 3.1.2 : Species/group listing of cyanobacteria isolated from the Peel/Harvey Estuarine system

FAMILY	GENUS	SPECIES	PLATE NO.
Nostocaceae	Nodularia	spumigena	3.1.2.1 a-d
	N	spumigena	3.1.2.1 e,c
	N	spumigena	3.1.2.1 f
	N	Harveyana	3.1.2.1 g,h
	Nostoc	aff. calcicola	
	N	carneum	3.1.2.2 a
	N	commune	3.1.2.2 b
	N	Linckia	3.1.2.2 c
	N	muscorum	3.1.2.2 d
	N	paludosum	–
	N	piscinale	3.1.2.2 e
	N	punctiforme	3.1.2.2 f
	N	aff. spongiaforme	–
	Anabaena	aff. ambigua	3.1.2.3 a
	A	aff. gelatinicola	–
	A	aff. oryzae	–
	A	sp.	3.1.2.3 b
	A	torulosa	3.1.2.3 c
	A	aff. vaginicola	3.1.2.3 d
	A	variabilis	
		var Ellipsospora	3.1.2.3 e
	A	" var kashiensis	3.1.2.3 f
	Anabaenopsis	elenkini	3.1.2.3 g
	Aphanizomenon	gracile	3.1.2.3 h
Rivulariaceae	Calothrix	brevissima	3.1.2.4 a
	C	confervicola	–
	C	contarenii	3.1.2.4 b
	C	marchia	3.1.2.4 c
	C	sp.	3.1.2.4 d
	Microchaete	sp.	3.1.2.4 e
	Scytonema	sp.	3.1.2.4 f
Oscillatoriaceae	LPP group A		3.1.2.5 a
	LPP group B		3.1.2.5 b
	Oscillatoria	aff. amphibia	3.1.2.5 c
	O	limosa	3.1.2.5 d
	O	sp.	3.1.2.5 e
	Spirulina	subsalsa	3.1.2.5 f

FAMILY	GENUS	SPECIES	PLATE NO.
Chroococcaceae	Aphanothece	clathrata	3.1.2.6 a
	A	minuta	3.1.2.6 b
	Aphanocapsa	delicatissima	-
	Gleothece	membranacea	3.1.2.6 c
	Microcystis	aeruginosa	3.1.2.6 d
	Synechococcus	cedrorum	3.1.2.6 e
	S	elongatus	3.1.2.6 f
Chamaesiphonaceae	Chamaesiphon	sp.	3.1.2.6 g
	Xenococcus	sp.	3.1.2.6 h
	Dermacarpon	sp.	3.1.2.6. i

GRID STUDIES

TABLE 3.2.2.1 Viable numbers of heterocystous cyanobacteria in surface and bottom waters at stations 3, 8, 9, 10, 11 and 2, 21, 22, 6, 12; March, 1979.

Station #	Surface or Bottom	Total viable count per 100 ml	*Nodularia*		Other genera present
			Viable count per 100 ml	Percent of total	
3	S	0	0	-	
	B	4	4	100	
8	S	1	0	0	
	B	4	2	50	
9	S	0	0	-	
	B	1	1	100	
10	S	2	0	0	
	B	4	3	75	
11	S	1	0	0	
	B	2	0	0	
Average	S	1	0	0	
	B	3	2	66.7	
2	S	13	12	92	*Nostoc*
	B	5	4	80	"
21	S	1	1	100	
	B	1	1	100	
22	S	4	4	100	
	B	7	7	100	
6	S	7	5	71	
	B	-	-	-	
12	S	14	12	86	*Nostoc*
	B	8	6	75	"
Average	S	8	7	87.2	
	B	4	3.5	85.7	

GRID STUDIES

TABLE 3.2.2.2 Viable numbers of heterocystous cyanobacteria in surface and bottom waters at stations 4, 5, 7, 13 to 20 and 36; March, 1979.

Station #	Surface or Bottom	Total viable count per 100 ml	*Nodularia*		Other genera present
			Viable count per 100 ml	Percent of total	
4	S	15	0	0	
	B	4	0	0	
5	S	6	0	0	*Nostoc, Oscillatoria*
	B	9	0	0	"
7	S	10	2	20	
	B	4	0	0	
13	S	1	1	100	
	B	1	1	100	
14	S	0	0	-	
	B	0	0	-	
15	S	3	0	0	*Nostoc, Oscillatoria,* unicells
	B	0	0	-	unicells
16	S	0	0	-	
	B	1	0	0	*Nostoc*
17	S	1	1	100	
	B	1	0	0	*Nostoc*
18	S	5	1	20	*Oscillatoria,* unicells
	B	4	3	75	" "
19	S	8	0	0	Unicells
	B	12	0	0	"
20	S	42	4	10	*Nostoc,* unicells
	B	28	0	0	" "
36	S	2	1	50	
	B	3	3	100	
Average	S	8.5	0.9	10.6	
	B	6.1	0.6	9.8	
Average for 4 to 7 and 18 to 36	S	12.6	1.1	8.7	
	B	9.1	0.8	8.8	
Average for 13,14,15,16, 17.	S	1.0	0.5	50.0	
	B	0.8	0.3	37.5	
Peel Average	S	6.6	2.0	30.9	
	B	5.0	1.6	32.0	

GRID STUDIES

TABLE 3.2.2.3 Viable numbers of heterocystous cyanobacteria in surface and bottom waters at stations 23 to 28, 34, 35, and 1, 29 to 33; March, 1979.

Station #	Surface or Bottom	Total viable count per 100 ml	*Nodularia*		Other genera present
			Viable count per 100 ml	Percent of total	
23	S	6	6	100	
	B	5	5	100	
24	S	37	35	94	*Nostoc*
	B	2	0	0	"
25	S	13	12	92	*Nostoc*
	B	13	13	100	
34	S	3	2	67	*Nostoc*
	B	11	10	91	
26	S	18	18	100	
	B	115	99	86	*Nostoc*
27	S	-	-	-	
	B	41	10	24	
35	S	2	1	50	*Nostoc*
	B	12	7	58	"
28	S	10	10	100	
	B	12	12	100	
Average	S	12.7	12.0	94.5	
	B	26.4	19.5	73.9	
1	S	4	4	100	
	B	4	4	100	
29	S	37	37	100	
	B	21	19	90	*Nostoc*
30	S	18	18	100	
	B	-	-	-	
31	S	21	21	100	
	B	16	16	100	
32	S	36	35	97	*Nostoc*
	B	19	19	100	
33	S	16	13	81	*Nostoc*
	B	12	11	65	"
Average	S	22.0	21.3	96.8	
	B	15.4	13.8	89.6	
Harvey Average	S	16.7	14.3	85.5	
	B	21.7	17.7	77.5	

GRID STUDIES

TABLE 3.2.3.1 Viable numbers of heterocystous cyanobacteria in surface waters of the Peel Inlet; July, 1979.

Sampling Location	Surface or Bottom	Total viable count per 100 ml	*Nodularia*		Other genera present
			Viable count per 100 ml	Percent of total	
76 P26→P46	S	6	6	100	
77 P26→P46	S	6	0	0	*Nostoc*
79 P46→4	S	12	4	33.3	*Nostoc*
3 P28→P46	S	7	1	9.9	
4 P28→P46	S	17	2	11.8	
7 P46→P68	S	14	0	0	
10 P46→17	S	18	15	83.0	
12 17→5	S	39	0	0	
15 5→13	S	25	0	0	
16 5→13	S	12	5	41.7	
19 13→4	S	13	2	15.4	
Average	S	15.4	3.2	20.8	
71 8→3	S	1	1	100	
72 8→3	S	3	2	62.7	
68 10→8	S	17	17	100	
65 P47→10	S	6	6	100	
22 P27→7	S	8	5	62.5	
23 P27→7	S	12	1	8.3	
29 6→12	S	11	8	72.7	
25 7→6	S	12	8	66.7	
26 7→6	S	11	6	54.5	
17 13	S	15	13	86.7	
24 7	S	9	9	100	
Average	S	9.5	6.9	72.6	
Peel Average	S	12.5	5.1	40.8	

GRID STUDIES

TABLE 3.2.3.2 Viable numbers of heterocystous cyanobacteria in surface waters of the Harvey Estuary; July, 1979.

Sampling Location	Surface or Bottom	Total viable count per 100 ml	*Nodularia*		Other genera present
			Viable count per 100 ml	Percent of total	
63 P59→P57	S	21	21	100.0	
64 P59→P57	S	8	7	87.5	
38 24→P58	S	23	23	100.0	
41 P58→26	S	4	3	75.0	
42 P58→26	S	16	15	93.8	
45 26→1	S	8	8	100.0	
56 37→1	S	15	13	86.7	
57 37→1	S	6	6	100.0	
58 1→28	S	5	5	100.0	
Average	S	11.7	11.2	95.7	
50 29→31	S	20	18	90.0	
51 29→31	S	25	22	88.0	
54 31→37	S	18	15	83.3	
Average	S	21.0	18.3	87.1	
Harvey Average	S	16.4	14.8	90.2	

WEEKLY/BIWEEKLY MONITORING

TABLE 3.3.1.1 Concentrations[a] of Heterocystous Cyanobacteria at Stations 2, 3, 8.

Date		22.05.79			29.05.79			5.06.79			13.06.79			19.06.79			26.06.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present[c]	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
2	S[b]	16	15		8	7	*Nostoc*	7	7		2	2		16	16		3	3	
2	B[b]	-	-		-	-		-	-		-	-		-	-		-	-	
3	S	18	16		0	0		15	11	*Nostoc*	12	8		4	4		6	5	*Nostoc*
3	B	-	-		-	-		-	-		-	-		-	-		-	-	
8	S	47	42		1	1		8	6	*Nostoc*	0	0		2	2		2	2	
8	B	-	-		-	-		-	-		-	-		-	-		-	-	
Average	S	27	24.3		3	2.7		10	8		4.7	3.3		7.3	7.3		3.7	3.3	
	B	-	-		-	-		-	-		-	-		-	-		-	-	

Date		3.07.79			10.07.79			17.07.79			24.07.79			31.07.79			14.08.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
2	S	1	0	*Nostoc*	2	2		20	0	*Nostoc*, *Anabaena*	8	4		0	0		0	0	
2	B	-	-		-	-		6	4	*Nostoc*	17	4		6	2	*Nostoc*	2	2	
3	S	5	1	*Nostoc*	5	4	*Nostoc*	12	4		8	0	*Nostoc*	17	1	*Nostoc*, *Anabaena*	1	1	
3	B	-	-		-	-		0	0		18	2	*Nostoc*, *Anabaena*	2	0	*Nostoc*	1	1	
8	S	5	0	*Nostoc*	0	0		16	2	*Nostoc*, *Anabaena*	19	12	*Nostoc*	4	2		1	0	*Calothrix*
8	B	-	-		-	-		22	8	As above	86	72	As above	3	2		1	1	
Average	S	3.7	0.3		2.3	2.0		16	2		11.7	5.3		7	1		0.7	0.3	
	B	-	-		-	-		9.3	4		40.3	2.6		3.7	1.3		1.3	1.3	

TABLE 3.3.1.1 (con't) Concentrations[a] of Heterocystous Cyanobacteria at Stations 2, 3, 8.

Site	Sample Depth	22.08.79 Total	*Nodularia*	Other Genera present	28.08.79 Total	*Nodularia*	Other Genera present	4.09.79 Total	*Nodularia*	Other Genera present	23.10.79 Total	*Nodularia*	Other Genera present	4.11.79 Total	*Nodularia*	Other Genera present	21.11.79 Total	*Nodularia*	Other Genera present
2	S	25	23		6	5	*Nostoc*	8	6		0	0		2	2		13	9	*Nostoc*
2	B	13	10		6	6		17	13		4	4		12	10	*Nostoc*	21	19	
3	S	13	10		0	0		2	0	*Calothrix, Nostoc*	-	-		-	-		-	-	
3	B	13	13		2	0		5	5		-	-		-	-		-	-	
8	S	26	21		3	3		4	3	*Nostoc*	12	10		0	0		4	4	
8	B	22	19		8	6		9	9		-	-		-	-		-	-	
Average	S	21.3	18		3	2.7		4.7	3		6	5		1	1		8.5	6.5	
	B	16	14		5.3	4		10.3	9		4	4		12	10		21	19	

Site	Sample Depth	29.11.79 Total	*Nodularia*	Other Genera present	18.12.79 Total	*Nodularia*	Other Genera present	16.01.80 Total	*Nodularia*	Other Genera present	30.01.80 Total	*Nodularia*	Other Genera present	13.02.80 Total	*Nodularia*	Other Genera present	27.02.80 Total	*Nodularia*	Other Genera present
2	S	-	-		10	9		3	3		2	2		2	2		5	5	
2	B	-	-		-	-		-	-		-	-		6	3	*Nostoc, Calothrix*	4	3	
3	S	-	-		-	-		-	-		-	-		4	3.5	*Nostoc*	-	-	
3	B	-	-		-	-		-	-		-	-		-	-		-	-	
8	S	9	4		6	6		2	0	*Calothrix*	48	7		-	-		2	2	
8	B	-	-		-	-		-	-		16	15		-	-		-	-	
Average	S	9	4		8	7.5		2.5	1.5		25	4.5		3	2.8		3.3	3.3	
	B	-	-		-	-		-	-		16	15		6	3		4	3	

TABLE 3.3.1.1 (con't) Concentrations[a] of Heterocystous Cyanobacteria at Stations 2, 3, 8.

Date		13.03.80			27.03.80			9.04.80			23.04.80			6.05.80			20.05.80		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
2	S	5	4	Unicells	9	9	Unicells	0	0	Unicells (very high numbers)	14	8	*Nostoc*, *Calothrix*	12	10	*Nostoc*	10	10	
2	B	2	1		6	4		1	0		10	7	*Calothrix*	30	22	As above	4	4	
3	S	-	-		-	-		-	-		-	-		-	-		-	-	
3	B	-	-		-	-		-	-		-	-		-	-		-	-	
8	S	2	2		11	3	*Nostoc*	0	0	Unicells	2	2		18	16	*Nostoc*	0	0	
8	B	-	-		-	-		-	-		-	-		10	10		-	-	
Average	S	3.5	3		10	6		0	0		8	5		15	13		5	5	
	B	2	1		6	4		1	0		10	7		20	21		4	4	

a. Concentrations refer to the number of colonies developing after a 4 week incubation /100ml.

TABLE 3.3.1.2 Concentrations [a] of Heterocystous Cyanobacteria at Stations 4, 5, 6, 7.

Date		22.05.79			29.05.79			5.06.79			13.06.79			19.06.79			26.06.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
4	S[b]	6	2		1	0	*Nostoc*	27	2	*Nostoc*	2	2		2	0		2	2	
4	B[b]	–	–		–	–		–	–	Unicells	–	–		–	–		–	–	
5	S	13	1		0	0		11	1	*Nostoc*	5	0	*Nostoc*	8	4		6	0	*Nostoc*
5	B	–	–		–	–		–	–		–	–		–	–		–	–	
6	S	3	2		8	7	*Nostoc*	4	1	*Nostoc*	2	2		8	8		2	0	*Nostoc*
6	B	–	–		–	–		–	–		–	–		–	–		–	–	
7	S	5	5		3	2	*Nostoc*	7	5	*Nostoc*	6	4		0	0		2	2	
7	B	–	–		–	–		–	–		–	–		–	–		–	–	
Average	S	6.8	2.5		3	2.3		12.3	2.3		3.8	2.0		4.5	3.0		3.0	1.0	
	B	–	–		–	–		–	–		–	–		–	–		–	–	

Date		3.07.79			10.07.79			17.07.79			24.07.79			31.07.79			14.08.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
4	S	2	0	*Nostoc Calothrix*	19	15	*Nostoc*	84	8	*Nostoc*	48	0	*Nostoc, Anabaena*	6	0	*Nostoc, Anabaena*	2	0	
4	B	–	–					22	16	*Nostoc*	3	0		10	5		2	1	
5	S	2	0	*Nostoc*	9	0	*Nostoc*	214	0	*Nostoc* Unicells	1	0	*Nostoc*	18	1	*Nostoc*	1	0	
5	B	–	–		–	–		32	0	as above	3	2	as above	14	2		0	0	
6	S	1	0	*Nostoc*	4	0	*Nostoc*	92	0	*Nostoc*	2	1	*Nostoc*	2	2		2	1	
6	B	–	–		–	–		82	0	as above	7	2	as above	2	1	*Nostoc*	0	0	
7	S	6	0	*Nostoc*	–	–		24	0	*Nostoc*	19	12	*Nostoc*	1	0		0	0	
7	B	–	–		–	–		18	6	as above	13	5	*Nostoc Anabaena*	1	0		2	1	
Average	S	2.8	0		10.7	5.0		103.5	2		17.5	3.3		6.8	0.7		1.3	0.3	
	B	–	–		–	–		38.5	5.5		6.5	2.3		6.8	2		1.0	0.5	

TABLE 3.3.1.2 (con't)

Site	Sample Depth	Date 22.08.79 Total	*Nodularia*	Other Genera present	28.08.79 Total	*Nodularia*	Other Genera present	4.09.79 Total	*Nodularia*	Other Genera present	23.10.79 Total	*Nodularia*	Other Genera present	4.11.79 Total	*Nodularia*	Other Genera present	21.11.79 Total	*Nodularia*	Other Genera present
4	S	11	4		12	0	*Calothrix*	12	1	*Nostoc*	6	2	*Nostoc*	0	0		338	23	*Nostoc, Calothrix*
4	B	6	5		6	0	As above	11	4	As above	2	2		0	0		270	53	As above
5	S	3	0	*Oscillatoria* *Nostoc*	0	0		0	0		-	-		-	-		-	-	
5	B	3	0	As above	0	0		1	0	*Nostoc*	-	-		-	-		-	-	
6	S	32	2		0	0		10	0	*Nostoc*	-	-		-	-		-	-	
6	B	14	2		0	0		4	1	As above	-	-		-	-		-	-	
7	S	16	16		0	0		8	0	*Nostoc*	0	0		0	0		17	8	
7	B	9	8		0	0		6	1	As above	0	0		4	2		26	10	
Average	S	26.8	5.5		3	0		7.5	0.3		3	1		0	0		177.5	7.8	
	B	8.0	3.8		1.5	0		5.5	1.5		1	1		2	1		143.	15.8	

Site	Sample Depth	Date 29.11.79 Total	*Nodularia*	Other Genera present	18.12.79 Total	*Nodularia*	Other Genera present	16.01.80 Total	*Nodularia*	Other Genera present	30.01.80 Total	*Nodularia*	Other Genera present	13.02.80 Total	*Nodularia*	Other Genera present	27.02.80 Total	*Nodularia*	Other Genera present
4	S	6	6		0	0		0	0		6	6		32	0	*Nostoc, Calothrix*	29	1	*Nostoc, Calothrix*
4	B	-	-		25	10		4	0	*Nostoc*	3	2		2	1	*Nostoc*	15	1	As above *Anabaena*
5	S	-	-		-	-		-	-		1	0		-	-		-	-	
5	B	-	-		-	-		-	-		-	-		-	-		-	-	
6	S	-	-		-	-		-	-		7	6		-	-		-	-	
6	B	-	-		-	-		-	-		-	-		-	-		-	-	
7	S	2	2		5	3	*Nostoc*	10	4		16	15		3	2	*Nostoc*	5	3	*Anabaena*
7	B	-	-		-	-		6	6		10	9		0	0		2	1	*Nostoc*
Average	S	4	4		2.5	1.5		5	2		7.5	6.8		17.5	1		17	2	
	B	-	-		25	10		5	2		6.5	5.5		2.5	0.5		8.5	1	

TABLE 3.3.1.2 (con't)

Date		13.03.80			27.03.80			09.04.80			23.04.80			06.05.80			20.05.80		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
4	S	2	0	*Nostoc, Anabaena*	17	8	*Nostoc*	0	0	Unicells	90	3	*Nostoc, Anabaena, Calothrix*	12	6	*Nostoc*	10	4	*Nostoc*
4	B	4	1	*Nostoc*	-	-		4	1	As above	16	7	*Nostoc, Calothrix*	12	6	*Nostoc*	6	6	
5	S	-	-		-	-		-	-		-	-		-	-		-	-	
5	B	-	-		-	-		-	-		-	-		-	-		-	-	
6	S	-	-		-	-		-	-		-	-		-	-		-	-	
6	B	-	-		-	-		-	-		-	-		-	-		-	-	
7	S	9	4	*Nostoc*	1	1		0	0		6	5	*Calothrix*	34	18	*Nostoc*	2	2	
7	B	4	1	As above	1	1		1	1		2	1	*Nostoc*	62	44	As above	2	0	*Nostoc*
Average	S	5.5	2.0		9	4.5		0	0		48	4		23	12		6	3	
	B	4.0	1.0		1	1		2.5	1		9	4		37	25		4	4	

a Numbers given refer to colonies developing after a four week incubation period.
b Non-heterocystous cyanobacteria are not included in the numbers given.

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TABLE 3.3.2.1 Concentrations [a] of Heterocystous Cyanobacteria at Stations 1, 29, 31.

Date		22.05.79			29.05.79			5.06.79			13.06.79			19.06.79			26.06.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
1	S[b]	38	35		7	6	*Nostoc*	5	4	*Nostoc*	10	10		10	6		18	18	
1	B[b]	-	-		-	-		-	-		-	-		-	-		-	-	
29	S	62	61		14	13		16	15	*Nostoc*	1	1		6	6		7	6	
29	B	-	-		-	-		-	-		-	-		-	-		-	-	
31	S	46	44		10	9		23	17	*Nostoc*	0	0		14	14		10	6	
31	B	-	-		-	-		-	-		-	-		-	-		-	-	
Average	S	48.7	46.7		10.3	9.3		14.7	12.0		3.7	3.7		10.0	8.7		11.7	10.0	
	B	-	-		-	-		-	-		-	-		-	-		-	-	

Date		3.07.79			10.07.79			17.07.79			24.07.79			31.07.79			14.08.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
1	S	6	3		17	14		49	14		19	14		2	0		0	0	
1	B	-	-		-	-		13	8		10	9		3	2		2	1	
29	S	6	5		9	9		68	30		16	10	*Nostoc*	5	3		0	0	
29	B	-	-		-	-		30	24		10	9	*Nostoc*, *Anabaena*	4	0		2	2	
31	S	6	4		14	11	*Nostoc*	12	4		6	3	*Anabaena*, *Nostoc*	11	2		1	0	
31	B	-	-		-	-		10	8		5	5	*Nostoc*	2	0		4	2	
Average	S	6	4		13.3	11.3		43	16		13.7	9.0		6.0	1.7		0.3	0	
	B	-	-		-	-		17.7	13.3		8.3	7.6		3.0	0.7		2.7	1.7	

a. Concentrations given refer to the number of colonies developing after a 4 week incubation/100ml.

b. Non-heterocystous cyanobacteria are not included in the numbers given.

TABLE 3.3.2.1 (con't)

Site	Sample Depth	22.08.79 Total	*Nodularia*	Other Genera present	28.08.79 Total	*Nodularia*	Other Genera present	4.09.79 Total	*Nodularia*	Other Genera present	23.10.79 Total	*Nodularia*	Other Genera present	4.11.79 Total	*Nodularia*	Other Genera present	21.11.79 Total	*Nodularia*	Other Genera present
1	S	7	6		29	27	*Nostoc, Anabaena*	25	23		8	2		2	0	*Nostoc*	85	2	*Anabaena* Unicells
1	B	4	3		17	16	As above	12	10		2	0		6	4	As above	5	1	
29	S	6	2		8	7		24	22	*Nostoc*	2	2		0	0		-	-	
29	B	6	3		6	3		24	22	As above	-	-		-	-		-	-	
31	S	15	9		9	6		15	11		2	2		0	0	Unicells (very high numbers)	60	35	
31	B	10	7		6	0		6	5		4	4		0	0	As above	13	6	
Average	S	9.3	5.7		15.3	13.3		21.3	18.7		4.0	2.0		0.7	0		72.5	18.5	
	B	6.7	4.3		9.7	6.3		14.0	12.3		3.0	2.0		3.0	2.0		9.0	3.5	

Site	Sample Depth	29.11.79 Total	*Nodularia*	Other Genera present	18.12.79 Total	*Nodularia*	Other Genera present	16.01.79 Total	*Nodularia*	Other Genera present	30.01.80 Total	*Nodularia*	Other Genera present	13.02.80 Total	*Nodularia*	Other Genera present	27.02.80 Total	*Nodularia*	Other Genera present
1	S	14	8	Unicells (high numbers)	10	5		12	8	*Nostoc Calothrix*	10	7		9	6	*Nostoc Calothrix*	12	9	*Anabaena*
1	B	-	-		-	-		6	3	As above	12	10		8	6	As above	3	2	*Calothrix*
29	S	-	-		11	10	*Calothrix*	-	-		8	6		16	15	*Nostoc*	18	15	
29	B	-	-		-	-		-	-		-	-		-	-		-	-	
31	S	2	2	Unicells (high numbers)	0	0		6	4		2	2		3	3		5	15	
31	B	-	-		0	0		-	-		2	2		0	0		-	-	
Average	S	8.0	5.0		7.0	5.0		9.0	6.0		6.7	5.0		9.3	8.0		11.7	9.7	
	B	-	-		0	0		6.0	3.0		7.0	6.0		8.0	6.0		3.0	2.0	

TABLE 3.3.2.1 (con't)

Date		13.03.80			27.03.80			9.04.80			23.04.80			06.05.80			20.05.80		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
1	S	4	4		1	1	Unicells	1	0	*Anabaena* Unicells (high numbers)	10	8		0	0		0	0	
1	B	7	7		0	0		1	1		7	6	As above	2	1	*Anabaena*	4	2	*Nostoc*
29	S	9	0		7	7	Unicells (high numbers)	0	0	Unicells	12	8	*Nostoc*	17	16	*Nostoc*	1	0	
29	B	-	-		-	-		-	-		-	-		-	-		-	-	
31	S	0	0		5	3	Unicells (high numbers)	1	1	Unicells	41	3	*Nostoc*, *Anabaena*	18	10	*Nostoc* *Lyngbya*[b]	8	4	*Nostoc* LPP
31	B	-	-		4	4		0	0	As above	-	-		17	16	*Oscillatoria*[b]	0	0	
Average	S	4.3	1.3		4.3	3.7		0.7	0.3		21.0	6.3		11.7	8.7		3.0	1.3	
	B	3.5	3.5		2.0	2.0		0.5	0.5		7.0	6.0		9.5	8.5		2.0	1.0	

a. Concentration refers to the number of colonies developing after a 4 week incubation /100ml.

b. Non-heterocystous cyanobacteria are not included in the numbers shown.

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TABLE 3.3.2.2 Concentrations: [a] of Heterocystous Cyanobacteria at Stations P58, 24, 28, 35.

Date		22.05.79			29.05.79			5.06.79			13.06.79			19.06.79			26.06.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present[c]	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
P58	S[b]	90	89		18	17		27	24	*Nostoc*	8	6		6	6		8	8	
P58	B[b]	-	-		-	-		-	-		-	-		-	-		-	-	
24	S	156	154		15	15		21	20	*Nostoc*	38	38		22	20		13	11	*Nostoc*
24	B	-	-		-	-		-	-		-	-		-	-		-	-	
28	S	20	18		1	1		12	12		16	16		14	14		14	14	
28	B	-	-		-	-		-	-		-	-		-	-		-	-	
35	S	48	42		15	12		15	9	*Nostoc*	4	4		8	6		16	10	*Nostoc*
35	B	-	-		-	-		-	-		-	-		-	-		-	-	
Average	S	78.5	75.8		12.3	11.3		18.8	16.3		16.5	16.0		12.5	11.5		12.8	10.8	
	B	-	-		-	-		-	-		-	-		-	-		-	-	

Date		3.07.79			10.07.79			17.07.79			24.07.79			31.07.79			14.08.79		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
P58	S	7	5		35	34	*Nostoc*	26	10		19	17		4	4		2	0	
P58	B	-	-		-	-		14	8		40	40		1	1		0	0	
24	S	7	4		67	66	*Nostoc*	38	14		61	60	*Nostoc* *Oscillatoria*[b]	14	13		1	0	
24	B	-	-		-	-		28	16		71	69		18	18		2	0	
28	S	3	3		13	13		104	34		10	10		25	20	*Nostoc* *Anabaena*	0	0	
28	B	-	-		-	-		84	38		23	20	*Nostoc* *Anabaena*	25	19	As above	1	1	
35	S	7	3		30	25		30	14		20	18	*Anabaena* *Nostoc*	1	0		0	0	
35	B	-	-		-	-		52	36		77	62	*Nostoc*	1	1		0	0	
Average	S	6	3.8		36.3	34.5		49.5	18.0		27.5	26.3		11.0	9.3		0.8	0	
	B	-	-		-	-		44.5	24.5		52.8	27.5		11.3	9.8		0.8	0.3	

TABLE 3.3.2.2 (con't)

Site	Sample Depth	22.08.79 Total	22.08.79 *Nodularia*	22.08.79 Other Genera present	28.08.79 Total	28.08.79 *Nodularia*	28.08.79 Other Genera present	4.09.79 Total	4.09.79 *Nodularia*	4.09.79 Other Genera present	23.10.79 Total	23.10.79 *Nodularia*	23.10.79 Other Genera present	4.11.79 Total	4.11.79 *Nodularia*	4.11.79 Other Genera present	21.11.79 Total	21.11.79 *Nodularia*	21.11.79 Other Genera present
P58	S	21	19		6	0		13	12		2	2		4	4		40	36	
P58	B	21	20		8	4		34	31		4	2	*Nostoc*	10	10		58	50	
24	S	32	31		80	80		74	74		30	30		8	8		13	13	
24	B	46	46		70	66		203	202	*Nostoc*	-	-		-	-		-	-	
28	S	15	12		109	100		23	20	*Nostoc* *Anabaena*	26	24		8	8		2	2	
28	B	26	22		74	67		66	61		-	-		-	-		11	9	
35	S	6	6		5	5		12	10		4	2		8	4		16	12	
35	B	-	-		11	10		23	19		-	-		-	-		-	-	
Average	S	18.5	17.0		50.0	46.3		30.5	29.0		15.5	14.5		7.0	6.0		17.8	15.8	
	B	31.0	29.3		40.8	36.8		81.5	78.3		4.0	2.0		10.0	10.0		34.5	29.5	

Site	Sample Depth	29.11.79 Total	29.11.79 *Nodularia*	29.11.79 Other Genera present	18.12.79 Total	18.12.79 *Nodularia*	18.12.79 Other Genera present	16.01.80 Total	16.01.80 *Nodularia*	16.01.80 Other Genera present	30.01.80 Total	30.01.80 *Nodularia*	30.01.80 Other Genera present	13.02.80 Total	13.02.80 *Nodularia*	13.02.80 Other Genera present	27.02.80 Total	27.02.80 *Nodularia*	27.02.80 Other Genera present
P58	S	6	6		25	25		26	26		54	54		10	9	*Nostoc*	28	27	*Nostoc*
P58	B	-	-		35	25	*Nostoc*	20	20		23	22		-	-		15	15	
24	S	39	36		40	39	*Nostoc*	14	14		41	41		32	31.6	*Anabaena*	34	33	*Nostoc*
24	B	-	-		-	-		-	-		-	-		-	-		-	-	
28	S	-	-		22	15	*Calothrix*	-	-		23	22		27	25	*Anabaena* *Nostoc*	22	21	
28	B	-	-		-	-		-	-		-	-		-	-		-	-	
35	S	-	-		16	16		-	-		38	37		20	18		12	10	
35	B	-	-		-	-		-	-		-	-		-	-		-	-	
Average	S	22.5	20.0		25.8	23.8		20.0	20.0		39.0	38.5		22.3	20.9		24.0	22.8	
	B	-	-		35.0	25.0		20.0	20.0		23.0	22.0		-	-		-	-	

TABLE 3.3.2.2 (con't)

Date		13.03.80			27.03.80			9.04.80			23.04.80			6.05.80			20.05.80		
Site	Sample Depth	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
P58	S	43	41	*Anabaena* *Nostoc*	27	27		0	0		9	8	*Nostoc*	74	70	*Calothrix*	20	20	*Nostoc*
P58	B	28	27		62	60		18	18		10	10		38	38		14	10	*Nostoc*
24	S	26	26		1	1	Unicells	3	3		13	12	*Nostoc*	10	8	*Nostoc*	52	36	*Nostoc*
24	B	-	-		-	-		-	-		-	-		-	-		-	-	
28	S	26	26		18	18	Unicells	20	20		2	2	*Nostoc*	12	12		26	26	*Nostoc*
28	B	-	-		-	-		-	-		-	-		-	-		-	-	
35	S	12	11	*Nostoc*	14	14	Unicells	8	7		2	2		9	9		0	0	Unicells
35	B	-	-		-	-		-	-		-	-		-	-		-	-	
Average	S	16.1	26.0		15.0	15.0		7.8	7.5		6.5	6.0		26.3	24.8		24.5	20.5	
	B	28.0	27.0		62.0	60.0		18.0	18.0		10.0	10.0		38.0	38.0		14.0	10.0	

a. Concentrations refer to the number of colonies developing after a 4 week incubation /100ml

b. Non-heterocystous cyanobacteria are not included in the numbers shown.

TABLE 3.3.3 Concentrations[a] of Heterocystous Cyanobacteria at Mandurah Bridge

Date		22.05.79			29.05.79			5.06.79			13.06.79			19.06.79			26.06.79		
Site	Surface or Bottom	Total	*Nodularia*	Other Genera Present	Total	*Nodularia*	Other Genera Present	Total	*Nodularia*	Other Genera Present	Total	*Nodularia*	Other Genera Present	Total	*Nodularia*	Other Genera Present	Total	*Nodularia*	Other Genera Present
MB	S	1	0	*Calothrix*	6	4		7	6		0	0		2	2		1	1	
	B	-	-		-	-		-	-		-	-		-	-		-	-	
		3.07.79			10.07.79			17.07.79			24.07.79			31.07.79			14.08.79		
MB	S	5	2	*Nostoc*	4	2	*Nostoc*	18	2		7	3	*Nostoc* *Michrocete*	11	2		0	0	
	B	-	-		-	-		20	2		15	4	*Oscillatoria*[b]	1	0		0	0	
		22.08.79			28.08.79			4.09.78			23.10.79			4.11 79			21.11.79		
MB	S	8	3	*Calothrix* *Nostox*	4	1		0	0		0	0		0	0		-	-	
	B	-	-		2	0		2	0		-	-		-	-		-	-	
		29.11.79			18.12.79			16.01.80			30.01.80			13.02.80			27.02.80		
MB	S	6	6		5	5		10	10		12	12		15	14	*Nostoc*	19	18	*Nostoc*
	B	-	-		-	-		-	-		-	-		-	-		-	-	
		13.03.80			27.03.80			9.04.80			13.03.80			6.05.80			20.05.80		
MB	S	16	15	*Nostoc*	6	6		1	1		14	11	*Nostoc*	16	15	*Nostoc*	4	4	
	B	-	-		-	-		-	-		-	-		-	-		-	-	

a. Concentrations given refer to colonies developing after a 4 week incubation period, per 100 ml.

b. Non-heterocystous cyanobacteria are notincluded in the numbers shown.

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TABLE 3.3.4 Concentrations [a] of Heterocystous Cyanobacteria in the Peel Inlet and Harvey Estuary - May 1979 to May 1980

Site	Sample Depth	22.05.79 Total	22.05.79 *Nodularia*	22.05.79 Other Genera present [c]	29.05.79 Total	29.05.79 *Nodularia*	29.05.79 Other Genera present	5.06.79 Total	5.06.79 *Nodularia*	5.06.79 Other Genera present	13.06.79 Total	13.06.79 *Nodularia*	13.06.79 Other Genera present	19.06.79 Total	19.06.79 *Nodularia*	19.06.79 Other Genera present	26.06.79 Total	26.06.79 *Nodularia*	26.06.79 Other Genera present
Peel Inlet	S [b]	15.3	11.8		3.0	2.4		11.3	6.3		4.1	2.6		5.7	4.9		3.3	2.0	
	B [b]	-	-		-	-		-	-		-	-		-	-		-	-	
Harvey Estuary	S	65.7	63.3		11.4	10.4		17.0	14.4		11.0	10.7		11.4	10.3		12.3	10.4	
	B	-	-		-	-		-	-		-	-		-	-		-	-	

Site	Sample Depth	3.07.79 Total	3.07.79 *Nodularia*	3.07.79 Other Genera present	10.07.79 Total	10.07.79 *Nodularia*	10.07.79 Other Genera present	17.07.79 Total	17.07.79 *Nodularia*	17.07.79 Other Genera present	24.07.79 Total	24.07.79 *Nodularia*	24.07.79 Other Genera present	31.07.79 Total	31.07.79 *Nodularia*	31.07.79 Other Genera present	14.08.79 Total	14.08.79 *Nodularia*	14.08.79 Other Genera present
Peel	S	3.1	0.1		6.5	3.7		66.0	2.0		15.0	4.1		6.9	1.0		1.0	0.3	
Inlet	B	-	-		-	-		26.0	4.9		21.0	12.5		2.2	1.1		0.6	0.3	
Harvey	S	6.0	3.9		26.4	24.6		46.7	17.1		21.6	19.0		8.9	6.1		0.6	0	
Estuary	B	-	-		-	-		33.0	19.7		38.0	19.0		7.7	5.9		1.6	0.9	

Site	Sample Depth	22.08.79 Total	22.08.79 *Nodularia*	22.08.79 Other Genera present	28.08.79 Total	28.08.79 *Nodularia*	28.08.79 Other Genera present	4.09.79 Total	4.09.79 *Nodularia*	4.09.79 Other Genera present	23.10.79 Total	23.10.79 *Nodularia*	23.10.79 Other Genera present	4.11.79 Total	4.11.79 *Nodularia*	4.11.79 Other Genera present	21.11.79 Total	21.11.79 *Nodularia*	21.11.79 Other Genera present
Peel	S	24.4	10.9		3.0	1.0		6.3	1.0		4.0	2.5		0.5	0.5		83.0	11.0	
Inlet	B	10.0	8.1		3.1	1.7		7.6	4.7		2.0	2.0		5.3	4.0		105.7	27.3	
Harvey	S	14.6	10.7		35.1	32.1		26.6	24.6		10.5	9.1		4.3	3.4		30.9	14.3	
Estuary	B	18.8	16.8		27.5	23.7		52.6	50.0		3.3	2.0		5.3	4.7		25.3	19.0	

TABLE 3.3.4 (con't)

Site	Sample Depth	Date	29.11.79			18.12.79			16.01.80			30.01.80			13.02.80			27.02.80		
			Total	*Nodularia*	Other Genera present[c]	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
Peel Inlet	S		5.7	4.0		5.3	4.6		3.8	1.8		13.0	6.0		10.2	1.4		8.2	2.2	
	B		-	-		25.0	10.0		6.0	6.0		9.7	8.7		2.7	1.3		7.0	1.7	
Harvey Estuary	S		10.4	7.5		17.7	15.7		8.3	7.4		25.3	24.3		16.4	15.4		18.7	17.1	
	B		-	-		17.5	12.5		13.0	11.5		12.3	11.3		4.0	3.0		9.0	8.5	

Site	Sample Depth	Date	13.03.80			27.03.80			9.04.80			23.04.80			06.05.80			20.05.80		
			Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present	Total	*Nodularia*	Other Genera present
Peel Inlet	S		3.6	2.0		7.6	4.2		0	0		50.4	3.6		15.2	10.0		4.4	3.2	
	B		3.3	1.0		3.5	2.5		2.0	0.7		9.3	5.0		28.5	20.5		4.0	3.3	
Harvey Estuary	S		17.1	15.4		11.9	10.1		4.6	4.4		12.7	6.1		20.0	18.1		15.3	12.3	
	B		17.5	17.0		22.0	21.3		6.3	6.3		8.5	8.0		19.0	18.3		6.0	4.0	

a. Concentrations given refer to the number of colonies developing after a 4 week incubation /100ml.

TABLE 3.4.1 Numbers of cyanobacteria in the water column, sediment water [a] and sediments; 24.07.79

Sample		Viable Numbers of Cyanobacteria	
Station	Sample Component	Total #/100ml	*Nodularia* #/100ml
1	Water - Surface	19	14
	- Bottom	10	9
	- Sediment [a]	670	670
	Sediment	15250	14000
P46	Water - Surface	-	-
	- Bottom	-	-
	- Sediment	100	100
	Sediment	5625	5625
4	Water - Surface	48	0
	- Bottom	3	0
	- Sediment	520	440
	Sediment	13659	11220
5	Water - Surface	1	0
	- Bottom	3	2
	- Sediment	195	109
	Sediment	17538	12923
6	Water - Surface	2	1
	- Bottom	7	2
	- Sediment	30	25
	Sediment	20702	18947
7	Water - Surface	19	12
	- Bottom	13	5
	- Sediment	220	205
	Sediment	22319	21739
8	Water - Surface	19	12
	- Bottom	86	72
	- Sediment	330	240
	Sediment	28353	27529

[a] Sediment water is defined as the water overlaying the bulked material from three sediment cores.

Table 3.5 Analyses conducted on the *Nodularia* bloom; 17.11.78-08.01.79.

Date	Secchi Depth	Fluorometry	Chlorophyll$_a$	Direct Cell Count	Nutrients[a]	Acetylene Reduction
17.11.78				S		S
23.11.78	S[b]	S,d[c]	S,d		S,d	d
30.11.78	S		d	d	d	d
13.12.78	S					
20.12.78	S					
28.12.78	S					
08.01.79	S					

[a] As well, the regular nutrient analysis program (Botany Dept., U.W.A.) was being carried out over this time.

[b] A survey of surface waters of the estuarine system was done.

[c] Depth profiles at one or more stations were examined.

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TABLE 3.5.j Secchi depths during the course of the *Nodularia* bloom; Nov. 1978 to Jan. 1979

Station #	Secchi Depth, meters					
	23.11.78	30.11.78	13.12.78	20.12.78	28.12.78	08.01.79
Mandurah Bridge	-	-	-	-	0.96	-
S1	>3.60	-	2.50	>3.00	-	0.90
S2	0.90	-	>1.70	-	-	-
PB3	-	-	-	-	0.99	-
P47	1.10	-	>1.78	-	-	-
P26	-	-	-	2.29	-	1.80
P27	-	-	-	2.26	-	-
P27+P47	-	>1.78	-	-	-	-
1	1.10	-	-	-	-	-
2	1.30	-	-	0.56	-	-
PB2	1.10	-	0.62	-	0.54	-
3	-	-	-	>1.96	-	-
4	0.70	-	-	-	-	-
5	0.95	-	1.00	0.96	0.75	-
6	1.00	-	0.69	1.25	0.81	-
PB7	1.20	0.44	0.90	2.46	1.15	0.68
7	0.45	1.06	0.91	0.46	0.54	-
8	0.25	-	0.90	0.39	0.46	-
9	0.10	0.30	0.54	0.43	0.43	-
10	0.10	0.36	0.45	0.30	0.47	0.48
11	0.10	0.27	0.46	0.35	0.48	0.48
12	0.20	0.24	0.38	0.36	0.51	0.56
13	0.20	0.26	0.33	0.35	0.47	-
15	-	-	0.16	0.27	0.42	-
12 + 17	-	0.33	-	-	-	-
17	0.40	0.23	0.25	0.37	0.50	0.45
18	0.25	0.23	0.37	0.41	-	0.46
19	0.50	0.30	0.24	0.37	0.41	0.52
20	0.45	0.27	0.51	0.41	0.48	0.46
22	0.50	-	0.60	0.50	0.44	-
26	0.40	0.30	0.32	0.29	-	-
PB5	-	-	-	-	-	1.00
PB4	-	-	>1.97	2.14	1.86	1.50
P46	-	1.10	>1.64	2.00	1.45	-
Serpentine R. mouth	-	0.52	-	-	-	-
Serpentine R.	-	0.50	0.68	>2.05	-	-

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TABLE 3.5.2.1 Secchi depths and surface water chlorophyll *a* concentrations· 23 .11.78

Site #	Secchi Depth (m)	Secchi Depth^{-1} (m^{-1})	Chlorophyll *a* (µg/l)
S1	>3.6	0	1.28
S2	0.9	1.1	8.88
2	1.3	0.8	3.76
PB2	1.1	0.9	14.2
4	0.7	1.4	7.8
5	0.95	1.1	12.88
6	1.0	1.0	7.55
1	1.1	0.9	-
7	0.45	2.2	32.4
8	0.25	4.0	46.83
9[b]	0.1	10.0	54.4
10	0.1	10.0	95.62
11	0.2	5.0	74.27
12	0.2	5.0	90.28
13[b]	0.2	5.0	110.6
15	-	-	100.96
17	0.4	2.5	26.57
18	0.25	4.0	38.39
19	0.50	2.0	17.42
20	0.45	2.2	29.10
22	0.50	2.0	23.19
26	0.40	2.5	37.55
PB7	1.2	0.8	5.28
P47	1.1	0.9	5.45

[a] Calculated from the standard curve, Figure 3.5.2.2.

[b] Data from sites 9 and 13 were not used in the calculation of the linear regression due to very high fluctuations in the fluorimetry readings at those sites.

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TABLE 3.5.2.2 Correlation between Chlorophyll *a* Concentrations and Fluorimeter Readings from Samples collected 23.11.78.

Site #	Chlorophyll *a* (µg/ml)	Fluorimeter Reading
S1	1.28	0
2	3.42	50.0
6	6.05	94.8
10	95.23	1137.6
20	34.18	350.0

The linear regression equation is:-

$$\text{Fluorometer Reading} = 11.84\ (\text{Chl}a) - 5.43$$

$$r^2 = 0.9958$$

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TABLE 3.5.3.1 Vegetative cell and heterocyst counts and acetylene reduction activities; 17.11.78

Station Number	Cells/ ml $x10^4$	Heterocysts/ ml $x10^3$	Cells/ heterocyst	Nitrogenase activity[a]	Nitrogenase activity per heterocyst[b]	(Nitrogenase activity per heterocyst)$^{-1}$
S1	2.13	1.20	17.75	0.14	0.12	8.3
S2	0.36	0.15	24.0	0.11	0.73	9.09
1	6.6	2.39	27.6	0.21	0.088	11.36
2	0.24	0.05	48.0	0.07	1.4	0.71
3	0.22	0.06	36.7	0	0	-
4	0.66	0.25	26.4	0.13	0.52	1.92
5	1.68	0.74	22.7	0.018	0.024	41.67
6	0.6	0.30	20.0	0	0	-
7	5.5	2.38	23.1	1.41	0.59	1.69
8	13.0	6.08	21.5	4.61	0.76	1.32
10	15.3	8.27	18.5	1.89	0.23	4.35
11	9.98	4.84	20.6	1.57	0.32	3.13
12	22.7	21.20	10.7	1.50	0.07	14.29
13	24.0	20.49	11.7	1.27	0.06	16.67
15	18.1	14.87	12.2	3.11	0.21	4.76
17	17.6	16.25	10.8	1.18	0.07	14.29
18	6.8	9.54	7.1	1.73	0.18	5.56
19	14.1	17.01	8.3	3.36	0.20	5.0
20	12.3	7.40	16.6	2.21	0.30	3.33
22	7.69	4.40	17.5	1.39	0.32	3.13
25	59.13	35.26	16.8	4.39	0.12	8.33
26S	22.02	20.62	10.7	1.43	0.07	14.29
26B[c]	11.04	15.04	7.34	1.89	0.13	7.69

a. nmoles C_2H_2 reduced/ml/hr

b. nmoles C_2H_2 reduced/heterocyst/hr

c. 26B was a bottom sample and terefore not included in linear regresstion calculations.

Note: The C_2H_2 reduction levels for sites S1 to 6 were too low to be accurate (less than about 0.2 nmoles/ml/hr) and were therefore not used in the linear regression calculations of heterocysts/ml vs (nmoles C_2H_2 reduced/heterocyst/hr)$^{-1}$.

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TABLE 3.5.4.1 Cell and Pigment Concentrations and Acetylene Reduction Rates in the Water Column at Bloom Station # 20 (Post 59); 30.11.78.

Depth (m)	Cell Concentrations			Pigment Concentrations					Acetylene Reduction Rates					
									In situ incubation (1hr)			Surface[a] incubation (1hr)		
	Vegetative cells/ml $x10^5$	Hetero-cysts/ml $x10^3$	Veg.cell to hetero-cyst ratio	Chl*a* µg/ml	Phaeo-phytin ug/ml	Chl*a* ug/cell $X10^5$	Phaeo-phytin ug/cell $X10^5$	Chl*a* to Phaeo-phytin Ratio	nmoles C_2H_2 reduced/ml/hr	nmoles C_2H_2 reduced/ml/hr $x10^{-5}$	nmoles C_2H_2 reduced/het/hr $x10^{-3}$	nmoles C_2H_2 reduced/ml/hr	nmoles C_2H_2 reduced/cell/hr $x10^{-5}$	nmoles C_2H_2 reduced/het/hr $x10^{-3}$
0	2.2	9.7	22.7	83.30	22.43	37.86	10.20	3.71	2.09	0.95	0.22	2.7	1.23	0.28
0.5	2.5	6.2	40.3	87.58	29.37	35.03	11.75	2.98	-	-	-	0.96	0.38	0.16
1.0	1.3	4.2	31.0	64.08	18.42	49.29	14.17	3.48	0.70	0.54	0.17	0.93	0.72	0.22
1.5	1.5	5.4	27.8	83.30	24.05	55.30	16.03	3.46	0.12	0.08	0.02	1.20	0.80	0.22

[a] Samples were incubated on board the boat, in direct sunlight.

TABLE 3.5.4.2 Nutrient concentrations in the water column at bloom station # 20 (Post 59); 30.11.79

Depth	Phosphorus			Nitrogen								Ratio
	Ortho P µg/l	Total P µg/l	Total P g/cell[a] ($\times 10^{-8}$)	NH_4 µg/l	NO_3+NO_2 µg/l	Organic µg/l	Total N µg/l	Org/cell ($\times 10^{-8}$)	Org/H ($\times 10^{-7}$)	Sol[b]/cell ($\times 10^{-8}$)	Sol/H ($\times 10^{-7}$)	N:P (totals)
0	12	64	?	42	4	3798	3844	1726.4	391.5	20.9	4.7	60.06
0.5	12	195	78.0	50	4	3687	3741	1474.8	594.7	21.6	8.7	19.18
1.0	12	171	131.5	60	9	3369	3438	2591.5	802.1	53.1	16.4	20.10
1.5	6	175	116.7	71	11	2980	3062	1986.7	551.9	54.7	15.2	17.49

a Cell numbers are those used in Table 3.5.4.1

b Sol refers to soluble nitrogen, i.e., nitrate + nitrite-N plus ammonia-N.

TABLE 3.5.4.3 Chlorophyll *a* and nutrient concentrations (Site 20), chlorophyll *a* (Site 11), and acetylene reduction activities (Site 25) in the water columns; 23.11.78.

Site No.	Depth metres	Chlorophyll *a* (µg/L)		Phosphorus (µg/L)		Nitrogen (µg/L)				Nitrogen to Phosphorus Ratio
				ortho-P	total-P	ammonia-N	nitrate + nitrite-N	organic-N	total-N	
20	0	83.93		1	172	78	5	3080	3168	18.4
	0.5	71.27		12	35	50	4	3004	3058	87.3
	1.0	45.96		10	44	21	9	945	975	22.2
	1.5	29.08		17	57	309	5	622	936	16.4
11	0	52.88								
	0.5	74.21			—	—	—	—	—	—
	1.0	26.21								
	1.5	31.54								
		C_2H_2 reduction (nmoles/L/hr)								
		in situ	surface							
25	0	4885	2150	0	234	64	3	7284	7351	31.4
	0.5	2940	1092	10	164	78	18	2114	2310	14.1
	1.0	185	588	52	227	92	7	5256	5355	23.6

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TABLE 3.5.5 Chlorophyll *a*, phosphorus and nitrogen, and nitrogen to phosphorus ratios for surface waters: 23.11.78

Sampling Location	Chlorophyll *a*	Phosphorus (µg/l)		Nitrogen (µg/l)				Total N:P Ratio	Soluble N:P Ratio
		Ortho P	Total P	NH_4^+	NO_3+NO_2	Organic	Total		
S_1	-	5	-	10	5	128	143	-	3.0
S_2	8.88	5	136	23	9	881	913	6.71	6.9
P27	5.45	4	27	27	4	667	698	26.22	7.8
4	7.8	0	13	44	2	909	955	73.46	-
5	12.88	0	0	22	9	944	975	-	-
6	7.55	3	26	25	1	679	705	27.12	8.7
PB7	5.28	0	22	23	3	733	759	34.50	-
2	3.76	4	6	13	1	569	583	97.12	3.5
PB2	14.2	4	59	50	2	2329	2381	40.36	13.0
7	32.4	8	76	107	1	3994	4102	53.97	13.5
22	23.19	3	26	84	4	3755	3843	147.81	29.3
8	46.83	5	176	151	4	10379	10534	59.85	31.0
9	20.6-54.4	4	113	69	3	3980	4052	35.86	18.0
10	15.62	9	108	342	1	3759	4102	37.97	38.0
19	17.42	10	45	107	2	1243	1352	30.04	10.9
11	74.27	4	294	189	3	17151	17343	58.99	48.0
18	38.39	1	108	86	1	5848	5935	54.95	87.0
26	37.55	4	46	34	2	2136	2172	47.21	9.0
12	90.28	3	236	114	1	10586	10701	45.34	38.3
17	26.57	2	76	53	1	4686	4740	62.24	27.0
13	110.6	2	309	86	3	11144	11233	36.22	44.5
15	100.96	9	351	211	4	24463	24678	70.30	23.9
Peel Average (S_2 →PB2)	8.2	2.5	21.9	28.4	3.9	963.9	996.1	45.6	12.9
Harvey Average (7→15)	50.1	4.9	151.1	125.6	2.3	7932.6	8060.5	53.4	26.0

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TABLE 3.5.6.1 Physical parameters, pigments, and nutrient concentrations and ratios in surface and bottom waters at Station PB1 (Post 60) from October 1978 to February 1979.

Date	Temp °C		O_2 mg/L		Salinity °/oo		Pigments (µg/ml)		Nitrogen (µg/ml)								Phosphorus (µg/ml)				Ratios			
							Chlor[a]	Phae[b]	$NO_3^- + NO_2^-$		NH_4^+		Organic		Total		Ortho P		Total P		N:P (totals)		N:P (solubles)	
	S	B	S	B	S	B	S	S	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
03.10.78	18.1	16.4	12.2	4.0	6.4	15.4	35.1	9.5	5	3	25	18	1413	1192	1443	1213	17	7	223	64	6.47	19.0	1.8	3.0
10.10.78	21.2	19.3	8.8	0.7	7.3	17.0	27.9	7.3	1	3	24	32	1465	1964	1490	1999	17	55	28	81	53.2	24.7	1.5	0.6
17.10.78	18.3	18.1	10.3	9.2	7.6	7.8	32.2	0.2	3	2	27	24	1436	1351	1466	1377	9	7	169	177	8.56	7.8	3.3	3.7
24.10.78	22.2	20.7	10.2	4.4	8.7	17.5	23.2	5.7	2	1	27	24	1000	902	1029	927	-	52	299	102	3.44	9.1	-	0.5
31.10.78	21.2	20.3	9.7	5.0	12.2	19.1	25.2	2.4	1	1	26	19	814	1120	841	1140	10	10	96	89	8.76	12.8	2.7	2.0
07.11.78	22.1	22.2	10.8	7.2	14.2	24.6	9.0	4.5	1	2	30	38	941	746	972	786	4	2	-	69	-	11.4	7.8	20.0
13.11.78	21.8	20.2	10.4	9.1	15.7	16.0	35.9	9.0	2	2	24	23	1339	1302	1365	1327	10	11	70	44	19.13	30.2	2.6	2.3
22.11.78	25.5	23.0	10.8	8.3	21.6	25.4	-	-	4	2	28	29	7719	3281	7751	3312	22	9	173	87	44.62	38.1	1.5	3.4
29.11.78	21.5	20.4	10.4	5.7	20.6	22.6	284.8	30.3	3	2	0	30	9222	4831	9225	4863	16	25	312	33	29.56	147.4	0.2	1.3
05.12.78	23.3	20.7	12.4	8.6	22.7	23.6	49.1	8.9	8	3	34	30	4534	1441	4376	1474	17	11	161	60	26.92	24.6	2.5	3.0
12.12.78	24.0	23.0	10.6	8.4	24.6	24.7	55.5	10.2	3	3	100	94	3873	3351	3976	3448	13	11	125	133	30.98	25.9	7.9	8.8
19.12.78	23.2	22.8	8.9	7.2	27.7	27.7	64.1	8.7	5	5	70	121	3571	2199	3646	2326	4	6	105	110	34.01	21.1	18.5	21.2
27.12.78	23.0	22.4	9.5	7.0	28.2	28.6	96.6	14.0	5	18	48	58	2239	3816	2292	3892	14	9	99	151	22.62	25.8	3.8	8.4
02.01.79	25.6	23.2	9.1	8.8	29.9	30.2	37.8	5.4	4	4	38	38	1699	1516	1741	1558	22	9	81	105	20.98	14.8	1.9	4.7
09.01.79	20.8	20.5	6.9	6.6	31.3	31.4	25.0	5.9	3	5	30	42	1840	1895	1873	1942	19	7	102	114	18.04	17.0	1.7	6.7
16.01.79	23.0	23.5	5.7	5.4	33.4	34.1	4.8	3.1	24	24	438	445	1120	1157	1582	1626	8	18	77	82	14.55	19.8	57.8	26.0
23.01.79	24.5	24.3	6.6	6.0	35.4	35.7	6.1	1.5	34	43	1016	1004	601	243	1615	1290	4	3	44	-	13.66	-	262.5	349.0
30.01.79	25.1	25.0	5.5	5.8	37.3	38.2	2.9	1.7	57	66	550	54	1421	830	2028	1417	9	5	157	55	9.05	25.8	111.9	117.4
06.02.79	26.1	24.6	4.2	3.0	39.2	38.8	2.4	0.8	193	175	465	535	1388	1200	2046	1910	5	4	161	-	12.5	-	131.6	177.5
13.02.79	24.1	24.1	6.2	6.2	40.5	40.5	5.0	2.8	190	195	547	568	966	889	1703	1652	6	7	115	130	12.7	14.8	122.8	109.0

a. chlorophyll *a*

b. phaeophytin

TABLE 3.5.6.2 Physical parameters, pigments, and nutrient concentrations and ratios in surface and bottom waters at Station PB2 from October 1978 to February 1979.

Date	Temp °C		Dissolved Oxygen mg/L		Salinity		Pigments (µg/ml)		Nitrogen (µg/ml)								Phosphorus (µg/ml)				Ratios			
							Chlor.[a]	Phae.[b]	$NO_3^-+NO_2^=$		NH_4^+		Organic		Total		Ortho P		Total P		N:P (totals)		N:P(solubles)	
	S	B	S	B	S	B	S	S	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
03.10.78	17.6	16.2	11.0	2.6	12.7	22.2	17.1	11.8	3	8	20	140	1479	740	1502	888	13	2	13	44	115.0	20.2	1.8	74.0
10.10.78	23.1	20.3	9.8	8.1	10.7	11.7	21.6	7.3	2	3	21	20	1125	1329	1148	1352	11	27	150	56	7.7	24.1	2.1	0.9
17.10.78	18.1	18.0	9.4	9.4	10.2	10.6	27.3	3.1	2	3	25	24	1235	1072	1262	1099	6	4	104	110	12.1	10.0	4.5	6.8
24.10.78	21.8	20.7	10.8	0.8	-	-	16.6	6.1	1	2	19	10	784	401	804	4130	49	24	261	44	3.1	9.4	0.4	0.5
31.10.78	22.4	19.7	8.6	6.7	17.9	20.5	21.4	1.1	2	1	15	24	713	704	730	729	7	7	55	17	13.3	42.9	2.4	3.6
07.11.78	21.8	22.1	10.2	7.9	18.2	24.5	12.5	1.4	2	2	29	40	211	894	842	936	3	5	55	48	15.3	19.5	10.3	8.4
13.11.78	21.8	20.2	10.4	9.1	15.7	16.0	35.9	9.0	2	2	24	23	1339	1302	1365	1327	10	11	70	44	19.5	30.2	2.6	2.3
22.11.78	26.5	25.2	9.3	7.6	26.0	26.2	-	-	3	3	25	28	1494	1451	1522	1482	10	11	55	74	27.7	20.7	2.8	2.8
29.11.78	21.5	19.5	9.4	6.1	24.6	29.6	26.1	7.1	3	5	46	75	2258	1379	-	-	16	10	48	23	-	-	3.1	8.0
05.12.78	25.1	22.5	10.5	9.6	30.2	30.5	9.8	3.6	6	7	32	60	648	458	686	525	11	11	50	44	13.7	11.9	3.5	6.1
12.12.78	24.7	23.6	11.0	9.2	32.0	32.5	6.4	5.1	7	8	52	105	1155	780	1214	893	6	7	58	43	20.9	20.8	9.8	16.1
19.12.78	23.8	22.9	8.4	7.0	33.0	33.9	9.4	3.5	18	15	172	162	882	542	1072	719	6	3	60	49	17.9	14.7	31.7	59.0
27.12.78	22.9	21.6	8.3	7.6	31.0	34.8	24.7	4.9	14	10	66	79	1288	875	1368	964	15	12	54	30	25.3	32.1	5.3	7.4
02.01.79	26.0	25.1	9.0	7.1	33.5	33.8	8.3	1.9	11	12	82	97	188	607	281	716	-	-	62	58	4.5	12.1	-	-
09.01.79	21.3	21.6	7.6	8.0	35.9	36.0	5.3	2.1	9	9	78	80	942	774	1021	863	4	2	58	30	17.7	28.8	21.8	44.3
16.01.79	23.5	23.5	6.9	6.7	36.8	36.8	2.5	2.5	13	13	101	102	732	672	846	787	10	10	90	83	10.6	9.5	11.4	115.0
23.01.79	24.3	24.3	8.8	9.5	37.0	38.3	1.0	0.5	45	48	220	234	747	777	1012	1059	2	4	36	28	28.1	37.8	132.5	70.5
30.01.79	26.0	25.5	8.1	6.2	40.0	40.1	3.6	0.9	10	10	56	62	851	565	917	637	7	6	154	-	6.0	22.8	9.4	12.0
06.02.79	25.5	24.7	5.0	7.1	41.0	41.0	1.4	1.1	12	15	65	67	783	826	860	908	5	3	81	41	11.8	22.1	15.8	27.3
13.02.79	24.0	24.0	8.4	8.2	40.8	40.8	1.6	2.0	27	28	64	63	523	640	616	731	11	9	60	59	10.3	12.4	8.3	10.4

a. chlorophyll *a*

b. phaeophytin

TABLE 4 Magnesium and iron concentrations for surface estuary water

Station #	Magnesium (Mg^{++}) µg/ml		Iron (Fe^{++}) µg/ml
	18.10.79[a]	18.06.80[b]	18.06.80[b]
1	640	1175	0.026[c]
2	-	1375	0.013
4	913	1299	0.013
7	-	1302	0.026
8	915	-	-
MB	-	1404	0.013
P58	-	1330	0.026
24	-	1384	0.026
28	-	1293	0.026
29	-	1325	0
31	-	1278	0.013
35	-	1380	0.026

[a] samples unfiltered

[b] samples filtered

[c] The levels shown are just above the detection level (0.01 µg/ml) for the assay technique (high resolution atomic absorption) and, therefore, may not be very accurate.

TABLE 5: Parameters examined during the 1980-81 and 1981-82 *Nodularia* blooms.

1980-1981 *Nodularia* bloom

Weekly data

physical data: salinity, temperature, Secchi depth

chemical data: total phosphorus, orthophosphorus, total nitrogen, nitrate and nitrite nitrogen, ammonia nitrogen

biological data: chlorophyll *a*, phaeophytin, direct and viable *Nodularia* counts, fluorometric measurements, spectrophotometric measurements, acetylene reductions.

Diurnal data

physical data: salinity, temperaute, pH, dissolved oxygen, Secchi depth.

chemical data: as above

biological data: fluorometric measurements, direct counts, acetylene reductions.

Other data: Sediment *Nodularia* populations.

1981-1982 *Nodularia* bloom

Weekly data

physical data: salinity, temperature, Secchi depth, pH,dissolved oxygen.

chemical data: as above

biological data: chlorophyll *a* and phaeophytin, direct counts of *Nodularia*, phosphatases, growth and phosphatase response to added nutrients and changes in physical conditions.

Diurnal data

physical data: as above

chemical data: as above

biological data: chlorophyll *a*, direct counts, phosphatases, ultrastructure.

Other data: Chlorophyll *a* grid study

Sediment *Nodularia* populations (pre- and post-bloom)

Station 1 water, biomass and sediment phosphorus analyses.

Plate 3.1.2.1a


Plate 3.1.2.1b

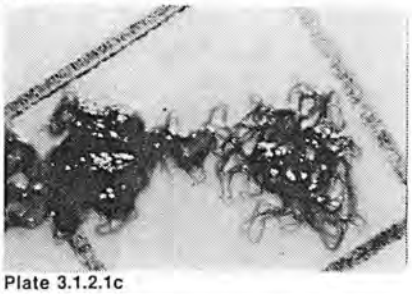
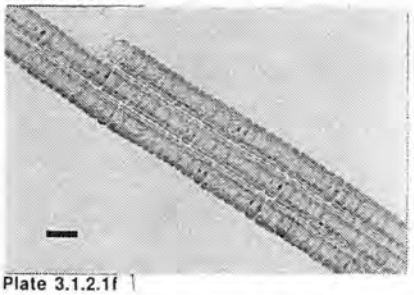


Plate 3.1.2.1c


Plate 3.1.2.1d


Plate 3.1.2.1e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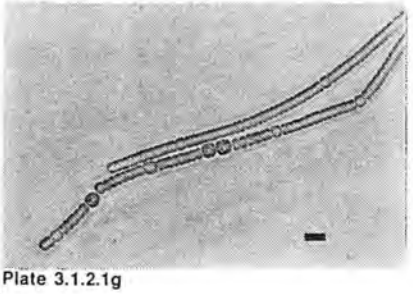
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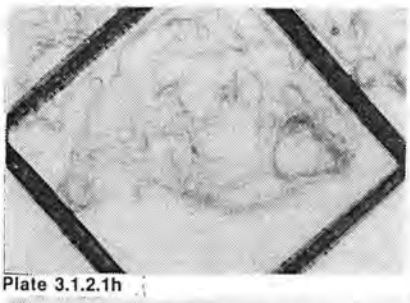
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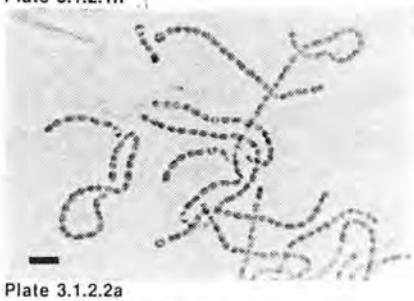
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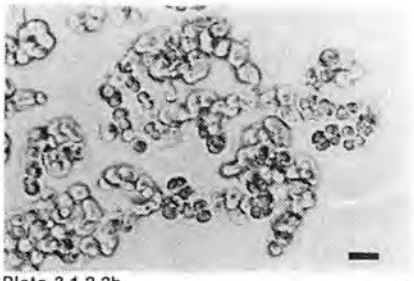
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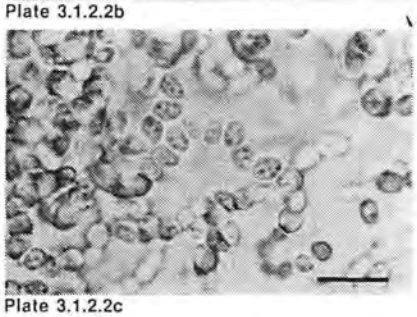
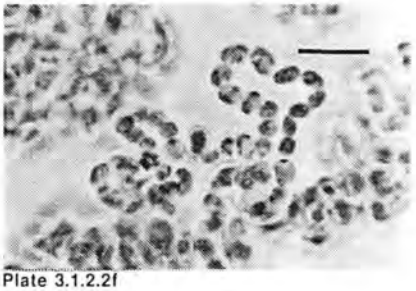


Plate 3.1.2.2c


Plate 3.1.2.2d


Plate 3.1.2.2e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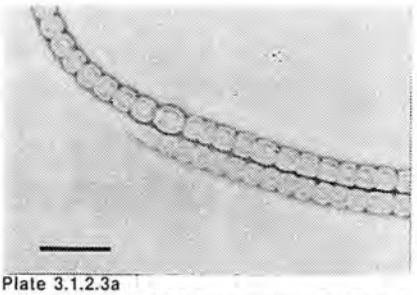
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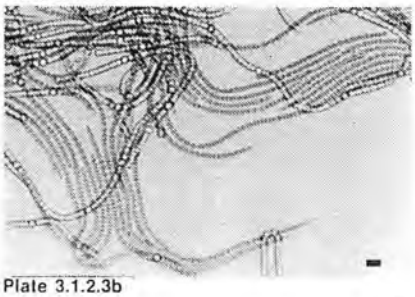
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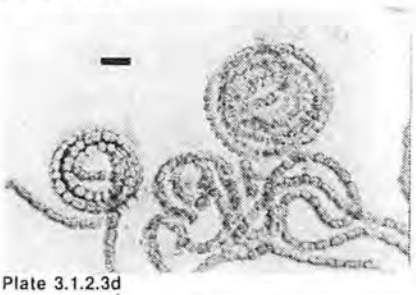
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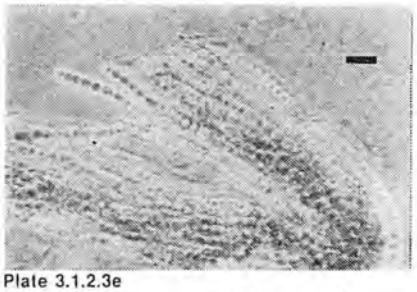
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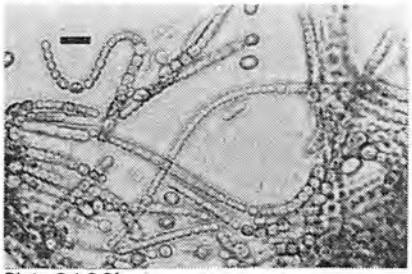
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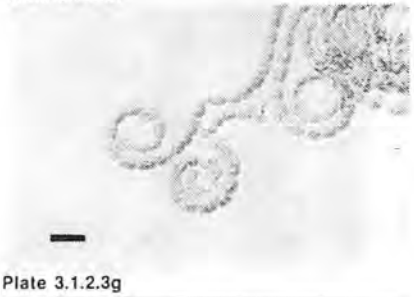


Plate 3.1.2.3g

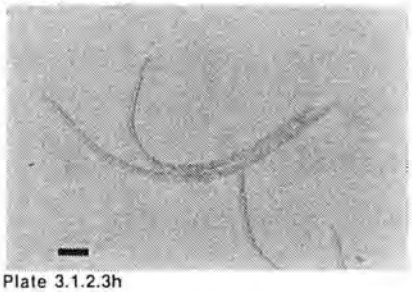


Plate 3.1.2.3h

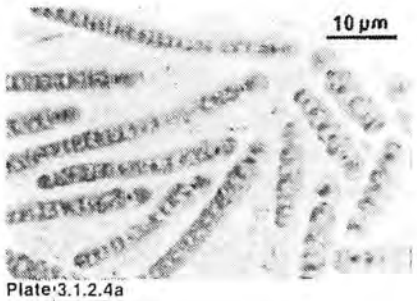
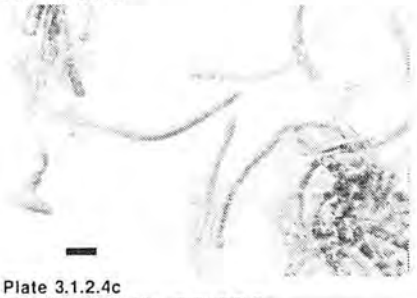


Plate 3.1.2.4a


Plate 3.1.2.4b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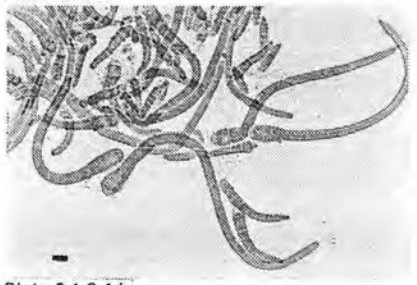
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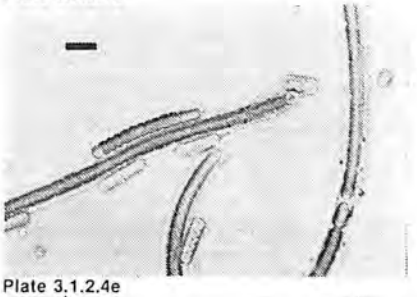
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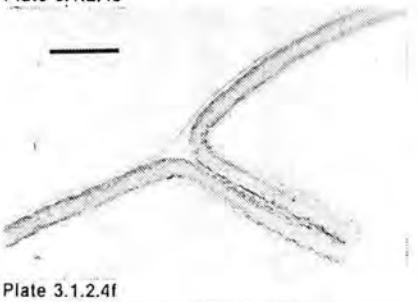
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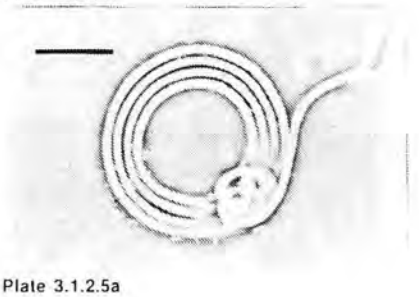
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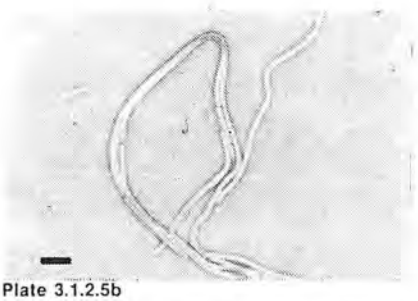
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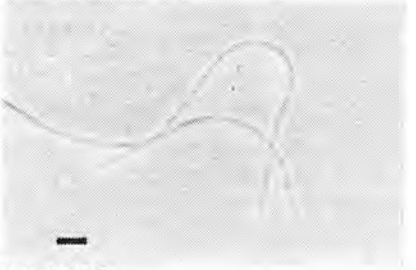
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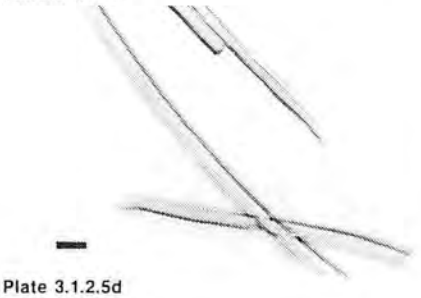
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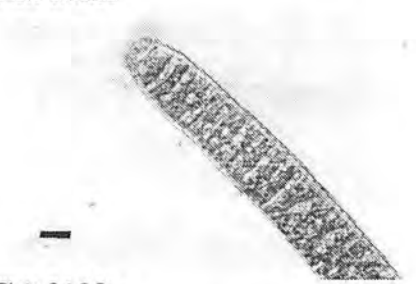
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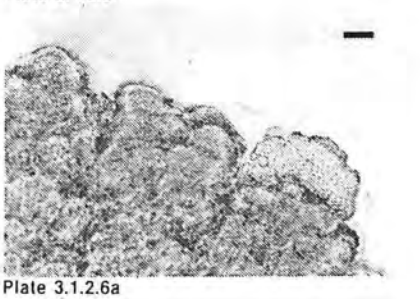
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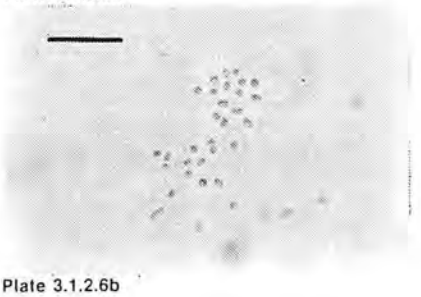
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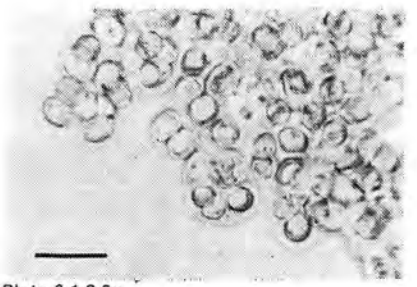
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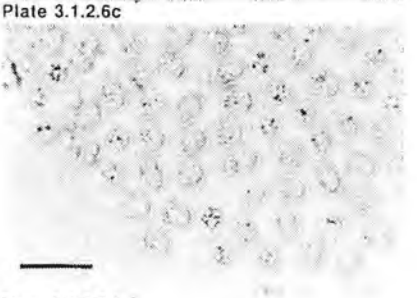
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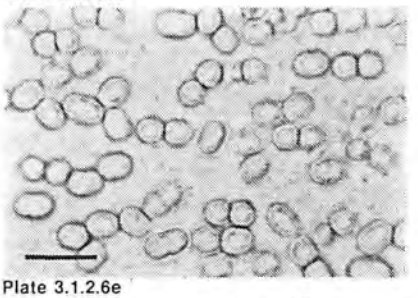
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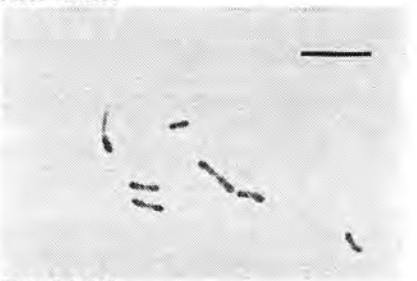
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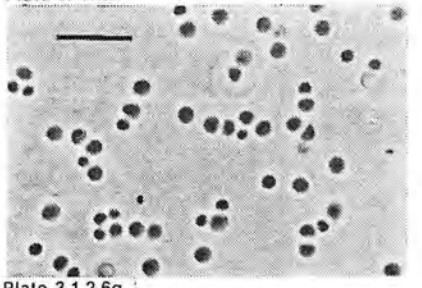
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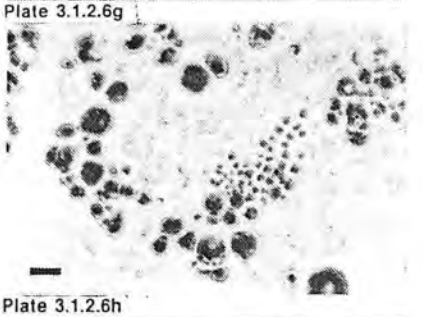
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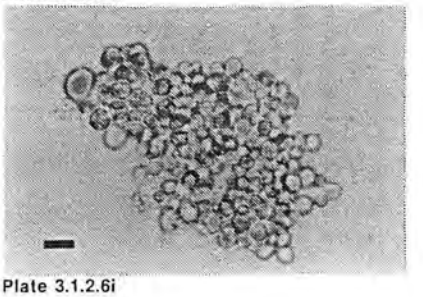
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