THE BLUE-GREEN ALGAL BLOOM IN THE HAWKESBURY RIVER AT SACKVILLE FERRY DURING THE SUMMER OF 1991/2

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INTRODUCTION

The Hawkesbury-Nepean River is an important resource for the Sydney Basin. The river is used extensively for recreation, irrigation, water supply and effluent disposal. Since European settlement, human activity in the catchment has caused a rapid deterioration in water quality and it is now unsatisfactory for many uses (SPCC, 1983). In particular, the incidence of blue-green algal (cyanobacterial) blooms has increased in recent years as a consequence of eutrophication (Heath & Cannon, 1990).

The presence of algal blooms at the North Richmond water abstraction off-take have caused taste and odour problems in the past. The presence of toxins was demonstrated in blue-green algal blooms at this site in 1983, 1985 and 1988, and this is a cause for concern (Water Board, unpublished data).

In addition to the problems blue-green algal blooms pose for water treatment, blooms also reduce the aesthetic amenity of the river, causing unsightly scums and odours. Blue-green algal toxins may also cause stock deaths and contact with humans can cause skin, eye or respiratory irritation while ingestion can cause hepato-enteritis (Codd, 1990)

The success of blue-green algae in forming blooms and competing with other species has been discussed by Hardiman (1993). Blue-green algae are able to grow in conditions of high temperature (Fogg, 1975) and high light intensity (Robarts & Zohary, 1992). In addition, blue-green algae have an enhanced ability to take up dissolved inorganic carbon and form blooms under alkaline, CO_2-limited conditions compared with other phyla (Talling, 1976), and surface scums have the ability to exploit atmospheric CO_2 (Pearl, 1983).

The formation of perennating stages in many species of blue-green algae enables them to 'overwinter' and quickly exploit favourable conditions by maintaining a potential inoculum in the sediment (Reynolds *et al.*, 1981).

Gas vesicles provide a mechanism for buoyancy regulation, permitting cells to remain in the euphotic zone under calm conditions and to rise and fall in the water column to harvest nutrients (Reynolds & Walsby, 1975). The ability of some blue-green algae to fix nitrogen and grow at nitrogen to phosphorus ratios less than 10:1 (NRA, 1990) is advantageous. The colony size of species such as *Microcystis* limits grazing pressure by zooplankton (Hecky & Kilham, 1974).

In this paper we examine the algal bloom in the Hawkesbury River at Sackville Ferry, which occurred during the period July 1991 to February 1992, in relation to river discharge and the concentration of the nutrients, nitrogen, phosphorus and silica.

STUDY AREA

The Hawkesbury River is tidal and the salt wedge has penetrated up the estuary as far as the Colo River, downstream of Sackville Ferry (Figure 1). The depth of the river in the Sackville Reach ranges between three to six metres (PWD, 1987) and the substrate is mostly sand (Neville, 1976).

The four headwater storages in the Illawarra Range, to the south of Sydney, and Lake Burragorang, on the Warragamba River, supply water to Sydney. Riparian releases are made from these storages to maintain flow over Penrith Weir above 60 ML/d to meet requirements for irrigation and abstraction for domestic water supply at North Richmond.
The most significant point sources of

nutrients immediately upstream of Sackville Ferry are the sewage treatment plants (STP) at Kellyville, Round Corner and Castle Hill (discharging to the Cattai Creek), Quakers Hill, St Marys, Riverstone plus 3 smaller STPs (discharging to the South Creek system). During dry weather, effluent forms the bulk of the flow in streams receiving treated effluent (Kinhill Stearns, 1986). The combined estimated dry weather discharge from the STPs in the Cattai and South Creek systems alone is 70 ML/d.

SAMPLING AND ANALYSIS

Sub-surface samples were routinely collected at fortnightly intervals from the Hawkesbury River at Sackville Ferry, and more frequently during the blue-green algal bloom in November and December of 1991. Algal samples were fixed in Lugol's Iodine (Saraceni & Ruggiu, 1971) and counted using the sedimentation technique of Hasle (1978) for larger algae, and the modified Lund chamber for nanoplankton (WRA, 1966). Only blue-green algal species were enumerated in samples collected additional to the routine fortnightly sampling program. Phytoplankton were identified using the taxonomic works of Bourrelly (1966-70), Desikachery (1959), Huber-Pestalozzi (1968-82) and Prescott (1969).

Nutrient samples and *in situ* measurements (dissolved oxygen, Secchi depth, pH and temperature) were made at the time of routine fortnightly sample collection. Nutrient analyses were carried out using modified Standard Methods (Water Board, 1992).

The Hawkesbury River is under tidal influence and discharge data are not available at Sackville Ferry. However, flow data for Penrith Weir, 68 km upstream, are used to indicate periods of high flow at Sackville Ferry.

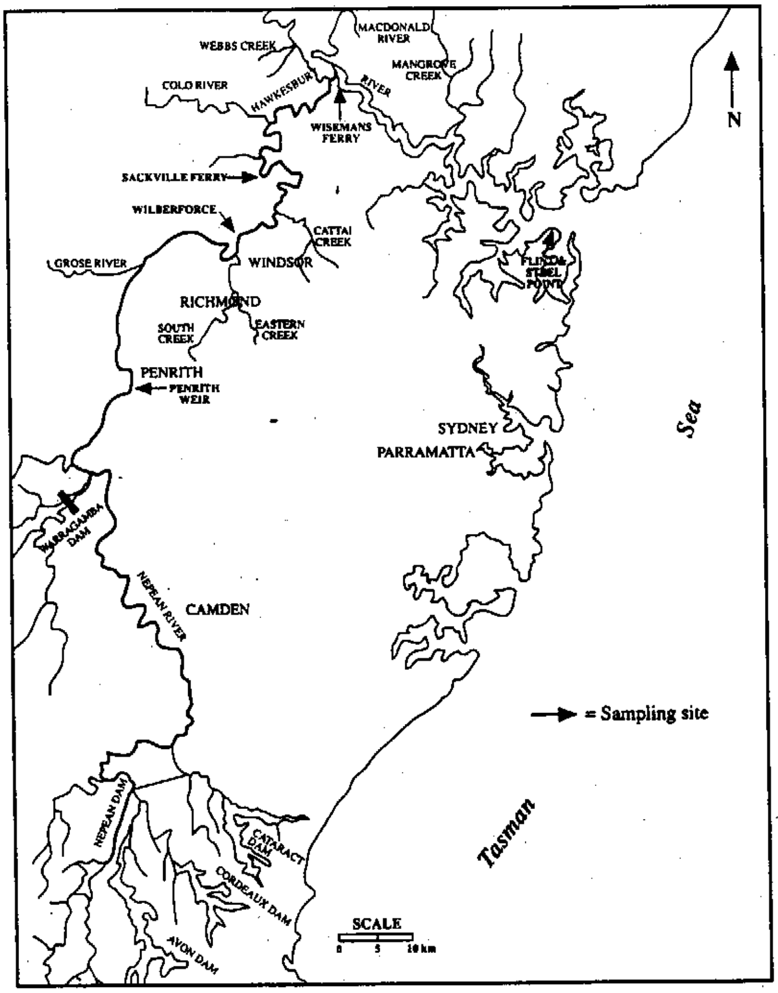

Figure 1 The Hawkesbury-Nepean River

RESULTS

Physical/chemical conditions.

Discharge

Following heavy rainfall in the catchment, floods occurred in mid-July (21,300 ML/d), mid-December, 1991 (11,000 ML/d), and late February, 1992 (307,000 ML/d)(Figure 2).

Controlled releases from Warragamba Dam occurred intermittently during August and September to draw down the storage to accommodate the high inflows. This resulted in discharge at Penrith Weir oscillating between 400 ML/d and 2,800 ML/d with a period of four to seven days. Elevated flows also occurred in November (peak flow of 800 ML/d) and January (peak flow of 2,000 ML/d). Under the warm, dry conditions during October, discharge at Penrith Weir receded to the range 39 to 120 ML/d.

Phosphorus

Filterable phosphorus levels increased to 26 µg P/L in late July, after the passage of the flood water, and dropped rapidly to less than 10 µg P/L (minimum recorded, 5 µg P/L) until the next flood in late February. Total Phosphorus levels over this period remained between 33 and 52 µg P/L (Figure 2).

Nitrogen

Oxidised nitrogen levels remained high (greater than 0.3 mg N/L) during the period studied. Oxidised nitrogen was the major proportion of the total nitrogen in the water column (Figure 2).

Ratio of nitrogen to phosphorus

The depressed,filterable phosphorus levels during the bloom period resulted in elevated ratios (by weight) of the readily available species of inorganic (nitrate, nitrite and ammonia) nitrogen : filterable phosphorus (Figure 2). The highest ratios recorded, 100:1 and 110:1,were associated with bloom peaks in early September and January respectively. The bloom in November was associated with a ratio of 65:1. These ratios suggest potential phosphorus limitation.
The lowest ratio recorded was 4:1, which occurred due to a combination of high rainfall in mid-February and elevated phosphorus levels resulting from runoff. The ratio of Total Nitrogen to Total Phosphorus followed a similar pattern. The ratio did not fall below 20:1 during the blooms, also indicating potential phosphorus limitation.

Dissolved silicate

Dissolved silicate levels were elevated during high flow periods in July (5 mg SiO_2/L), December (3 mg/L) and February (5 mg/L). While flows remained less than 2,000 ML/d (measured at Penrith Weir), silicate levels remained less than 0.6 mg SiO_2/L. From September through to November levels were less than 0.3 mg SiO_2/L and decreased to below the detection level (0.1 mg SiO_2/L) in early October.

In situ Measurements

Secchi depth varied between 0.3 and 1.1 metres during the course of the study and turbidity was generally less than 15 NTU (Nephelometric Turbidity Units),except during the flood in July. pH varied between 7.0 in July, 1991 and 9.6 during the bloom of *Microcystis* in December, 1991.

Phytoplankton Dynamics

A bloom of the blue-green alga *Microcystis aeruginosa* Kutzing, which occurred in the river between Windsor and Wisemans Ferry, reached its maximum development at Sackville Ferry between mid-November and mid-December, 1991. *Microcystis* formed a bloom containing over 450,000 cells per mL (9-13th, December 1991) (Figure 3). The blue-green algae, *Anabaena spp.* and *Merismopaedia sp.*, were also present, but in much lower numbers (5,000 and 7,000 cells/mL, respectively). The development of the bloom coincided with increasing water temperature (in excess of 20°C), calm, sunny weather and low flow conditions.

The bloom of *Microcystis* and *Anabaena* declined in late November coinciding with a change in weather conditions and rain over the three previous days. Further unfavourable weather and rain in mid-

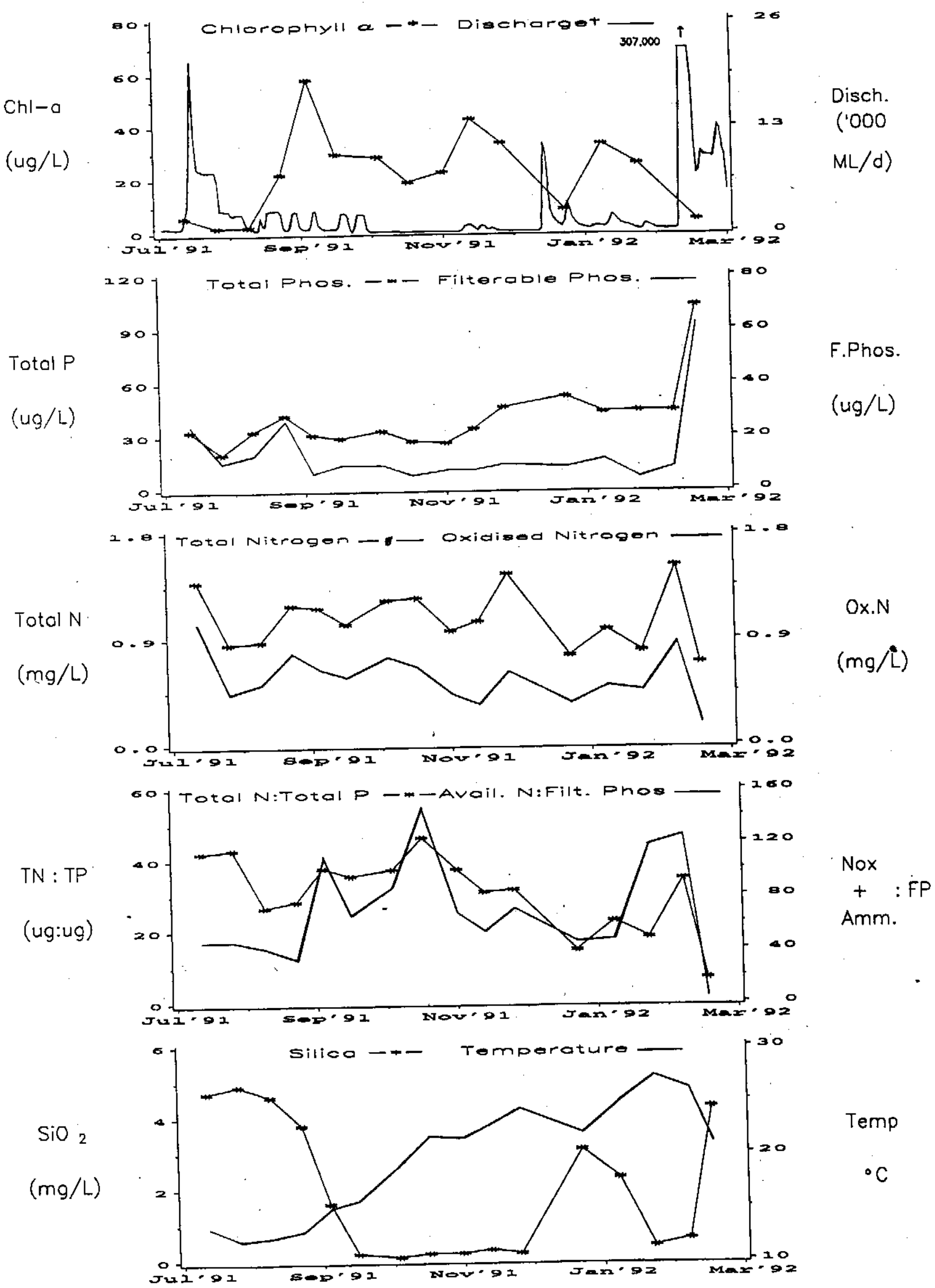

Figure 2 **Physico-chemical variables in the Hawkesbury River at Sackville, July 1991 - March 1992**

December again dramatically reduced numbers in the surface waters. The bloom decreased dramatically in March after the passage of high flows resulting from the heavy rain in early February (300 mm recorded at Wilberforce, between 4 -14th February, 1992).

The *Microcystis* bloom was preceded by a diatom bloom in early September (maximum recorded chlorophyll *a*, 58 µg/L). The diatom bloom consisted mainly of *Cyclotella* spp. and *Skeletonema potamos* (Weber) Hasle. *Asterionella formosa* Hassall, *Melosira granulata* (Ehr.) Ralfs and *M.distans* (Ehr.) Ralfs were also present. This diatom bloom was also accompanied by a mixed population of green algae : *Sphaerocystis sp., Scenedesmus spp., Dimorphococcus lunaris* A.Br., *Elaktothrix sp.*, and *Dictosphaerium sp.*. During this diatom bloom dissolved silicate fell below the detection limit.

Following the *Microcystis* bloom in mid-December, a smaller population (maximum recorded chlorophyll *a*, 33 µg/L) of diatoms (*Cyclotella spp.*) and green algae (*Sphaerocystis sp., Scenedesmus spp., Pediastrum sp.*, and *Dictosphaerium sp.*) developed in early January, 1992.

DISCUSSION

The development of the algal bloom on the Hawkesbury River was accompanied by fine, warm weather, falling river discharge, elevated water temperatures and depletion of water column concentrations of dissolved silicate and filterable phosphorus.

Floods in July, December and February played an important role in depressing the phytoplankton standing crop. Floods washed out the plankton at Sackville Ferry and phytoplankton numbers declined dramatically. In particular, the large bloom of *Microcystis* was reduced significantly in the surface waters at Sackville Ferry by the flood in December.

However, moderately elevated flows (less than 2,000 ML/d) coincided with the growth of diatoms (*Cyclotella, Skeletonema* and *Melosira*) and green algae. In the Murray River, diatom production is stimulated after elevated flows in the spring (Sullivan *et al.*, 1988) and similarly in the Nile (Talling & Rzoska, 1967). Turbulence is important for the suspension and recruitment of diatoms (Lund, 1966) plus the replenishment of nutrients, in particular silica (Talling & Rzoska, 1967; Bowles, 1983).

The blue-green algal bloom at Sackville Ferry was preceded by a mixed bloom of diatoms and green algae. The development of a large diatom population, and the corresponding decline in dissolved silicate levels to below detection limit as the diatom population developed and declined, is consistent with silica limitation. Below a concentration of 0.5 mg SiO_2/L most diatoms cannot compete effectively with non siliceous algae (Wetzel & Likens, 1991).

The apparent silica limitation of the diatom population and its subsequent decline may reduce the competition for the depleted levels of phosphorus in the water column. The higher growth rates and lower half saturation constants for phosphorus uptake by diatoms, compared to those of *Microcystis*, would predict the dominance of diatoms during periods of phosphorus limitation, but *Microcystis* dominance when silica is limiting (Holm & Armstrong, 1981). The succession from diatoms to *Microcystis* during the bloom in the Hawkesbury River is consistent with this observation, and supports the view that dissolved silicate concentrations in the water column limited diatom growth and influenced species succession to non siliceous algae.

Filterable phosphorus levels below 5-10 µg P/L, are likely to limit the growth of some species in the phytoplankton community (Reynolds, 1990). However, depleted levels of filterable phosphorus do not necessarily reflect the flux of this nutrient. Grazing and decomposition of the plankton, particulate phosphorus and sediment release and advection and intracellular storage, can contribute to the rate of supply of phosphorus experienced by the plankton.

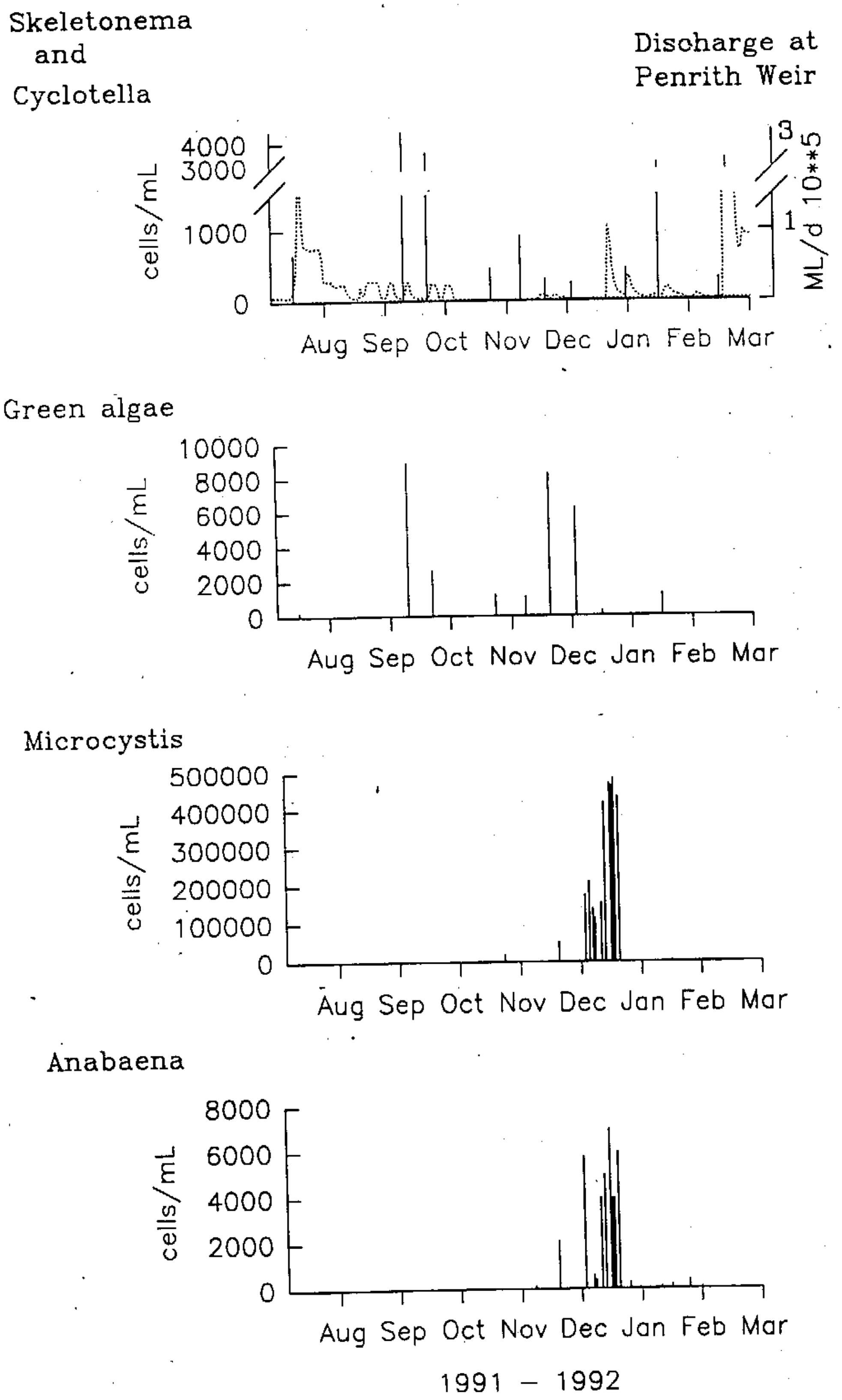

Figure 3 Selected algal genera in the Hawkesbury River at Sackville, July 1991 - March 1992

The continued growth of the phytoplankton community during October and November indicates that nutrient depletion influenced species succession without limiting phytoplankton standing crop. Other factors, such as selective grazing of small-sized algae (diatoms and green algae), may also affect the species succession by increasing the availability of nutrients to large slow-growing colonies of *Microcystis*, less subject to grazing (Gliwicz, 1990).

The ratio of nitrogen to phosphorus is often used to infer which of these macronutrients may limit algal growth. Phytoplankton require these nutrients in the physiological ratio of 7:1 by weight (Redfield *et al.*, 1963). Nitrogen to phosphorus ratios less than 29:1 are often associated with domination of the plankton by blue-green algae (Smith, 1983). The nitrogen to phosphorus ratio, however, did not appear to be a significant factor in the development of the bloom of *Microcystis*, a poor nitrogen fixer. Ratios of inorganic nitrogen to filterable reactive phosphorus did not fall below 40:1. Similarly, the ratio of total nitrogen to total phosphorus did not fall below 20:1 at Sackville Ferry. Oxidised nitrogen levels remained above 0.3 mg/L during the diatom and subsequent *Microcystis* bloom (Figure 3) and did not appear to limit the development of the blooms.

In competitive laboratory culture experiments, under identical resource supply, diatoms dominate at cooler temperatures (10-17 °C), green algae at intermediate temperatures (17-24 °C) and blue-green algae at warmer temperatures (24°C) (Tilman *et al*, 1986). These observations are also in accord with the species succession observed at Sackville Ferry and the development of *Microcystis* at temperatures greater than 20°C.

These data alone are not sufficient to determine the factors limiting algal growth during the period investigated. While it is clear that floods may dilute populations and provide conditions of light availability, turbulence and residence time unsuitable for algal growth (particularly blue-green algae), the role of nutrients in limiting algal growth during the blooms is less clear.

The influence of nutrients in determining the species succession cannot be readily separated from correlated factors such as : turbulence, light, temperature plus interactions with picoplankton, bacteria and zooplankton under field conditions. However, the isolation of the algal assemblage during laboratory bioassay from external sources of nutrients, and the alteration of light and turbulence during incubation, can also prove misleading (Elser *et al.*, 1990). For these reasons, Tilman *et al.* (1982) emphasise the need to carry out both laboratory and field enrichment experiments to determine the resource limiting a phytoplankton population.

CONCLUSIONS

Factors associated with the development of the blue-green algal bloom at Sackville Ferry were : dissolved silicate depletion during the preceding diatom bloom, depleted phosphorus levels, elevated water temperatures above 20°C, low flow conditions and fine weather conditions. The blue-green algal bloom was eventually dispersed by high flows in February.

The preceding diatom bloom appeared to be limited by the dissolved silicate concentration in the water column and possibly rising water temperature.

The determination of the nutrient or physical factors limiting algal growth requires field observation combined with both laboratory and field nutrient addition experiments in order to elucidate relationships between the phytoplankton and nutrient or physical factors, which are often correlated.

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