Technical Memorandum 14

Fate of Heavy Metals in the Magela Creek System, Northern Australia

II. Experiments with plastic enclosures placed in Island Billabong during the 1980 Dry Season: limnology and phytoplankton

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II. EXPERIMENTS WITH PLASTIC ENCLOSURES PLACED IN ISLAND BILLABONG DURING THE 1980 DRY SEASON: LIMNOLOGY AND PHYTOPLANKTON

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This Technical Memorandum was prepared by:

B.T. Hart, M.J. Jones, and P. Bek

of the

Water Studies Centre,
Chisholm Institute of Technology
Caulfield East, 3145

and J. Kessell

Botany Department, University of Tasmania,
Hobart, 7000

acting as consultants to the Supervising Scientist for the
Alligator Rivers Region, Northern Territory

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ABSTRACT

Hart, B.T., Jones, M.J., Bek, P. and Kessell, J. (1985). Fate of heavy metals in the Magela Creek System, northern Australia. II. Experiments with plastic enclosures placed in Island Billabong during the 1980 Dry Season: limnology and phytoplankton. Technical Memorandum 14, Supervising Scientist for the Alligator Rivers Region.

Two 5 m plastic cylinders (enclosures) were used to isolate parts of Island Billabong so that the influence of added heavy metals on the phytoplankton could be assessed. A mixture of the metals manganese, cadmium, copper, lead and zinc was added to one enclosure and the other was kept as a control. The changes in physico-chemical qualities, phytoplankton species and numbers, and concentrations of the metals were monitored over a six-week period from 6 November 1980.

Temperature and dissolved oxygen measurements indicate that the water in the control enclosure simulated the water in the billabong. In the early part of the study, the pH values were similar in both, but there were considerable differences towards the end of the experiment.

In situ measurement of absolute fluorescence was found to be a poor indicator of algal cell numbers, probably because the algal species present fluctuate considerably in their relative abundance and different species give different fluorescence signals.

Species and total numbers of algae present showed that, in the first half of the study, the control enclosure behaved like the billabong. After Day 15, the billabong and the enclosure differed markedly in both cell concentrations and species composition. Cell numbers stayed approximately constant in the control enclosure, but marked changes in the species composition were noted, with the diatom *Eunotia zasuminensis* (Cabesjz) Körner becoming increasingly dominant.

The metals added to the metal-loaded enclosure caused a significant reduction in the cell numbers, particularly during the first three days of the experiment. The most affected of the algae was the diatom *E. zasuminensis* whose numbers were reduced by over two orders of magnitude. Numbers began to increase again around Day 15 of the experiment so that after Day 36 of the study both the numbers of phytoplankton and the species composition were similar to those in the control enclosure.

The metals added to Island Billabong waters were relatively rapidly removed from the water column and had little long-term effect on species composition or abundance.

1 INTRODUCTION

Much of the present knowledge about the behaviour of heavy metals in water bodies has been obtained from laboratory-based experiments, and extrapolation of such results to the field situation is fraught with difficulties. Studies on the water bodies themselves have their own set of problems, particularly the inability to control such important variables as temperature, light regime and intensity, and water dynamics. An alternative method is to isolate part of the water body by means of a plastic or rubber enclosure, add heavy metals of interest to the enclosure and monitor any resulting changes. This method has the inherent advantage that it is a semi-field experiment, and as such should reflect an 'open' field experiment more closely than do laboratory studies.

Experiments using enclosures to study the effects of added nutrients or heavy metals on aquatic organisms have been carried out in various parts of the world. Lund (1972) was probably the first to exploit the use of enclosures ('Lund tubes') to study phytoplankton populations in Blelham Tarn in the English Lakes District (Lack and Lund 1974). In Switzerland, the MELIMEX experiments used enclosures to determine the effects of adding heavy metals over a continuous period of time (Gachter 1979). In Canada, enclosures have been used in lake acidification studies (Schindler et al. 1980) as well as in studies on the chemical and biological processes which affect oxidation and reduction of arsenic (Brunskill et al. 1980), the uptake of radiocarbon by algae (Bower and McCorkle 1980) and the influence of cadmium on zooplankton and periphyton (Marshall and Mellinger 1980). Kerrison et al. (1980) used small enclosures to study the effect of cadmium on zooplankton and phytoplankton populations in an Italian lake.

A number of experiments using enclosures have been run in the marine environment. One of the most comprehensive was the CEPEX experiments conducted in Saanich Inlet, British Columbia (CEPEX 1977; Reeve et al. 1976). Hunt and Smith (1980) have reported enclosure experiments, conducted in Narragansett Bay (MERL system), in which the long-term response and variability of iron, copper, cadmium and lead were studied. In Japan, Maeda and Tanaka (1977) studied the behaviour of zinc and copper in coastal seawater isolated by plastic enclosures.

During November 1980, we placed two plastic enclosures in Island Billabong. A mixture of heavy metals was added to one and the other, which received no treatment, was used as a control. The enclosures and the billabong were monitored over a six-week period, and the changes in limnology and phytoplankton are discussed in this report. The changes that occurred in the heavy metal concentrations are discussed in Hart et al. (1985b).

2 METHODS

2.1 Enclosures

Two 5 m diameter, cylindrical enclosures were constructed from 1 mm nylon-reinforced polyethylene film. Each enclosure had an inflatable ring sealed around the top of the polyethylene curtain for flotation, and had pockets around the bottom in which sand was placed for anchorage.

To install an enclosure in the billabong, the float was inflated, sand was added to the bottom pockets and the whole was floated out to the required position. At this stage the curtain was gathered and tied to the float. After the required position had been reached, the curtain was released and the sand pockets were pushed into the sediments to ensure an effective seal. Installation was carried out by divers.

2.2 Addition of Heavy Metals

One enclosure was used to study the fate and effects of the added metals and the other (to which nothing had been added) was used as a control. The following amounts of metals (in mg) were added to the 'metal-loaded' enclosure: Mn 10 650, Cd 49.1, Cu 599, Pb 88.4 and Zn 1 910; this gave initial concentrations approximately ten times the Wet Season concentrations reported by Hart et al. (1982).

2.3 Monitoring Program

Water samples were taken from the billabong each week and analysed for turbidity, suspended solids, conductivity, sodium, potassium, calcium, magnesium, chloride, sulphate, alkalinity and dissolved organic carbon (DOC). Results are given in Table 1.

More frequent *in situ* observations of temperature, dissolved oxygen and pH were undertaken in each enclosure and in the billabong. Measurements were made in the morning and evening on eleven occasions between 5 November 1980 and 18 December 1980. The metals were added on 6 November (Day 1). Measurements were made at 0.1 m, 0.3 m, 0.5 m and then at 0.25 m intervals to the bottom (approx. 2.0 m). At each depth a water sample was taken for fluorescence measurement. Results are given in Tables 2 to 4.

On the morning of each of the eleven days of observation a sample of water was taken for identification and quantification of algae.

Water samples for heavy metal analysis were taken on the morning of each sampling occasion. Samples were taken from just below the surface in acid-washed 1 L polyethylene bottles. They were processed in the laboratory within two hours of sampling. The changes in metal concentrations and speciation are discussed in Hart et al. (1985b).

2.4 Analytical Methods

Analysis for turbidity, suspended solids, conductivity, alkalinity and sodium, potassium, calcium, magnesium, chloride and sulphate were carried out using the methods recommended by APHA (1975).

2.5 Fluorescence Measurements

The fluorescence in well-shaken water samples was measured on the day of collection. A Turner fluorometer (Model 10-005) was used.

Three aspects of the fluorescence measurements were investigated:

(i) Influence of temperature on the reading: when taken in the field, samples were at temperatures generally in excess of 30°C, while in the laboratory they were at temperatures around 20°C. Comparison of the fluorescence readings showed that the readings at 20°C were some 12% lower than the readings at 30°C. This differs from the finding of Yentsch and Menzel (1963), who reported that the fluorescence of acetone extracts held at 1° to 2°C was some 10% higher than that of those held at room temperature. The present results could be explained if the fluorescence signal decreased rapidly in the first few hours after sampling, since the samples at 30°C were measured within two hours of collection while those measured at 20°C stood for some time before coming to equilibrium at that temperature.

(ii) Change in the reading over time: the fluorescence of samples was measured on the day of sampling and again five days later (samples were kept at 4°C, in the dark, between measurements). No consistent pattern was found. Some samples showed an increase in fluorescence, others a decrease and some no change.

(iii) Relationship between fluorescence signal and chlorophyll *a* concentration: the concentration of chlorophyll *a* was determined (APHA 1975), in triplicate, on water samples from the billabong and from both enclosures. Regression analysis of the fluorescence reading (Flu) against chlorophyll *a* concentration (Chl) gave the following relationship:

$$Flu = 0.05\ Chl\ (\mu g/L) + 0.9 \qquad (r = 0.882,\ n = 9)$$

More detailed work had shown that the relationship between the fluorescence reading and chlorophyll *a* concentration varies with both time and the billabong investigated (Kessell and Tyler 1982). For this reason the fluorescence reading was not used to determine chlorophyll *a* concentration. It was only used to give an estimate of the relative biomass.

2.6 Collection, Identification and Counting of Algae

On the morning of each day of observation a 200 mL sample of surface water was collected for the identification and counting of the algae present. The samples were preserved with formalin.

The counting method was based on that of Steel (1969). Millipore filter membranes (0.45 µm) were placed in a Swinnex holder and a small volume of the well-shaken sample was passed through using a syringe. The membranes were then placed on microscope slides to dry at room temperature. Microscope immersion oil was dropped on the filters to render them clear and a cover slip was placed over the top.

A microscope with phase-contrast optics was used for the counting and identification of algae. Routinely, a magnification of x160 was used, but higher magnification was used when necessary. Counting was continued until either 500 of the most common species had been enumerated, or 25% of the total field area had been counted.

There was difficulty in counting *Microcystis aeruginosa* Kuetz. because this species occurs in irregular clumps.

Species identification was assisted by reference to Ling and Tyler (1985), whose nomenclature was used.

3 RESULTS AND DISCUSSION

3.1 Changes in the Chemical Limnology of Island Billabong Water

Little change was noted in the chemical quality of the billabong water during the six week period of the experiment. This was particularly true for the conductivity and the concentrations of the major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (Cl^-, SO_4^{2-}). The results are given in Table 1 together with data obtained earlier in the Dry Season. Between the Early- and Late-dry seasons there was around a 1.5-fold increase in the conductivity and in the concentrations of the major cations and of chloride. These increases would be due to concentration through water evaporation, since over the four month period in question, the water level fell by 1.6 m, corresponding to a volume decrease of around 1.8-fold (85×10^4 to 46×10^4 m^3).

The three-fold increase in sulphate concentration between the Early- and Late-dry seasons was somewhat unexpected, since it was almost double that which occurred with the other ions. This suggests that, in addition to evaporation, there is probably an input of groundwater with a high sulphate concentration to this billabong. Groundwater taken from the extensive sandy aquifers beneath Magela Creek is quite low in sulphate (approx. 0.1-0.2 mg/L) and it seems unlikely that this is the source. The topography of the land surrounding Island Billabong suggests that the most likely source of shallow groundwater high in sulphate would be from the east (Walker and Tyler 1982).

The concentration of suspended solids and the turbidity increased over the duration of the experiment with maximum values recorded in early December; the time when a diatom bloom (*E. zasuminensis* (Cabesjz) Körner) was observed. This bloom is discussed fully in Section 3.3.1.

3.2 Simulation of the Billabong by the Enclosures

If plastic enclosures are to be used to simulate the response of the billabong to various perturbations, they must be shown to behave as the billabong does. Here the behaviour of waters inside and outside the enclosure was compared using temperature, concentration of dissolved oxygen, pH and fluorescence data.

3.2.1 Temperature

Water in the billabong and the control enclosure showed similar temperature profiles (Tables 2 and 3; Figs 1 and 2). The profiles were similar to those reported for this billabong by Walker et al. 1981.

In the morning, the water temperature in the billabong and in both enclosures was found to be essentially constant throughout the 2 m deep

water column; values ranged between 30° and 32°C. During the day, however, the surface layer heated up. The temperature difference between the surface and bottom water, when measured in the late afternoon, varied according to the type of day. On cloudy days, the temperature difference was small (0.2-0.3°C), while on hot sunny days it was as high as 3°C (Figs 1 and 2). Obvious temperature stratification was observed on only one occasion (11 November 1980).

These data confirm that there were no marked differences in the temperature patterns recorded in the billabong and in the 5 m diameter enclosures. This was also the finding of a previous study in which 3 m diameter enclosures were placed in Gulungul Billabong (Hart et al. 1985a).

3.2.2 Dissolved oxygen

The dissolved oxygen (DO) profiles (Fig. 1) in Island Billabong were variable and no doubt reflect the conditions of illumination and the behaviour of the phytoplankton on each sampling day.

During most days there was an expected increase in dissolved oxygen concentration in the water column; this can be seen by comparing the morning and late afternoon DO profiles shown in Figure 1. By late afternoon, the DO concentration in the surface 1 m of the water column was generally between 7 mg/L and 8.5 mg/L and in the bottom 1 m of the water column was between 5 mg/L and 8 mg/L. The difference in the DO concentrations in the top and bottom water was generally less than 2 mg/L. The high DO concentrations recorded in the afternoons were positively correlated with high algal photosynthesis and with high fluorescence readings (see Sections 3.2.4 and 3.3.1). During the evening, the DO concentration in the bottom water consistently dropped to around 2 mg/L to 3 mg/L, presumably as a result of the high bacterial and algal respiration rates which occur in these billabong waters.

Dissolved oxygen concentrations in the control enclosure showed a very similar pattern to those in the billabong (Fig. 2). This is best illustrated by the data collected on 11 November 1980 when, by the late afternoon, the concentrations of DO were stratified in both the billabong and the control enclosure, with significantly reduced DO concentrations (around 2 mg/L) in the bottom waters.

Despite the many similarities in the dissolved oxygen patterns recorded inside and outside the enclosures, there were also major differences. For example, on 18 December 1980, the DO concentration in the billabong was found to be very low throughout the water column. This was not so in the control enclosure. On this occasion, the low concentrations of DO in the billabong probably resulted from the decomposition of dead algal matter, the result of a bloom which occurred about one week earlier (see Sections 3.2.4 and 3.3.1). This bloom did not occur in the control enclosure.

3.2.3 pH

Trends in pH are difficult to interpret, since, in addition to long-term changes, pH also varies diurnally as a result of biological production and

respiration. Diurnal changes were particularly noticeable in Island Billabong because the water has very little buffering capacity. For example, the alkalinity, a measure of the buffering capacity of a water, ranged between 1.0 and 3.4 mg/L measured as $CaCO_3$ (mean 2.8; SD 0.9; n = 6) during the study period.

During the day, water in the enclosures and the billabong showed an increase in pH (Tables 2-4); the pH of the surface water was slightly greater than that of the bottom water. This pH increase was probably caused by the utilisation of dissolved CO_2 by phytoplankton throughout the day, causing the $CO_2/HCO_3^-/CO_3^{2-}$ equilibrium to shift (Stumm and Morgan, 1981).

Over the period of the study, the pH of the surface waters of Island Billabong, when measured in the late afternoon, decreased from about 6 to around 5; the lowest values were recorded in December (Table 2). A decrease in pH was not observed in the control enclosure, where the pH remained consistently above 6 (pH 6.2 to 6.9; Table 3).

Two possible reasons may be advanced to explain the observed pH decrease in Island Billabong:

(i) When the algal bloom (which occurred around 4 to 11 December 1980) 'crashed', the bacterial decomposition of the organic matter would have produced considerable quantities of dissolved CO_2. Because of the low buffering capacity of these waters, this would have resulted in a lowering of pH.

(ii) Rain fell in the catchment at the end of November (29th: 29.8 mm; 30th: 9.6 mm) and the early part of December (3rd: 1 mm; 4th: 73.6 mm; 5th: 8.6 mm; 6th: 18.8 mm; 7th: 2.2 mm; 8th: 3.0 mm), and although Magela Creek did not flow into Island Billabong at the time, the billabong could have received some local runoff. This runoff would have contained organic matter, possibly derived in part from buffalo and bird excreta, and bacterial decomposition of this organic matter would have caused a pH reduction. No information, however, was obtained on organic matter in drainage water.

It is also possible that this 'first flush' was itself slightly acidic. Acidic waters are known to enter some billabongs further north on the flood plain (e.g. Mine Valley). Evidence is available suggesting that high sulphate, and hence possibly low pH, groundwaters enter Island Billabong during the Dry Season (Walker and Tyler 1982).

3.2.4 Fluorescence measurements

On each sampling occasion, fluorescence was measured at a number of depths and the results for waters in the billabong and the two enclosures are shown in Figure 4. Fluorescence measurements are often used to give a measure of the algal biomass in much the same way as chlorophyll a concentrations are (Kessell and Tyler 1982).

A number of trends are apparent from these data. The vertical profile of fluorescence was generally constant in the mornings, and, on cloudy days, little change was noted in the profile during the day. On sunny days, however, a marked change in the profile occurred during the day, with

higher values recorded at depth. This suggests that the position of the algae in the water column depends on light intensity; on sunny days, at least part of the algal population may migrate down the water column to avoid the most intense sunlight, while on cloudy days and during the night, they redistribute themselves evenly throughout the water column.

The very high fluorescence readings in Island Billabong water around Day 29 of the study (4 December 1980) coincided with an algal bloom; high numbers of algae (Fig. 6) and a high concentration of chlorophyll *a* (129.6 µg/L) were recorded on Day 33. A more typical value for the concentration of chlorophyll *a* is 30 µg/L, recorded in the non-bloom period (29 November 1980). On the basis of the rather general correlation found between high fluorescence values, high numbers of algae and elevated concentrations of chlorophyll *a*, it was expected that comparison of the fluorescence profiles in the billabong and the control enclosure should provide information on the behaviour of algae in the two systems.

Over the first five days, the profiles in the control enclosure were very similar to those in the billabong. After this time, significant differences were observed; by Day 15 (20 November), the fluorescence values in the control enclosure were less than half those in the billabong (Figs 4 and 5). Thus, on the basis of fluorescence measurements, it would appear that the control enclosure and the billabong contained quite different densities of algal biomass. However, as shown in Section 3.3, this was not confirmed by the data on algal numbers.

3.2.5 Summary

On the basis of temperature and dissolved oxygen measurements, water in the control enclosure appears to behave like the water in the billabong. Qualitatively, the diurnal changes in pH were similar both inside and outside the control enclosure, but major differences were observed in the mean pH values recorded in the two systems. Water in the billabong decreased in pH from around 6 to 5, while the water in the enclosure was always above pH 6 (6.2 to 6.9). Most of this difference can be accounted for by the extra nutrient and organic matter added to the billabong, but not to the enclosures, as a result of rainfall that occurred near the end of the study period.

On the basis of *in situ* fluorescence measurements, algal growth and density in the control enclosure appeared to be quite different from that in the billabong. This finding was not confirmed, however, by the numbers of algae recorded in the two systems, at least over the first fifteen days of the study. Because fluorescence readings are very dependent upon the algal species present, we believe that they are an inappropriate parameter to use in comparing the behaviour of waters in the billabong and the enclosures.

3.3 Variations in the Phytoplankton Population

Figures 6 and 7 give the total algal numbers (cell/L) and taxonomic composition of the phytoplankton in the billabong and the two enclosures. The raw data on algal cell numbers are recorded in the Appendix (Tables A1-A3).

3.3.1 Billabong and control enclosure

Two problems with the use of enclosures are that, initially, the biomass tends to decrease and the species composition changes in the enclosed water (Thomas et al. 1977; Gachter 1979). Reasons advanced to explain these changes include the reduced nutrient loading of the water in the enclosure (Gachter 1979), decreased turbulent mixing in the enclosure resulting in a somewhat shallower epilimnion compared with that in the open lake, and probably an increase in sedimentation rates (Imboden et al. 1979).

Figure 6 shows that, for the first six to eight days, the cell numbers in the billabong and control enclosure remained constant; but cell numbers in the enclosure were some 20% lower (mean number of cells/L, Day 1 to Day 8: billabong $5.6 \pm 0.5 \times 10^6$; enclosure $4.5 \pm 0.5 \times 10^6$). The lower cell numbers in the control enclosure possibly resulted from the slightly lower degree of turbulence, which would make it more difficult for certain algae, particularly the diatoms, to stay in the water column. Between days 8 and 15 there was a very rapid decrease in phytoplankton numbers both in the billabong and the control enclosure. The reason for this is not known, but the weather was unusually calm during this time.

Initially, both the billabong and the control enclosure were dominated by the diatom *E. zasuminensis* (Fig. 7; Appendix Tables 1 and 2), and during the first fifteen days of the study, the species composition was similar in both. Diatoms were dominant, but the degree of dominance decreased with time from an initial value in excess of 98% of the phytoplankton numbers, to approximately 87% in the billabong water and 74% in the control enclosure. In the control, the main changes in species composition were a marked increase in the numbers of *Peridinium* sp. 3 at Day 15 and the replacement of this species by *Anabaena flos-aquae* (Lyngb.) Breb. the following week; this latter species disappeared a week later. These rapid changes in the species composition of phytoplankton appear to be a feature of billabong waters in the Magela Creek region (Kessell and Tyler 1982) and must be taken into consideration when interpreting results.

As previously noted, the fluorescence readings in the control enclosure were considerably lower than the readings in the billabong (Fig. 5), but the total cell numbers in the billabong and the control enclosure were similar (Fig. 6). A possible reason may be that the different species composition in the two waters resulted in different fluorescence signals.

3.3.2 Metal-loaded enclosure

There was a very rapid decrease in the numbers of algae in the metal-loaded enclosure, particularly in the first three days of the experiment (Fig. 6). Interestingly, after Day 15 the cell numbers in the metal-loaded enclosure were considerably higher than in the control and, in fact, were almost the same as in the billabong. This may reflect a lower level of grazing by zooplankton, which had been affected by the added heavy metals (Gachter and Mares 1979), but no data on zooplankton numbers are available. This result suggests that, after the added heavy metals have been removed from the water column, the lasting effect on the phytoplankton community is small.

In addition to a marked reduction in cell numbers, there was also a significant change in the species composition in the metal-loaded enclosure (Fig. 7c). Initially, this enclosure was numerically dominated by diatoms (approx. 96% of the phytoplankton) but by Day 15 the proportion of diatoms had fallen to 13%. Over the same period the euglenoids increased from less than 1% to 70%. These changes were essentially due to a massive reduction in the numbers of *E. zasuminensis*, from 4.74 x 10^6 cell/L to 0.03 x 10^6 cells/L, and a modest increase in the numbers of *Trachelomonas oblonga* Lemm., from 0.05 x 10^6 to 0.31 x 10^6 cell/L (Appendix Table A3).

Over the first fifteen days of the study the fluorescence readings in the metal-loaded enclosure were very similar to those in the billabong (Fig. 5). In view of the obvious reduction in the numbers of algae in the metal-loaded enclosure, fluorescence measurements are of little value in monitoring the changes in algal populations.

4 DISCUSSION

It is well-documented that heavy metals, such as copper, cadmium, lead and zinc, are able, at trace concentrations, to inhibit growth and photosynthesis of phytoplankton (Barlett and Raber 1974; Dayton and Lewin 1975; Sunda and Guillard 1976; Davies 1978; Wong et al. 1978; Anderson and Morel 1978; Gachter and Mares 1979; Allen et al. 1980). Additionally, there is much evidence that the toxicity of these metals depends not only on the total concentration of the metal but also on the chemical speciation (Sunda and Guillard 1976; Allen et al. 1980; Petersen 1982, Hart 1982), in particular the concentrations of the toxic species. Thus, toxicity will depend upon pH, alkalinity, the concentration and nature of inorganic and organic ligands, and the concentration and nature of colloids and suspended particulates capable of sorbing free and complexed metals. In addition to metal speciation, the toxicity of a metal at any given concentration also depends upon the phytoplankton density (Gachter 1979) and species composition (Gibson 1972; Wong et al. 1978).

When concentrations of heavy metals in lakes and billabongs are increased above a critical level, a reduction in the growth rate of the most sensitive species would be expected. There would be shifts in the phytoplankton community structure, resulting in the dominance of the most resistant species.

Experimental evidence supporting this hypothesis has been provided by Thomas and Seibert (1977) who found that in a marine ecosystem, a single dose of copper (5 µg/L or 10 µg/L) resulted in a change in the phytoplankton species composition. Wuhrmann and Eichenberger (1975) also observed distinct shifts in the periphyton community structure in artificial streams when metal concentrations were increased.

One of the most informative experiments on the long term effects of heavy metals was the Swiss MELIMEX experiment (Gachter 1979). Several 12 m diameter enclosures were placed in Lake Baldegg and were continuously dosed, for over one year, with Hg, Cu, Cd, Pb, and Zn at levels equal to the legal limit in Switzerland. In the experiments reported here a single addition of the metals increased the metal concentrations to approximately ten times their natural levels, and although this difference in experimental design is significant, the results from the MELIMEX experiments are of considerable interest.

Gachter and Mares (1979) found that the original phytoplankton population was reduced in numbers, photosynthetic activity was depressed and there were major changes in phytoplankton community structure, populations less susceptible to heavy metals becoming more dominant. By the end of the experiment, however, the chlorophyll levels in the metal-loaded enclosures were actually higher than in the control due to the reduced grazing by zooplankton in the metal-loaded enclosure.

In view of the rapid changes in phytoplankton species abundance that have been observed in Magela Creek billabongs, it might be expected that the behaviour of phytoplankton in the enclosures and in the billabong would differ. In the early part of the experiment (to Day 15), the cell numbers in the control enclosure were less than in the billabong, although an overall reduction in numbers was shown by both. The species composition was also similar in both, particularly in the first eight days when they were dominated by the diatom *E. zasuminensis*. This diatom continued to dominate the flora in both to Day 15. However, at this time the control enclosure contained higher numbers of the dinoflagellate *Peridinium* sp. 3 (Fig. 7). There were also some differences in the species of Chlorophyceae (blue-green algae) present in each (Appendix Tables A1 and A2).

Between Day 15 and the end of the study differences were observed, in the numbers of cells (Fig. 6) and in the species composition (Fig. 7), between the billabong and the control enclosure. Cell numbers in the control stayed approximately constant over this period but there were changes in the species composition, the diatom *E. zasuminensis* becoming increasingly dominant. An algal bloom occurred in the billabong around Day 29, possibly as a result of an influx of nutrients brought in by rain which fell around this time. This bloom consisted essentially of two species; *E. zasuminensis* and the euglenoid *Trachelomonas oblonga*. The species composition changed little during the bloom. After the bloom there was a massive drop in the diatom numbers (and a lesser one in *Trachelomonas*). On 11 December (Day 36), there was an increase in the numbers of *Scenedesmus quadricaudus* (Turp.) Breb. but these did not last.

The added heavy metals obviously had a very significant effect on both the numbers of phytoplankton (Fig. 6) and species composition (Fig. 7c) in the metal-loaded enclosure. This was, of course, to be expected but it was not expected that the enclosure would recover quite so rapidly. The data in Figures 6 and 7 show that the major changes in both phytoplankton numbers and species composition occurred by Day 15. Over this period, the numbers were reduced by over one order of magnitude, (4.9×10^6 cells/L to 0.4×10^6 cells/L), owing almost entirely to a decrease in the numbers of *E. zasuninensis*, from 4.7×10^6 cells/L on Day 1 to 3×10^4 cells/L on Day 15. During this time there was a small increase in the numbers of *Trachelomonas oblonga*, which by Day 15 dominated the phytoplankton community.

From Day 15 until the end of the study, the phytoplankton numbers increased to levels in excess of those in the control (Fig. 6). The phytoplankton species composition also changed, with diatoms (predominantly *E. zasuminensis*) increasing in abundance (from 13% of the total on Day 15 to 85% on Day 36), and *Trachelomonas oblonga* reducing in abundance.

In summary, the added metals had most effect on the diatom *E. zasuminensis*, causing the numbers to be reduced by over two orders of magnitude. After concentrations of the metals had been reduced to around those in the

control enclosure and the billabong (about Day 15), the metal-loaded enclosure recovered, so that after Day 36 of the study both the numbers of phytoplankton and the species composition were similar to those in the control enclosure.

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TABLE 1 WATER QUALITY CHANGES IN ISLAND BILLABONG.

Parameter	Units	29.vii.80[a]	4.xi.80	11.xi.80	8.xi.80	29.xi.80	2.xii.80	16.xii.80
Time	h	0915	1050	1315	1040	1045	0950	1005
Gauge height	m	1.830	0.615	0.545	0.427	B[b]	B[b]	B[b]
Temperature	°C	25.0	33.2	35.1	32.0	32.5	31.8	31.5
DO	mg/L	3.85	6.75	6.75	7.60	5.90	7.35	4.75
pH		6.05	6.03	5.82	6.43	5.55	5.51	5.10
Conductivity	µS/cm	28	49	46	44	46	53	49
Alkalinity	mg/L $CaCO_3$	-	2.9	2.8	1.0	3.4	3.3	3.10
Sus. solids	mg/L	3.6	6.8	5.0	12.6	10.2	19.0	14.7
Turbidity	NTU	4.9	3.7	4.6	4.0	6.5	8.2	8.9
Na^+	mg/L	2.8[c]	3.6	3.7	3.9	4.0	4.3	-
K^+	mg/L	0.60[c]	0.75	0.82	0.89	0.93	1.2	-
Ca^{2+}	mg/L	0.75[c]	1.0	1.1	1.1	1.1	1.1	-
Mg^{2+}	mg/L	1.2[c]	1.7	1.7	1.6	1.8	1.8	-
Cl^-	mg/L	4.8	9.8	6.4	6.8	7.4	7.8	8.1
SO_4^{2-}	mg/L	2.4	6.3	5.6	7.5	5.6	7.4	13
DOC	mg/L	5.6	11	23	6.8	5.6	-	12

[a]very early in the Dry Season; [b]B = below gauge; [c]data provided by Northern Territory Dept. Transport and Works (Water Division), for 12.viii.80.

TABLE 2 TEMPERATURE, DO, PH AND FLUORESCENCE VARIATIONS IN ISLAND BILLABONG.

Date	4. X1. 80				5. X1. 80				6. X1. 80				7. X1. 80				9. X1. 80				11. X1. 80				13. X1. 80				20. X1. 80				27. X1. 80				4. X11. 80				11. X11. 80				18. X11. 80			
Time (hr)					0950				0945				0837				0925				0825				0945				0930				0915				0925				0915				0915			
Depth (m)	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor
0.1					31.2	6.15	5.68	1.90	31.9	6.15	5.72	1.83	31.3	5.80	5.49	2.29	31.8	5.00		2.43	31.3	4.45	5.58	2.33	31.6	6.08	5.75	2.00	30.4	5.58	5.57	1.84	31.6	6.00	5.57	1.84	30.3	7.15	5.03	9.16	31.5	6.98	5.29	1.68	31.0	3.45	5.23	0.85
0.3					31.2	5.75	5.78	1.70	31.6	6.25	5.96	2.49	31.4	5.50	5.58	2.16	31.8	4.90		2.41	31.2	4.10		2.35	31.6	6.01	5.82	2.06	30.8	5.83	5.57	2.33	31.8	5.70	5.58	4.88	30.4	6.95	4.96	11.2	31.6	6.95	5.31	2.03	30.9	3.15	5.35	0.91
0.5					31.1	5.80	5.80	2.19	31.4	6.25	5.97	2.75	31.4	5.50	5.65	2.22	31.8	4.90		2.43	31.0	4.04	5.66	2.42	31.6	5.87	5.82	2.89	30.7	5.52	5.63	2.73	31.8	5.55	5.54	5.21	30.4	6.75	4.99	11.0	31.6	7.00	5.37	2.21	31.0	2.90	5.34	0.92
0.75					31.0	5.70			31.4	6.25			31.4	5.36			31.7	4.80			31.0	3.97			31.3	5.21			30.8	5.02			31.8	5.35			30.5	6.86			31.6	6.86			30.9	2.58		
1.00					30.9	5.45	5.78	2.17	31.2	5.90	5.83	2.70	31.4	5.12	5.58	2.27	31.6	4.56		2.61	31.1	3.73	5.59	2.51	31.1	4.22	5.75	2.17	30.5	4.45	5.62	3.12	31.6	4.45	5.49	4.93	30.6	6.45	5.03	10.7	31.1	5.75	5.34	2.23	30.8	2.25	5.30	0.86
1.25					30.9	5.45			31.1	5.80			31.3	5.02			31.5	4.20			31.1	3.40			31.1	3.33			30.4	3.95			31.6	4.35			30.6	6.25			31.0	5.25			30.7	2.05		
1.50					30.8	5.40	5.78	1.90	31.0	5.25	5.72	2.52	31.3	4.96	5.80	2.28	31.4	3.69		2.66	31.1	3.37	5.58	2.64	31.0	2.58	5.87	2.83	30.2	3.61	5.71	2.96	31.6	4.30	5.45	4.74	30.5	5.75	5.03	7.81	30.9	4.85	5.24	2.13	30.5	1.85	5.30	0.82
1.75					30.7	4.75			30.9	5.13			31.3	4.80			31.4	3.50			31.0	3.04			31.0	2.30			30.0	3.22			31.5	4.00			30.4	5.15			30.9	4.40			30.4	1.75		
2.00					30.6	4.25	5.70	2.06	30.9	5.10	5.66	2.63	31.2	4.78	5.55	2.16	31.3	3.50		2.61	31.0	2.83	5.61	2.53	31.0	2.02	5.68	2.58	30.1	3.20	5.51	2.82	31.6	3.95	5.45	5.15	30.3	5.10	5.03	7.44	30.8	4.30	5.25	2.10	30.4	1.80	5.39	0.92
Time (hr)	1625				1840				1725				1730				1640				1707				1745				1620				1600				1611				1604							
Depth (m)	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor
0.1	35.1	6.80	6.15		34.2	8.83	6.00	1.71	34.8	7.20	5.74	1.27	32.7	7.30		1.84	32.9	7.30	6.36	1.57	34.9	7.20	6.15	1.80	31.8	7.18	5.93	2.53	33.1	7.25	5.87	2.36	33.2	7.70	5.90	5.28	33.0	8.55	5.16	11.6	33.0	8.55	4.58	1.52	31.5	4.05	5.05	0.81
0.3	35.1	6.80			33.2	8.65	6.13	1.85	34.9	7.21	6.15	1.45	33.0	7.20		1.80	33.1	7.05	6.41	1.60	34.9	7.03	5.92	1.66	31.8	7.02	6.05	2.52	33.2	7.10	5.24	2.34	32.8	7.45	5.67	4.96	33.1	8.40	5.17	11.3	32.7	8.30	4.58	1.64	31.3	3.85	5.15	0.85
0.5	34.7	6.60	5.97		33.2	8.40	6.18	1.84	34.3	7.48	5.95	1.46	33.1	7.07		1.87	33.1	7.00	6.39	1.59	34.9	6.50	5.85	1.67	31.8	7.00	6.06	2.48	33.1	6.85	5.30	2.34	32.5	7.45	5.78	5.66	33.1	8.40	5.18	10.8	32.4	8.40	4.70	1.78	31.3	3.70	5.14	0.95
0.75	33.7	6.45			32.9	8.60			33.2	7.49			32.7	6.60			33.1	7.00			34.9	5.42			31.8	6.82			33.0	6.50			32.3	7.30			33.0	8.35			32.2	8.20			31.3	3.35		
1.00	32.2	6.85	6.23		32.3	8.60	6.22	2.12	33.0	7.56	6.30	1.53	31.9	6.60		2.33	33.1	7.00	6.36	1.67	32.8	4.25	5.91	2.38	31.8	6.81	5.86	2.53	32.7	6.18	5.52	2.86	32.2	7.10	5.85	7.20	33.0	8.35	5.22	11.4	32.0	7.50	4.75	2.89	31.3	3.10	5.10	0.95
1.25	32.1	6.85			32.0	8.49			32.4	7.50			31.8	6.65			32.4	6.35			32.4	2.80			31.8	6.10			32.5	6.15			32.1	6.55			33.0	8.20			31.8	7.10			31.2	2.80		
1.50	31.7	6.50	6.16		31.8	8.21	6.01	3.20	32.2	7.30	6.02	2.54	31.7	6.30		2.54	32.2	6.20	6.09	2.58	32.2	2.25	5.90	2.68	31.5	5.60	5.83	2.93	32.3	5.73	5.58	2.57	32.0	6.15	5.68	7.90	33.0	8.20	5.31	10.8	31.7	6.90	4.74	2.31	31.2	2.50	5.10	0.98
1.75	31.6	6.05			31.5	8.08			32.0	7.06			31.7	5.90			32.1	5.80			32.0	2.00			31.5	5.23			32.2	5.30			31.9	5.95	32.7	7.85		7.85			31.6	6.75			31.1	2.75		
2.00	31.2	6.20	5.72		31.2	7.82	5.87	3.32	32.0	6.80	5.98	3.15	31.6	5.90		2.90	32.1	5.55	5.06	2.53	32.0	1.60	5.81	2.90	31.5	4.89	5.78	2.93	32.1	5.01	5.22	3.08	31.9	5.95	5.62	7.96	32.4	7.75	5.35	11.2	31.6	6.85	4.66	2.43	31.0	1.80	5.10	1.83
Temp (min)	25.1				25.5				25.9				25.6				25.0				25.0				25.7				25.6				26.3				23.1				24.8				26.4			
Temp (max)	40.3				38.2				39.7				36.8				37.1				39.5				37.8				38.6				38.1				32.3				36.0				34.8			
Cloud cover	1				5				4				5				7				4				5				1				2				8				3				6			
Hours Sunlight	9.9				9.8				8.2				4.8				6.6				8.8				6.8				10.4				7.5				2.7				10.1				3.1			

Temp – °C Dissolved Oxygen – mg/L; Cloud cover – relative scale 1-8

TABLE 3 TEMPERATURE, DO, PH AND FLUORESCENCE VARIATIONS IN THE CONTROL ENCLOSURE.

Date	5. X1. 80				6. X1. 80				7. X1. 80				9. X1. 80				11. X1. 80				13. X1. 80				20. X1. 80				27. X1. 80				4. X11. 80				11. X11. 80				18. X11. 80			
Time (h)	0900				0845				0815				0850				0754				0905				1020				1010				1005				0950				1000			
Depth (m)	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor
0.1	30.8	7.00	6.04	1.93	31.1	7.10	6.28	2.29	31.0	7.08	6.17	2.20	31.9	5.79	6.79	1.85	31.0	5.90	6.30	1.44	31.3	5.54	6.38	0.88	30.9	7.28	6.58	0.89	32.1	7.35	6.58	1.63	30.7	7.35	6.40	2.10	31.5	7.59	6.38	0.57	31.3	7.78	6.34	0.55
0.3	30.9	6.74	6.12	1.97	31.1	7.15	6.17	2.03	31.1	6.84	6.16	2.20	32.1	6.79	6.79	1.91	31.1	5.78	6.35	1.44	31.3	6.00	6.44	1.30	30.8	6.88	6.74	0.72	32.1	7.20	6.78	1.85	30.7	6.95	6.45	2.36	31.5	7.59	6.53	0.66	31.3	7.58	6.29	0.58
0.5	30.9	6.35	6.26	1.76	31.1	6.85	5.66	3.25	31.3	6.73	6.20	2.27	32.0	6.60	6.76	1.96	31.2	5.92	6.40	1.49	31.2	4.72	6.44	1.35	30.7	6.75	6.79	0.96	32.1	7.18	6.66	2.06	30.8	6.85	6.42	2.29	31.3	7.58	6.47	0.61	31.2	7.36	6.32	0.73
0.75	30.9	5.55			31.1	6.75			31.3	6.65			32.0	6.36	6.72		31.2	5.43			31.2	3.08			30.7	6.71			31.9	6.98			30.8	6.88			31.2	7.38			31.1	7.25		
1.00	30.8	5.05	5.02	1.99	31.0	6.58	5.90	2.94	31.3	6.62	6.14	2.38	31.9	6.30	6.60	1.90	31.2	4.95	6.45	1.42	31.2	2.00	6.36	1.18	30.6	6.65	6.88	1.53	31.9	6.75	6.65	2.20	30.8	6.75	6.43	2.24	31.1	7.88	6.55	0.57	30.9	7.98	6.39	0.71
1.25	30.7	4.60			31.0	6.29			31.3	6.56			31.8	6.19	6.30		31.1	4.13			31.1	1.50			30.5	6.32			31.8	6.50			30.8	6.65			31.1	6.70			31.1	6.85		
1.50	30.7	4.00	5.01	2.22	31.0	6.25	5.87	2.79	31.3	6.50	6.18	2.15	31.8	6.00	6.10	1.85	31.0	3.30	6.44	1.51	31.1	1.19	6.36	0.81	30.5	6.86	6.81	1.66	31.8	6.35	6.42	2.50	30.8	6.65	6.38	2.24	31.8	6.65	6.48	0.64	31.1	6.85	6.19	0.68
1.75	30.7	3.50			31.0	6.07			31.3	6.50			31.8	5.90	6.10		31.1	2.90			31.1	0.98			30.4	5.98			31.8	6.25			30.8	6.70			31.0	6.55			31.1	6.69		
2.00	30.7	3.50	5.96	2.12	31.0	6.00	5.96	2.50	31.3	6.42	6.10	2.09	31.8	5.82	6.10	1.90	31.1	2.50	5.42	1.47	31.1	0.85	6.46	1.18	30.3	5.67	6.71	1.03	31.8	6.10	6.18	2.56	30.8	6.55	6.23	2.36	31.0	6.85	6.53	0.72	31.1	6.48	6.17	0.68
Time (h)	1750				1700				1700				1615				1640				1715				1705				1645				1635				1640							
Depth (m)	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor
0.1	33.8	7.61	6.30	2.04	34.9	7.80	7.04	1.42	32.8	7.80		1.67	33.7	7.70	6.94	1.14	34.7	7.15	6.62	1.41	32.8	6.90	6.66	1.13	32.7	7.18	6.37	0.88	33.7	8.00	6.58	1.74	32.3	8.58	6.58	2.67	32.6	8.38	6.84	0.52	32.8	7.98	6.65	0.52
0.3	33.9	7.79	6.23	2.00	35.2	7.58	6.74	1.57	32.8	7.70		1.65	34.0	7.46	6.79	1.16	34.7	6.40	6.58	1.38	32.9	6.85	6.71	1.18	32.9	6.98	6.30	0.98	33.9	7.80	6.79	1.84	32.5	8.35	7.00	2.72	32.8	7.95	6.16	0.56	32.8	7.85	6.35	0.62
0.5	33.5	8.00	6.10	2.15	34.4	7.75	6.55	1.63	33.0	7.45		1.72	34.0	7.50	7.08	1.16	34.7	5.80	6.56	1.41	32.9	6.53	6.84	1.86	32.0	6.60	6.24	0.83	33.3	8.00	6.88	2.05	32.4	8.38	6.92	2.73	32.7	7.85	6.38	0.54	31.7	7.80	6.28	0.67
0.75	33.0	8.03			33.2	7.80			33.1	7.42			33.4	7.62			34.1	4.35			32.8	5.60			32.2	6.95			32.9	7.98			32.0	8.30			32.3	7.95			31.6	7.85		
1.00	32.2	8.10	6.08	3.06	32.7	7.80	6.63	1.88	32.8	7.38		1.85	32.8	7.40	7.14	1.43	33.6	3.42	6.56	1.57	32.2	4.62	6.66	1.22	32.1	7.10	6.21	0.88	32.7	7.85	6.90	2.63	31.7	8.15	6.84	2.87	31.8	7.78	6.25	0.66	31.5	7.88	6.22	0.70
1.25	31.9	7.95			32.0	7.68			32.1	7.56			32.4	7.00			33.2	3.00			32.0	3.68			31.9	6.90			32.6	7.85			31.5	8.00			31.7	7.50			31.5	7.88		
1.50	31.7	7.92	6.05	3.25	32.0	7.70	6.52	2.36	31.8	7.45		2.12	32.3	6.35	6.81	1.82	32.4	2.72	6.40	1.62	31.8	2.98	6.47	1.28	31.8	6.89	6.18	0.96	32.4	7.65	6.84	2.97	31.4	7.95	6.91	2.96	31.5	7.40	6.28	0.68	31.3	7.48	6.15	0.72
1.75	31.2	7.83			31.6	7.55			31.8	7.28			32.1	6.72			32.2	2.50			31.8	2.39			31.7	6.50			32.3	7.45			31.3	7.85			31.4	7.25			31.2	7.28		
2.00	31.2	7.88	6.12	2.30	31.4	7.00	6.37	4.45	31.7	7.05		3.20	32.1	5.67	6.66	1.83	32.0	2.00	5.00	1.60	31.8	2.05	6.32	1.37	31.6	6.35	6.30	1.15	32.2	7.35	6.78	2.79	31.2	8.80	6.95	3.16	31.4	7.35	6.18	0.72	31.2	7.98	6.18	0.75

TABLE 4 TEMPERATURE,DO, PH AND FLUORESCENCE VARIATIONS IN THE METAL-LOADED ENCLOSURE.

Date	5. X1. 80				6. X1. 80				7. X1. 80				9. X1. 80				11. X1. 80				13. X1. 80				20. X1. 80				27. X1. 80				4. X11. 80				11. X11. 80				18. X11. 80			
Time (h)	0930				0915				0900				0955				0900				1015				0945				0940				0945				0930				0935			
Depth (m)	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor
0.1	31.1	7.60	6.17	1.74	31.7	7.08	6.88	1.90	31.2	6.83	6.05	1.35	31.9	5.92		1.94	31.3	6.53	6.60	2.54	31.8	7.90	6.61	2.47	30.9	6.85	5.96	2.00	31.9	6.15	5.66	3.97	30.3	6.35	5.32	4.79	31.6	7.15	5.35	1.89	31.4	4.10	5.27	0.95
0.3	31.1	7.25		2.04	31.7	7.05	6.31	1.83	31.3	6.57	6.11	1.43	32.0	5.86		1.87	31.5	6.40	6.84	2.51	32.0	7.78	6.82	2.78	30.9	6.80	6.00	2.48	32.1	5.98	5.68	3.51	30.6	6.30	5.36	4.58	31.5	6.85	5.32	2.32	31.1	3.45	5.38	1.58
0.5	31.1	6.85	6.34	2.17	31.4	7.06	6.24	2.62	31.3	6.55	6.14	1.38	32.0	5.78		1.86	31.3	6.36	6.73	2.72	31.8	7.69	6.70	2.82	30.9	6.64	6.06	2.55	32.1	5.75	5.68	3.29	30.6	6.10	5.36	4.98	31.3	6.29	5.34	2.46	31.0	2.85	5.28	1.24
0.75	31.0	6.75			31.3	7.10			31.3	6.50			31.9	5.88			30.9	6.35			31.4	7.39			30.6	6.11			32.0	5.85			30.7	6.85			31.2	6.00			30.3	2.80		
1.00	31.0	6.35	6.11	1.83	31.2	6.75	6.21	3.25	31.3	6.47	6.17	1.41	31.9	5.88		1.83	31.1	6.20	6.88	2.67	31.2	6.60	6.58	3.24	30.4	5.95	6.02	2.88	32.0	5.45	5.62	3.87	30.7	6.85	5.36	4.54	31.1	5.35	5.29	2.17	30.8	1.60	5.31	1.15
1.25	30.9	5.30			31.1	6.32			31.3	6.43			31.9	5.50			31.1	6.14			31.1	5.98			30.4	5.35			32.0	5.06			30.7	5.85			31.8	4.80			30.8	1.58		
1.50	30.9	5.45	6.02	2.33	31.1	6.00	6.07	2.30	31.3	6.40	6.17	1.44	31.9	5.28		1.90	31.1	5.95	6.88	3.05	31.1	4.81	6.45	3.00	30.3	5.05	5.91	2.47	31.9	4.75	5.58	3.89	30.7	5.88	5.34	4.70	30.9	4.58	5.29	2.03	30.7	1.35	5.30	0.81
1.75	30.9	5.50			31.1	3.35			31.3	6.37			31.9	5.01			31.1	5.85			31.1	4.20			30.3	4.68			31.7	4.45			30.7	5.75			30.8	4.35			30.7	1.30		
2.00	30.9	5.45		1.86	31.1	3.18	6.05	1.91	31.3	6.32	6.18	1.47	31.8	5.01		1.86	31.1	5.82	6.50	2.53	31.0	3.30	6.37	2.76	30.3	4.53	5.85	2.59	31.9	4.25	5.55	4.93	30.7	5.79	5.28	4.98	30.8	4.38	5.33	1.97	30.6	1.28	5.31	0.91
Time (h)	1815				1755				1745				1705				1737				1815				1650				1620				1704				1625							
Depth (m)	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor	Temp	DO	pH	Fluor
0.1	33.0	8.50	5.82	1.87	33.7	7.70	6.28	0.83	32.6	6.75		1.87	33.0	7.46	6.92	1.52	34.3	7.90	7.22	2.62	32.5	7.83	7.46	2.19	32.2	7.50	5.00	1.94	34.0	7.90	5.85	2.84	32.2	8.55	5.54	7.95	33.9	8.55	4.88	1.49	32.0	4.35	5.19	0.89
0.3	33.0	8.28	5.75	1.85	34.3	7.60	6.47	0.87	32.7	6.78		1.12	33.4	7.35	6.94	1.55	34.4	7.65	7.13	2.61	32.5	7.67	7.21	2.26	32.5	7.70	5.50	1.77	34.0	7.90	5.82	2.78	32.3	8.30	5.45	8.79	33.8	8.10	4.65	1.45	31.6	3.55	5.86	1.49
0.50	32.9	8.32	5.82	1.94	34.2	7.62	6.52	0.87	32.8	6.86		1.13	33.4	7.35	6.93	1.57	34.3	7.25	7.11	2.55	32.5	7.58	7.25	2.27	32.7	7.70	5.45	1.83	33.5	7.85	5.87	2.94	32.4	8.25	5.44	8.88	33.0	8.05	4.88	2.82	31.4	3.85	5.85	1.38
0.75	32.5	8.25			33.3	7.81			32.8	6.83			33.2	7.36			34.0	6.83			32.3	7.52			32.7	7.50			33.2	7.55			32.4	7.55			32.2	7.55			31.1	2.58		
1.00	32.2	8.30	5.92	2.48	33.0	7.78	6.80	2.67	32.6	6.80		1.27	32.6	7.32	6.86	1.97	33.3	5.70	7.05	2.78	32.1	7.50	6.90	2.83	32.5	7.10	5.36	2.43	32.6	7.48	5.98	3.78	32.4	7.80	5.43	8.81	32.8	7.25	4.82	2.63	30.9	2.85	5.89	1.25
1.25	32.0	8.18			32.0	7.85			32.0	6.54			32.3	6.92			32.8	3.30			31.9	7.28			32.0	7.10			32.3	6.90			32.5	8.08			31.9	6.95			30.9	1.88		
1.50	31.8	7.82	5.56	3.46	32.8	7.62	6.52	2.33	31.8	6.33		1.39	32.1	6.25	6.47	2.29	32.2	2.70	6.86	2.82	31.7	6.75	6.49	2.95	31.9	6.90	5.22	3.10	32.3	6.80	5.83	4.80	32.6	8.88	5.42	10.2	31.9	6.55	4.85	2.75	30.9	1.55	5.16	1.88
1.75	31.6	7.33			31.6	7.50			31.7	6.26			32.0	5.80			32.8	2.25			31.4	6.18			31.7	6.25			32.1	6.46			32.5	7.98			31.8	6.68			30.8	1.58	5.23	
2.00	31.5	7.30		6.00	31.5	7.41	6.58	2.76	31.6	6.17		1.57	31.8	5.50	6.37	2.41	31.7	1.85	6.82	3.28	31.3	6.08	6.42	3.09	31.6	6.00	5.14	3.25	32.1	6.10	5.71	6.41	32.5	7.89	5.41	9.36	31.7	6.48	4.81	2.24	30.8	1.38	5.28	1.88

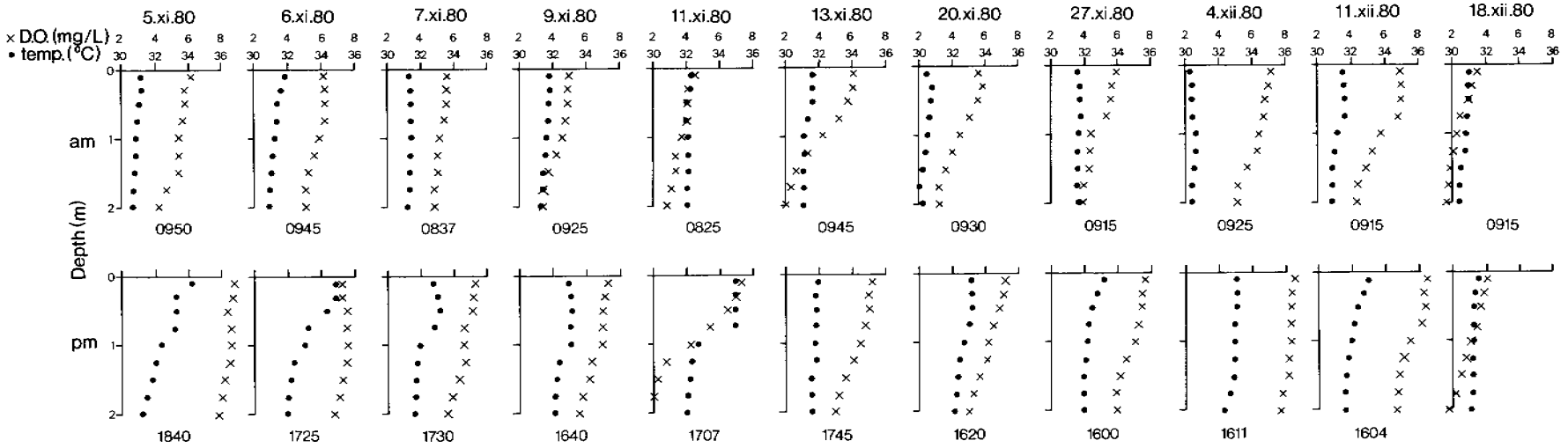

FIGURE 1 TEMPERATURE AND DISSOLVED OXYGEN PROFILES IN ISLAND BILLABONG.

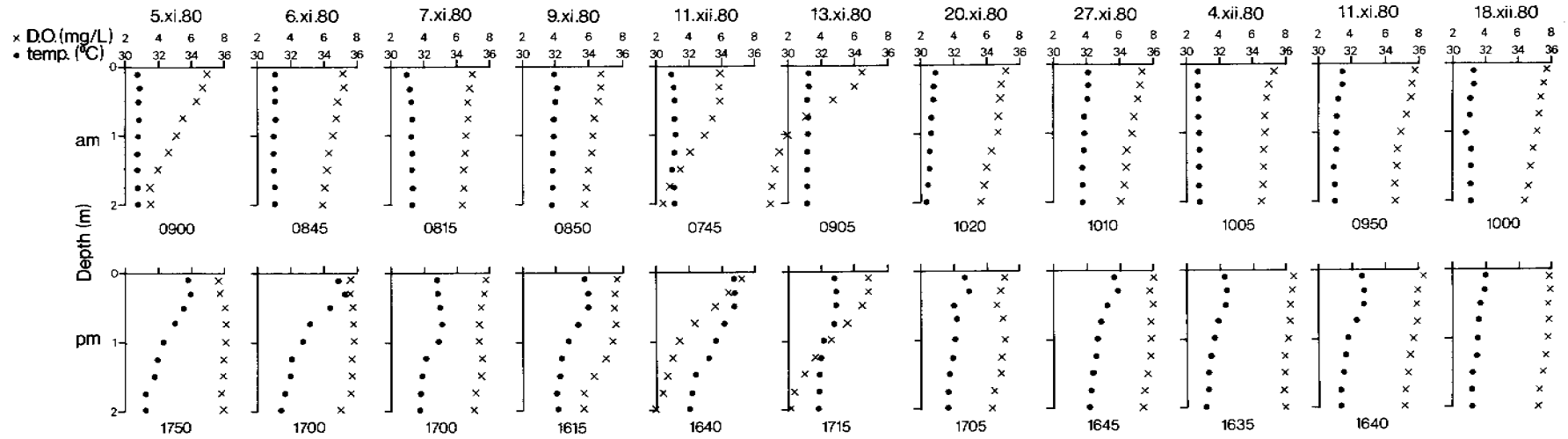

FIGURE 2 TEMPERATURE AND DISSOLVED OXYGEN PROFILES IN THE CONTROL ENCLOSURE.

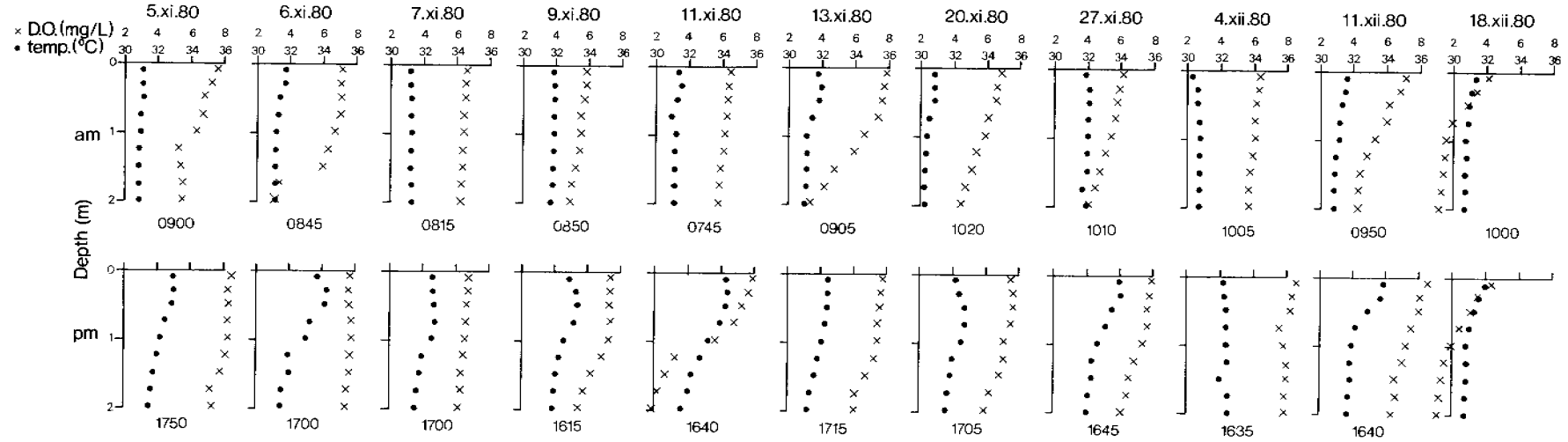

FIGURE 3 TEMPERATURE AND DISSOLVED OXYGEN PROFILES IN THE METAL-LOADED ENCLOSURE.

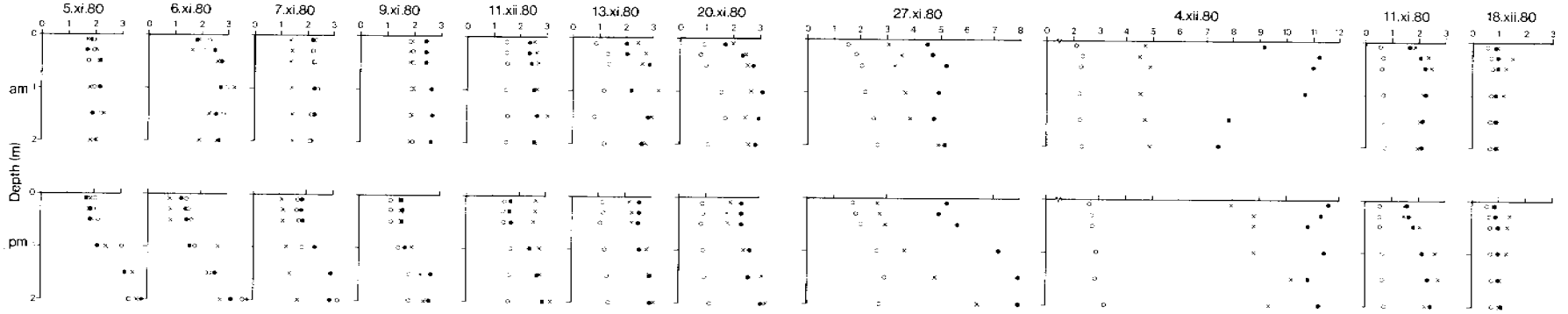

FIGURE 4 FLUORESCENCE PROFILES IN ISLAND BILLABONG AND THE ENCLOSURES.

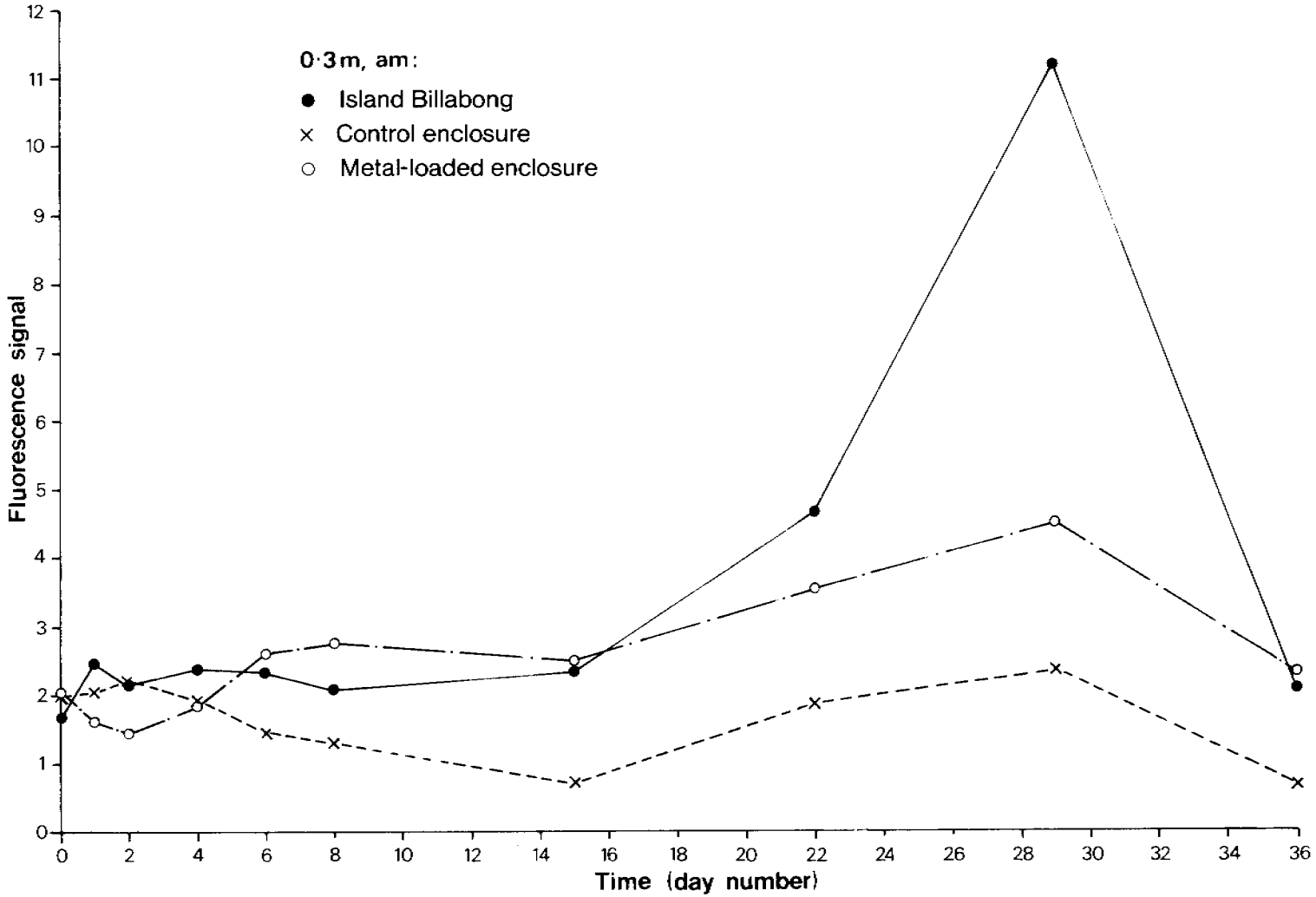

FIGURE 5 FLUORESCENCE MEASURED IN THE MORNING AT 0.3 M DEPTH IN ISLAND BILLABONG AND THE ENCLOSURES.

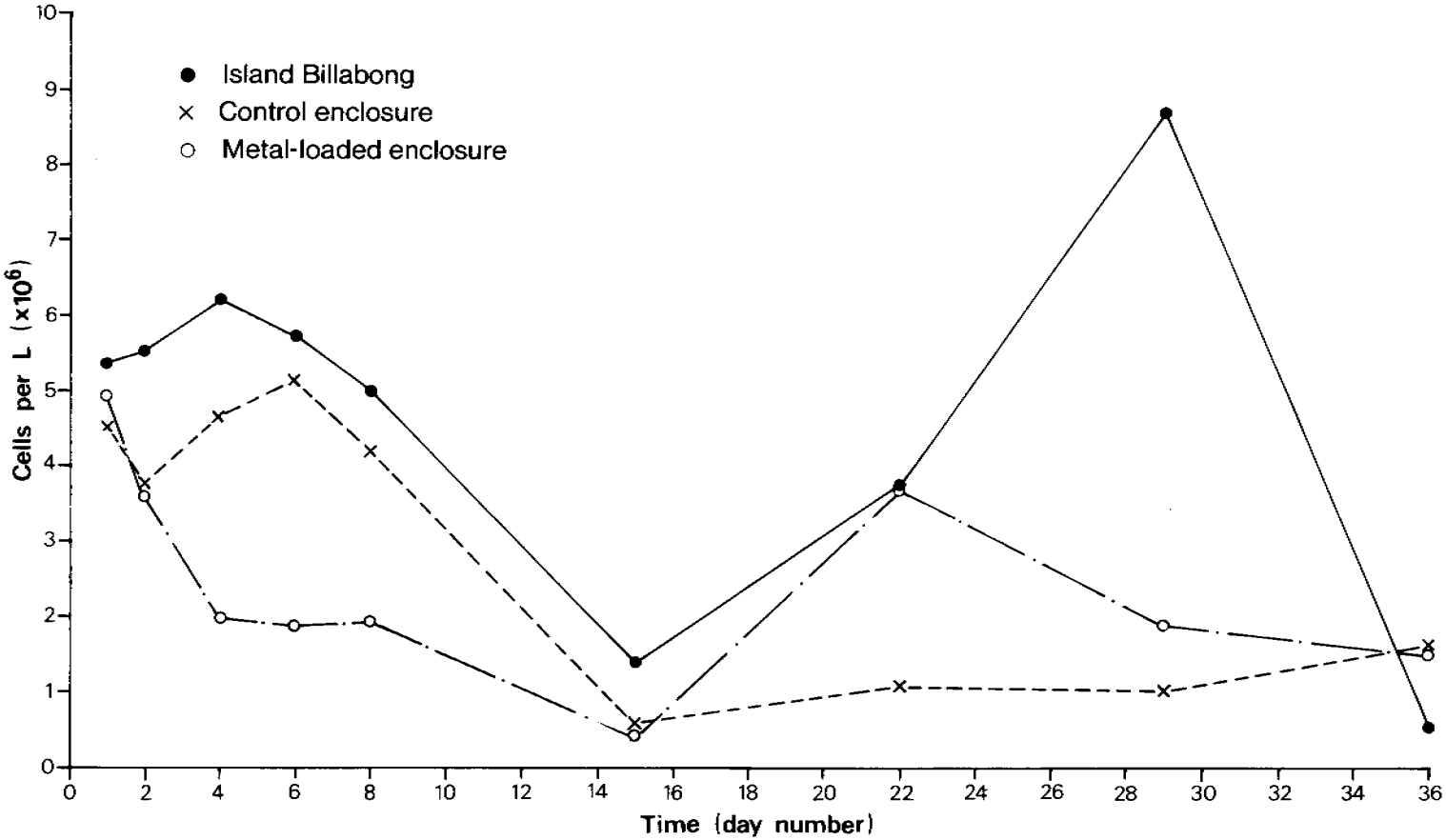

FIGURE 6 ALGAL CELL CONCENTRATIONS IN ISLAND BILLABONG AND THE ENCLOSURES.

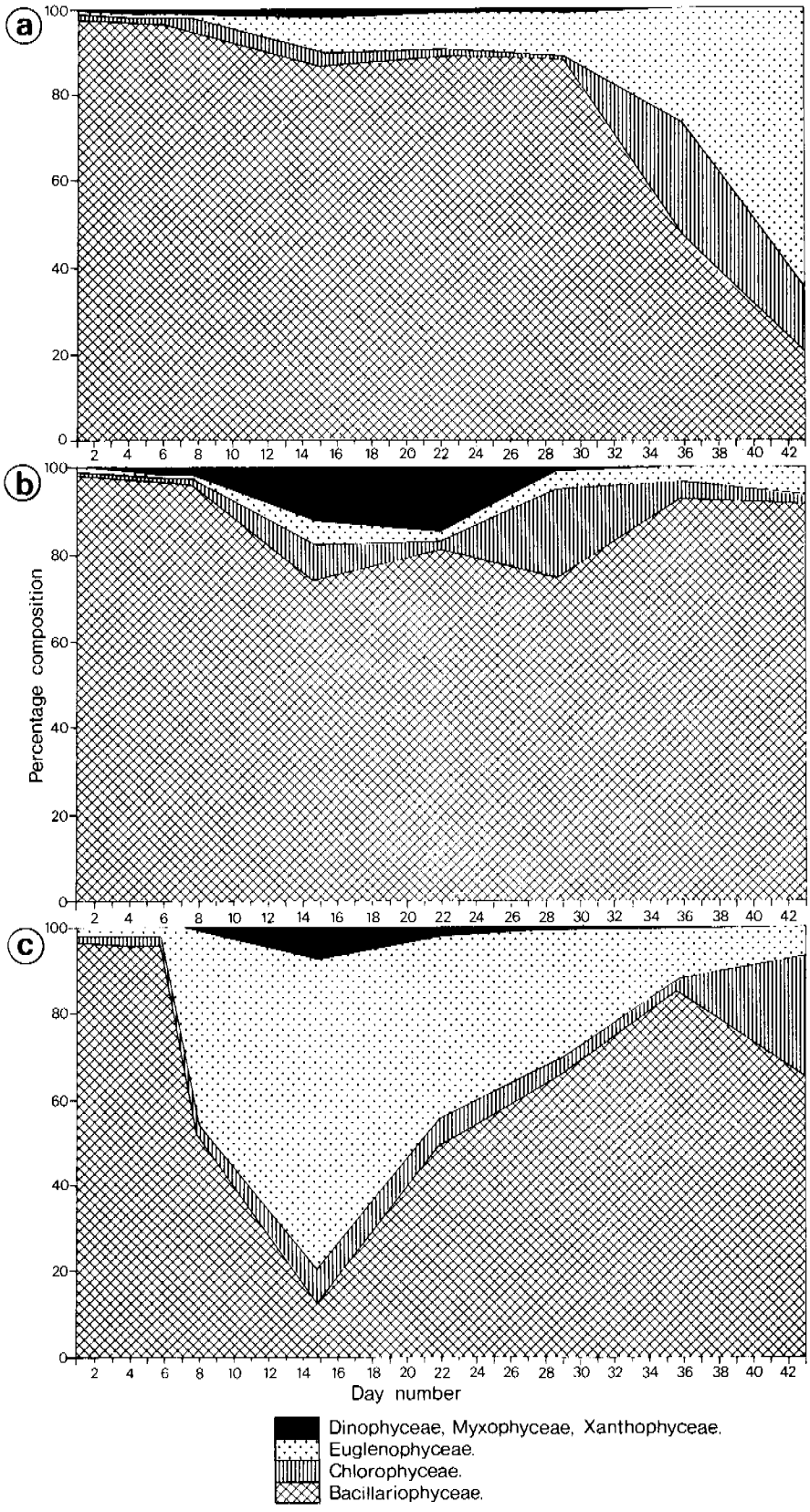

FIGURE 7 PERCENTAGE COMPOSITION OF PHYTOPLANKTON IN (A) ISLAND BILLABONG, (B) THE CONTROL ENCLOSURE AND (C) THE METAL-LOADED ENCLOSURE.

APPENDIX

TABLE A1 ALGAL NUMBERS (CELLS/ML) IN ISLAND BILLABONG.

FAMILY Species	6.xi	7.xi	9.xi	11.xi	13.xi	20.xi	27.xi	4.xii	11.xii	18.xii
EUGLENOPHYCEAE										
Trachelomonas oblonga	22	26	44	26	37	107	351	919	148	126
T. granulosa	4	-	4	-	-	4	4	-	3	-
Strombomonas	-	4	-	-	-	-	-	-	-	-
Phacus suecicus	-	4	-	-	4	-	-	-	-	-
Phacus longicauda	-	-	-	-	-	-	-	-	-	18
Euglena sp.	-	4	7	-	4	4	-	-	-	7
CHRYSOPHYCEAE										
Chloromonad	-	-	4	-	-	-	-	-	-	-
Dinobryon sertularia	-	-	-	-	-	-	4	-	-	-
Mallomonas sp.	-	-	7	-	-	-	-	-	-	-
BACILLARIOPHYCEAE										
Eunotia zasuminensis	5210	5390	6020	5510	4680	1150	3350	7720	246	18
Eunotia sp. 2	4	-	-	4	-	7	4	22	3	7
Melosira granulata	11	22	18	33	26	41	15	22	18	22
Navicula sp.	4	-	-	11	4	4	7	7	3	-
Pinnularia	-	-	-	-	4	-	-	-	-	-
Frustulia	-	-	-	-	-	-	-	7	-	-
Cymbella	-	-	-	-	-	-	-	-	-	4
CHLOROPHYCEAE										
Scenedesmus quadricauda	30	22	22	18	33	4	7	7	104	-
Scenedesmus braziliensis	-	-	-	-	4	-	-	-	-	-
Scenedesmus sp.	7	-	-	-	-	-	-	-	-	-
Staurastrum tetracerum	-	11	7	11	11	11	11	-	-	-

TABLE A1 (ctd)

FAMILY Species	6.xi	7.xi	9.xi	11.xi	13.xi	20.xi	27.xi	4.xii	11.xii	18.xii
Staurastrum sp.	18	22	11	11	7	4	4	4	15	4
Sphaerozosma	-	4	-	-	-	-	-	-	-	-
Closterium dianae	18	11	7	15	26	4	7	7	-	22
Closterium ralfsii	-	15	7	63	74	-	-	-	-	-
Euastrum pulcherrimum	7	4	7	-	-	-	-	-	-	-
Euastrum sp.	-	-	-	7	-	-	7	7	6	4
Tetraedron gracile	4	-	-	-	-	-	-	-	-	-
Tetraedron victoriae	-	7	-	-	15	7	-	-	6	-
Tetraedron regulare	-	-	-	7	-	-	-	-	-	-
Tetraedron limbatum	-	4	4	-	4	4	-	-	-	-
Tetraedron limneticum	-	-	-	-	4	-	-	-	-	-
Pediastrum duplex	-	7	4	-	4	-	-	-	-	-
Botryococcus braunii	-	-	7	-	-	4	4	7	18	4
Kirchneriella obesa	-	-	4	-	-	-	-	-	-	-
Cosmarium sp.	-	-	-	-	4	4	7	-	-	4
Coelastrum microporum	-	-	-	-	-	-	-	-	3	-
DINOPHYCEAE										
Peridinium sp. 3	11	15	15	26	18	26	22	-	-	-
Peridinium volzii	-	-	-	4	7	-	4	7	-	-
Glenodinium pulvisculus	7	-	-	-	-	-	-	-	-	-
XANTHOPHYCEAE										
Centritractus belanophorus	37	11	29	22	22	11	-	-	-	-
MYXOPHYCEAE										
Microcystis aeruginosa	4	-	-	-	-	-	-	-	-	-
Anabaena flos-aquae	-	-	-	-	-	-	-	15	-	-

TABLE A2 ALGAL NUMBERS (CELLS/ML) IN THE CONTROL ENCLOSURE.

FAMILY Species	6.xi	7.xi	9.xi	11.xi	13.xi	20.xi	27.xi	4.xii	11.xii	18.xii
EUGLENOPHYCEAE										
Trachelomonas oblonga	23	46	33	15	22	22	18	32	70	52
T. splendida	1	3	-	-	-	-	-	-	-	-
T. armata	1	-	-	-	-	-	-	-	-	-
Phacus suecicus	4	-	-	-	-	3	4	3	-	-
P. longicauda	-	-	-	-	-	-	-	2	-	-
Euglena sp.	-	-	4	4	-	7	-	-	-	-
CHRYSOPHYCEAE										
Mallomonas sp.	-	-	-	-	-	-	-	2	-	-
BACILLARIOPHYCEAE										
Eunotia zasuminensis	4450	3650	4520	4960	4010	418	867	762	1520	717
Eunotia sp. 1	-	-	-	4	-	-	-	-	-	-
Eunotia sp. 2	-	-	-	-	-	-	-	2	4	-
Frustulia	-	3	-	-	-	-	-	-	-	-
Melosira granulata	3	14	-	-	-	15	11	5	11	-
Navicula sp.	-	-	-	4	-	2	4	-	4	4
Nitzschia	-	-	-	-	-	-	-	2	-	-
CHLOROPHYCEAE										
Botryococcus braunii	-	3	4	-	7	5	4	2	7	4
Closterium dianae	9	-	11	11	-	-	-	-	-	
C. ralfsii	1	12	30	30	48	-	-	-	7	6
Cosmarium sp.	1	6	-	11	-	15	7	-	-	-
Staurastrum tetracerum	7	-	-	11	3	5	-	183	-	-
Staurastrum sp.	12	9	15	4	4	10	4	-	4	2
Staurastrum saltans	-	-	-	-	4	-	-	-	-	-

TABLE A2 (ctd)

FAMILY Species	6.xi	7.xi	9.xi	11.xi	13.xi	20.xi	27.xi	4.xii	11.xii	18.xii
Euastrum sp.	1	6	-	15	4	7	-	10	11	2
Euastrum pulcherrimum	3	-	7	-	-	-	-	-	-	-
Scenedesmus quadricauda	10	14	7	7	4		4	5	11	2
S. braziliensis	-	-	-	7	4	-	-	-	-	-
Scenedesmus sp.	3	-	-	-	-	-	-	-	-	-
Sphaerozosma sp.	1	-	4	-	-	-	-	-	-	-
Tetraedron limbatum	-	-	4	4	4	3	-	-	-	-
T. regulare	-	-	-	4	-	-	-	-	-	-
T. gracile	-	-	-	-	4	-	4	-	-	-
T. victoriae	3	-	-	-	-	3	4	3	7	6
Eudorina elegans	-	-	-	4	-	-	-	-	-	-
Coelastrum microporum	-	-	-	-	-	-	-	-	4	-
DINOPHYCEAE										
Peridinium volzii	-	-	-	11	-	-	4	-	-	-
Peridinium gutwinskii	4	6	11	-	-	-	-	-	-	-
Peridinium sp. 3	7	3	18	59	74	62	4	7	-	-
Glenodinium pulvisculus	1	-	-	-	-	-	-	-	-	-
XANTHOPHYCEAE										
Centritractus belanophorus	14	9	15	7	18	7	-	3	-	-
MYXOPHYCEAE										
Anabaena flos-aquae	-	-	-	-	-	7	156	13	-	-

TABLE A3 ALGAL NUMBERS (CELLS/ML) IN THE METAL-LOADED ENCLOSURE.

FAMILY Species	6.xi	7.xi	9.xi	11.xi	13.xi	20.xi	27.xi	4.xii	11.xii	18.xii
EUGLENOPHYCEAE										
Trachelomonas oblonga	51	30	22	18	870	306	1662	558	163	114
T. splendida	9	-	-	-	-	-	-	-	-	-
Euglena acus	-	-	-	-	-	-	-	-	-	5
Euglena sp.	-	4	-	4	-	2	-	5	-	-
Strombomonas sp.	-	-	4	-	-	-	-	-	-	-
Phacus longicauda	-	-	-	-	-	-	-	-	-	25
CHRYSOPHYCEAE										
Chloromonas sp.	-	-	-	4	-	-	-	-	-	-
BACILLARIOPHYCEAE										
Eunotia zasuminensis	4740	3450	1900	1780	1020	30	1920	1160	1150	1210
Eunotia sp. 1	-	-	-	-	-	-	-	5	5	-
Eunotia sp.2	-	-	-	-	-	-	-	-	10	-
Frustulia	-	-	-	4	-	-	-	-	19	-
Gomphonema	-	-	-	-	-	-	-	5	-	-
Melosira granulata	-	-	-	-	-	25	11	69	69	5
Navicula sp.	-	-	-	-	-	-	-	-	25	-
Nitzschia	-	-	-	-	4	-	-	-	-	-
Pinnularia	-	-	-	-	-	2	-	5	-	-
CHLOROPHYCEAE										
Closterium ralfsii	18	15	4	-	4	-	-	-	5	10
Cosmarium sp.	-	-	-	-	4	7	22	20	-	10
Scenedesmus quadricauda	14	7	4	4	4	2	4	-	-	-
Coelastrum microporum	-	-	-	-	-	-	2	-	-	-
Sphaerozosma sp.	5	7	-	-	-	-	-	-	-	-

TABLE A3 (ctd)

FAMILY Species	6.xi	7.xi	9.xi	11.xi	13.xi	20.xi	27.xi	4.xii	11.xii	18.xii
Staurodesmus	-	-	-	-	-	-	-	-	-	10
Staurastrum sp.	18	26	4	7	18	5	4	25	-	-
S. tetracerum	-	7	26	11	-	5	26	5	5	-
Tetraedron victoriae	-	4	11	4	-	2	-	-	-	-
Euastrum sp.	-	4	-	-	-	2	-	5	30	20
E. pulcherrimum	-	4	7	7	-	-	-	-	-	-
Closterium dianae	-	-	-	7	-	10	4	10	-	20
Botryococcus braunii	-	-	-	-	4	2	7	5	15	4
DINOPHYCEAE										
Peridinium gutwinskii	5	4	-	-	-	-	-	-	-	-
Peridinium sp. 3	-	11	-	4	-	22	26	5	-	-
Peridinium volzii	-	-	-	-	-	-	15	10	5	-
XANTHOPHYCEAE										
Centritractus belanophorus	23	7	4	-	-	2	4	-	-	-
MYXOPHYCEAE										
Anabaena flos-aquae	-	-	-	-	-	2	4	10	-	-

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