Technical Memorandum 28

A study of the reproducibility of water conditions between small enclosures and a tropical waterbody

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A STUDY OF THE REPRODUCIBILITY OF WATER CONDITIONS BETWEEN SMALL ENCLOSURES AND A TROPICAL WATERBODY

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ABSTRACT

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Limnological enclosures of 100 L volume were placed in a tropical waterbody for five weeks. Measurements were made regularly of the main physical water quality variables (temperature, pH, concentrations of seston [total, inorganic and organic] and dissolved oxygen) and two biological indicators (chlorophyll *a* and diatom assemblage composition) in the enclosures and in the surrounding waterbody. Good replication was obtained between identical enclosures containing water without sediment, but not between these enclosures and an enclosure containing water and sediment. The representativeness of the enclosures (ability to imitate the response of the waterbody to applied changes) was poor. Significant changes in the chlorophyll *a*/seston in the waterbody following rainfall were not detected in the enclosures. The inclusion of sediment in an enclosure significantly affected most of the variables measured, but did not improve the representativeness of the enclosure.

1 INTRODUCTION

Limnological enclosures are large-diameter cylindrical bags of plastic or similar inert material (open at one end) suspended by floats from the surface of a lake or other waterbody; they isolate a volume of water and are used to study the aquatic environment, especially the effects of deliberately made changes. Studies using such enclosures attempt to relate the results of experiments made under laboratory conditions to effects observed in natural waterbodies. The assumption made is that the mass of water isolated within an enclosure will respond in a manner similar to the main waterbody when subjected to some factor such as the deliberate addition of nutrients or heavy metals.

Following the pioneering work of Lund (1972) many studies, in both freshwater and marine waters have been made using this approach (CEPEX 1977, Gachter 1979, Gachter & Mares 1979, Imboden et al. 1979, Sanders 1984). In the Alligator Rivers Region of northern Australia, Hart et al. (1984, 1985*a,b*) have carried out experiments with enclosures to investigate the partitioning of added heavy metals between the various components of an enclosed aquatic ecosystem; the effects of chemical species such as heavy metals were examined at concentrations exceeding natural levels which could not be examined in the waterbody itself. No comparisons between enclosures were made with respect to general water quality.

Two concepts, which we call replication and representativeness, are fundamental to enclosure studies and have been generally unspecified in other studies. We have given these terms specific definitions for use in describing the relationships between individual enclosures and between enclosures and natural waterbodies.

For this study, replication is defined as the degree of similarity in the values of the main water quality variables between separate systems. One system is considered to replicate another if the values of the main water quality variables (temperature, pH, dissolved oxygen, conductivity and seston) measured regularly in each system could form part of the same 'population' ($P < 0.05$), e.g. as determined by analysis of variance calculation.

Representativeness is defined as the closeness of the response of two systems to applied changes, either natural or experimentally induced. For example, an enclosure which showed the same shifts in algal populations as its surrounding waterbody when nutrient concentrations were raised in both by the same amount, would have high representativeness regardless of whether water quality was replicated in the two systems. Representativeness is a qualitative measure unless restricted to specific responses. In this study, representativeness was determined by two biological measures: chlorophyll *a* concentration and the composition of diatom assemblages.

In addition, the value of including sediment in the enclosure when studying water quality variables has been assumed rather than demonstrated, and there have been few reports of the use of enclosures as described here in tropical situations. The study reported here had the following four objectives:

1) determination of the degree of replication which can be achieved between enclosures with respect to the water quality variables temperature, pH, dissolved oxygen, conductivity and seston;

2) determination of the degree to which the conditions within enclosures are representative of conditions in the surrounding waterbody;

3) determination of whether the inclusion of sediment in an enclosure improves representativeness; and

4) establishing the usefulness and limitations of enclosures to study the aquatic ecosystems of the Alligator Rivers Region.

2 MATERIALS AND METHODS

Description of the site and apparatus

During the late Dry season of 1983 (5 October to 9 November) four enclosures were set up in a permanent waterbody (Coonjimba Billabong, 133°54'E, 12°40'S of Magela Creek, Northern Territory, Australia (Fig. 1). Climatic conditions were typical for October-November with consistently high humidity and high temperature. Daily ranges for the study period recorded at the Jabiru East meteorological station, within 1 km of Coonjimba Billabong, were:

Humidity: 0900 hour 42-82% and 1500 hour 18-47%
Temperature: 0900 hour 21.5-26.0°C and 1500 hour 34.7-38.4°C

In this tropical region, the late Dry season is a stressful period for aquatic life as the water in the billabongs becomes increasingly turbid due to a lack of rainfall during the previous five or so months; the concentrations of dissolved ions increase and the pH drops, sometimes to below 4.

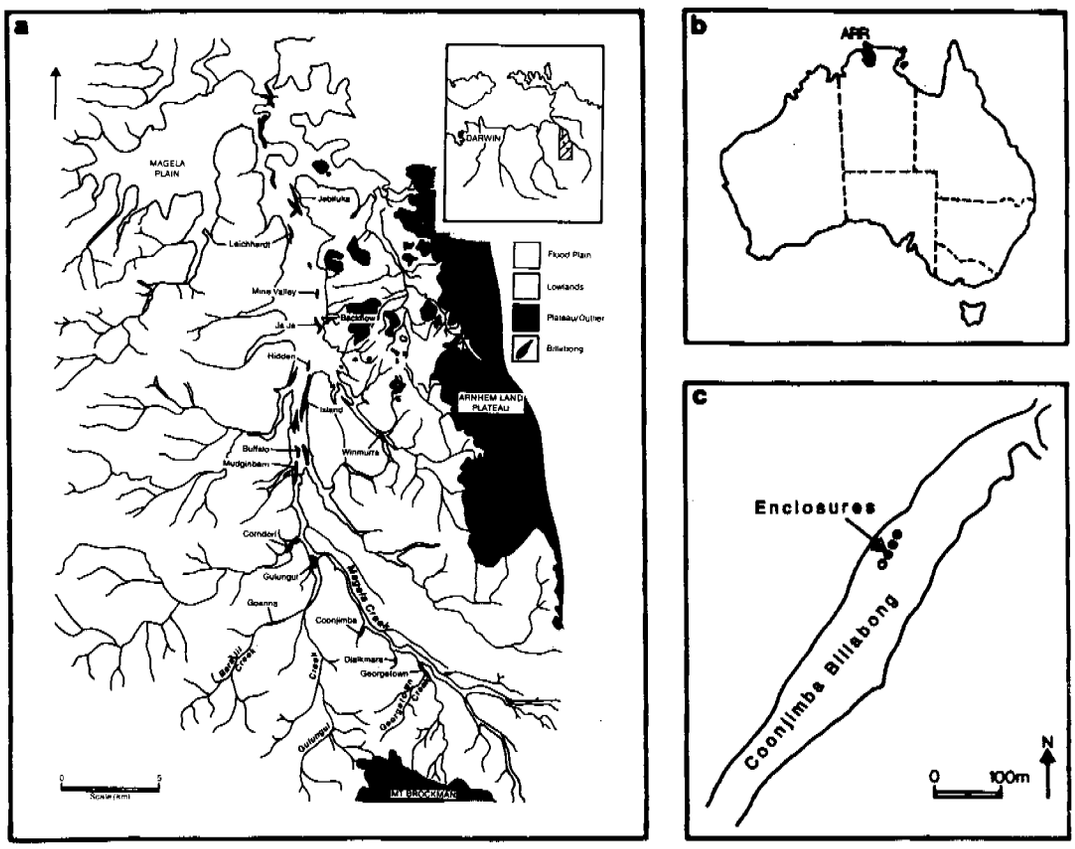

Figure 1. Study area showing the position of the enclosures and the geographic location of Coonjimba Billabong

At the time of the experiment, Coonjimba Billabong was about 50 x 300 m in size, and 2 m deep in the part containing the enclosures. The enclosures used in this study consisted of polyethylene bags (tubes, each of 200 L capacity) open at one end with the open end being supported at the water surface by an annular plastic float (approximately 64 cm i.d.) (Fig. 2). To ensure the absence of contaminating ions, the bags were washed successively with non-ionic detergent (Decon 90), 10% nitric acid, high purity water and billabong water before use. Using an Ekman grab, sediment was collected from Coonjimba Billabong and placed immediately in one enclosure (enclosure 1) to a depth of about 15 cm. All enclosures were then filled with surface billabong water.

The surface of the waterbody was covered in aquatic plants, principally *Nymphaea* spp. in the deep water and *Eleocharis* spp. near the banks except for an area of approximately 10 m^2 surrounding the enclosures. Water depth in the billabong decreased by 0.14 m during the first 30 days of the experiment due to evaporation but rose during the last 4-5 days, following rainfall, by 0.09 m, as shown by the gauge height readings (Fig. 3.)

Rainfall during the experiment totalled 118 mm, falling in four periods. These were: (i) 13 October (4 mm); (ii) 19-23 October (45 mm); (iii) 1 November (48 mm); and (iv) 5-7 November (21 mm). Rainfall was measured at the Jabiru East Airport meteorological station. The localised rain showers that occurred during the experiment were during the transitional part of the Wet season prior to the monsoonal rain which normally floods the low lying terrain in December, restoring good water quality in the billabongs.

Sampling and measurement of water quality variables

For five weeks, at 0900 h and 1600 h every Monday, Wednesday and Friday, measurements were made of temperature, pH and concentration of dissolved oxygen (DO) and, at 0900 h only, 500 mL water samples were taken in polyethylene bottles for the determination of seston (total, organic and inorganic) and chlorophyll *a* at 10 cm depth in enclosures and adjacent water of the billabong; temperature and DO concentration were also measured at 80 cm depth (close to the bottom) in the enclosures and at 80 cm and 170 cm depth (close to the bottom) in the billabong. Temperature, DO concentration (Hach DO meter model 16046) and pH (Metrohm pH meter model E604) were measured *in situ*. Minimum DO concentration is usually observed around 0600 h, however, it was more convenient to sample at 0900 h rather than at 0600 h. Sampling at 1500 h corresponded to conditions following oxygenation of the water column. Sampling on three days each week was considered to be a sufficiently frequent to examine replication of enclosures and representativeness of conditions in the surrounding waterbody.

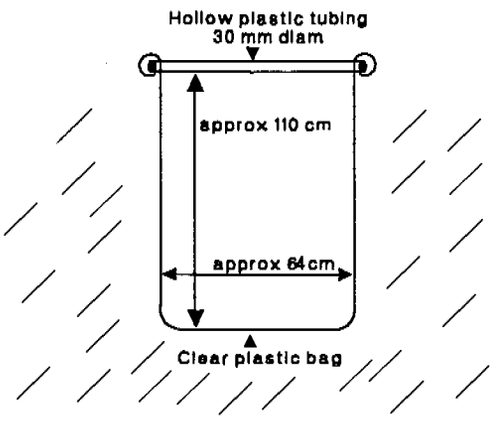

Figure 2. The design of enclosure used in this study

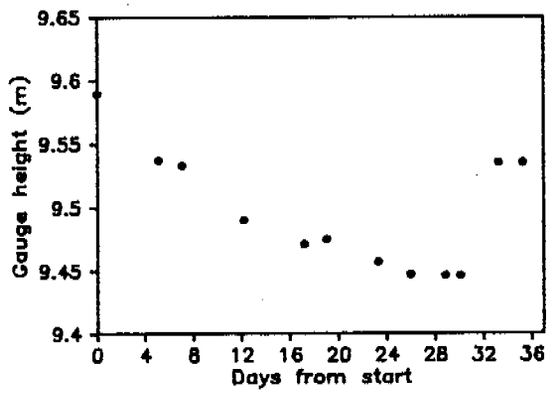

Figure 3. Gauge height over the period of the experiment at Coonjimba Billabong

Seston was collected by filtering a 150 mL aliquot of the sample through a 0.4 μm cellulose acetate membrane filter (Sartorius, Cat. No. 11106), pre-washed with 200 mL high purity water and supported in an all-glass filtration unit (Millipore, Cat. No. XX1504700). The filter and collected solids were placed in a plastic Petri dish (Millipore, Cat. No. PD1004700) and dried in an oven at 105°C for 2 h, allowed to cool in a desiccator over silica gel for at least 2 h and then weighed on an analytical balance to five decimal places.

To determine the 'inorganic' content of the seston, the filter material and the 'organic' part of the solids were removed by oxidation. This was done by placing each filter with its suspended solids in a silica boat in a low temperature plasma asher (LFE Corporation Model LTA-504) for 12 hours. The weight of remaining ashed material was calculated to give the weight (mg) of inorganic seston per litre. The 'organic' seston was taken as the difference between the total and the 'inorganic' seston. (The weight of ash from the membrane filter was < 0.1%.)

Measurement of chlorophyll *a* and counting of diatoms

Chlorophyll *a* in water samples was determined on a 200 mL aliquot using a modified APHA method (APHA 1980). The particulate matter (including algae) was collected on a 47 mm diameter glass fibre filter (Whatman GF/C) pre-washed with 200 mL high purity water and supported in an all-glass filtration apparatus. The glass fibre filter was then placed in a McCartney bottle pre-rinsed with AR grade acetone and 5-10 mL of a mixture of 90% AR grade acetone in high purity water. An ultrasonic probe (Branson sonifier B-15 using 'microtip') was placed in the bottle with the probe projecting approximately 1 cm into the solution and operated for 5 minutes. The bottle was then capped (cap lining seal removed) and left overnight in a refrigerator at 4°C (leaving the filter to stand in contact with the solvent assisted in extracting the chlorophyll *a* from the algal residues). The following day the acetone/water extract was filtered through a 25 mm diameter glass fibre filter into a culture tube previously rinsed with AR grade acetone. Two additional 5 mL aliquots of the acetone/water mixture were used to rinse the filter and the solution was adjusted to a final volume of 20 mL. Before use the glass fibre filters were rinsed with the acetone/water mixture and the culture tubes were washed with Decon 90 solution, rinsed with water and finally rinsed with the acetone/water mixture. The absorbance of the extract solution was read in a 5 cm cell using a Varian Superscan model 3 uv/visible spectrophotometer. Absorbance was measured at 630 nm, 656 nm, 663 nm and 750 nm. Using the known volumes of sample filtered and extracted, the chlorophyll *a* concentrations (in μg/L) were calculated as described in APHA 1002a (APHA 1980).

Samples of diatom assemblages were obtained using a floating device called a diatometer (Fig. 4) (McBride 1983) which exposed eight glass microscope slides (75 mm x 15 mm) at a depth of 20 cm. After a 'seeding' period of four days in the open water to allow uniform colonies to be established from the pseudoplanktonic (i.e. periphytic diatoms temporarily adrift in the water column) diatom populations, a single diatometer was placed in each of the four enclosures and a fifth left in the open water.

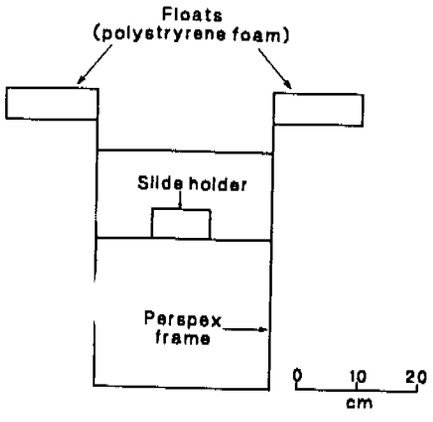

Figure 4. Diagrammatic elevation of the diatom sampler used in this study

Eight glass slides were supported at a depth of 20 cm for colonisation by micro-organisms

After 21 days in the water, the glass slides were removed from the diatometers and the attached diatoms separated and cleared of organic matter using boiling concentrated nitric acid. The diatom valves were rinsed with high purity water, then allowed to settle from suspension onto a cover slip. After drying, the cover slip was mounted on a slide using a mounting medium of high refractive index (Naphrax, r.i. = 1.7). To determine the population numbers, more than 300 valves from each sample were counted at 1000x magnification under Normarski. The identification of diatom taxa was based on Hustedt (1930), Patrick & Reimer (1966) and Thomas (1983).

Data treatment

The mean and standard error (SE) for temperature, DO concentration, pH and concentrations of seston, inorganic seston, organic seston and chlorophyll *a* were calculated from data categorised according to sampling time, depth, enclosure number and billabong.

Analysis of variance (on logarithmically-transformed data, except for pH) was used to determine which variables differed significantly between different enclosures and between the enclosures and the open water. The test of significance was that the confidence intervals of the means ($P < 0.05$) did not overlap.

To obtain an objective measure of similarity, the diatom assemblages from each diatometer were compared using the Bray-Curtis Similarity Index (Bray & Curtis 1957). This measure compares two biological communities in terms of both the number of species present and the number of individuals of each species and has been used previously to compare diatom assemblages from Magela Creek waterbodies (McBride 1983). The Bray-Curtis Similarity Index (SI) between two samples, 1 and 2, is given by:

$$SI = 200 \Sigma \min (n_{1i}, n_{2i})/\Sigma (n_{1i} + n_{2i})$$

where n_{1i} and n_{2i} are the numbers of the ith species in samples 1 and 2 respectively.

This index has a range of 0-100; communities with no species in common have a SI of zero and completely identical communities would have a SI of 100. To remove the effect of total population numbers (which are more variable than community composition) when calculating SI, the number of each species was expressed as a percentage of the total population.

3 RESULTS

A summary of the reproducibility of measurement for all variables is given in Table 1; reproducibility of respective variables was generally well below variations in data sets. Table 2 summarises data for all variable according to time of sampling, depth and location.

Table 1. Reproducibility of measurements (n = 5)

Variable	Typical value	Reproducibility
pH	6.6	± 0.1
Temperature (°C)	26	± 0.2
Dissolved oxygen (mg/L)	1.4	± 0.2
Seston (mg/L)	16	± 0.6
Inorganic seston (mg/L)	13	± 0.6
Organic seston (mg/L)	3	± 0.2
Chlorophyll *a* (mg/m^3)	110	± 5

Although replication of nutrient concentrations was not examined in this study, historical data are presented for Coonjimba Billabong in Table 3 to enable comparison with other tropical waterbodies.

Figure 5 shows data for DO concentration, Fig. 6 shows the data for pH and Fig. 7 the data for seston concentrations. Plots of other data were not considered to be warranted.

Table 2. Summary of results for physico-chemical variables in Coonjimba Billabong water inside and outside plastic enclosures

Enclosure 1 contained sediment, enclosures 2, 3 and 4 did not; n = 16

Variable	Time (h)	Depth (mm)	Mean ± S.E. Enclosure 1	Enclosure 2	Enclosure 3	Enclosure 4	Coonjimba Billabong
Temperature (°C)	0900	10	26.3 ± 0.2	26.2 ± 0.2	26.8 ± 0.6	26.1 ± 0.2	26.2 ± 0.2
	0900	80	25.7 ± 0.2	25.7 ± 0.2	25.6 ± 0.2	25.6 ± 0.2	25.5 ± 0.2
	0900	170	-	-	-	-	25.1 ± 0.2
	1600	10	29.8 ± 0.4	29.5 ± 0.3	29.4 ± 0.3	29.9 ± 0.5	29.0 ± 0.2
	1600	80	26.0 ± 0.2	25.8 ± 0.2	25.7 ± 0.2	25.8 ± 0.2	25.5 ± 0.2
	1600	170	-	-	-	-	24.8 ± 0.2
Dissolved oxygen (mg/L)	0900	10	4.0 ± 0.2	4.5 ± 0.2	4.2 ± 0.2	3.9 ± 0.2	1.4 ± 0.2
	0900	80	2.1 ± 0.4	4.1 ± 0.2	3.6 ± 0.2	3.5 ± 0.2	0.5 ± 0.2
	0900	170	-	-	-	-	0.4 ± 0.2
	1600	10	6.2 ± 0.3	6.1 ± 0.3	5.5 ± 0.3	5.5 ± 0.2	6.0 ± 0.4
	1600	80	4.0 ± 0.5	5.7 ± 0.3	5.3 ± 0.2	5.2 ± 0.3	1.0 ± 0.2
	1600	170	-	-	-	-	0.5 ± 0.2
pH	0900	10	6.9 ± 0.1	7.3 ± 0.1	7.3 ± 0.1	7.2 ± 0.1	6.6 ± 0.1
	0900	80	6.4 ± 0.1	7.0 ± 0.1	6.9 ± 0.1	6.8 ± 0.1	6.4 ± 0.1
	0900	170	-	-	-	-	6.2 ± 0.1
Seston (mg/L)	0900	10	10.1 ± 2.8	6.0 ± 1.2	5.4 ± 0.8	6.9 ± 1.9	16 ± 0.6
Inorganic seston (mg/L)	0900	10	2.5 ± 0.7	2.9 ± 0.9	2.6 ± 0.7	3.7 ± 1.3	4.5 ± 0.8
Organic seston (mg/L)	0900	10	7.6 ± 2.3	3.1 ± 0.7	2.8 ± 0.3	4.3 ± 1.2	11 ± 1
Chlorophyll *a* (mg/m^3)	0900	10	63 ± 13	41 ± 9	47 ± 6	63 ± 27	110 ± 19

Table 3. Summary of nutrient concentration and pH data for Coonjimba Billabong, October-December 1978-1983[a]

Variable	n	Range	Mean ± S.D.
pH	12	5.8-7.2	6.5 ± 0.4
Total nitrogen (as -N mg/L)	7	0.43-3.65	2.0 ± 1.4
Nitrate + nitrite (as -N mg/L)	12	< 0.005-1.5	0.21 ± 0.42
Ammonia (as -N mg/L)	10	< 0.01-3.5	0.69 ± 1.1
Total phosphorus (as -P mg/L)	11	< 0.01-0.07	0.025 ± 0.023
Phosphate (as -P mg/L)	11	< 0.003-0.015	0.007 ± 0.006

[a]Data from Water Resources Division, N.T. Department of Mines and Energy

Analysis of variance of all variables measured indicated the absence of significant differences between the three enclosures containing billabong water only. However, their pH, and DO and seston concentrations differed significantly from those of the water in the enclosure containing sediment and from those of the surrounding billabong water. These variables, as well as chlorophyll *a* concentrations, in the enclosure containing sediment were significantly different from the surrounding open water. Table 4 identifies the variables which were not significantly different ($P < 0.05$) between individual enclosures and between the enclosures and the waterbody.

Water temperature did not differ significantly between the individual enclosures or between the enclosures and the waterbody. The pH and DO and seston concentrations in the three enclosures

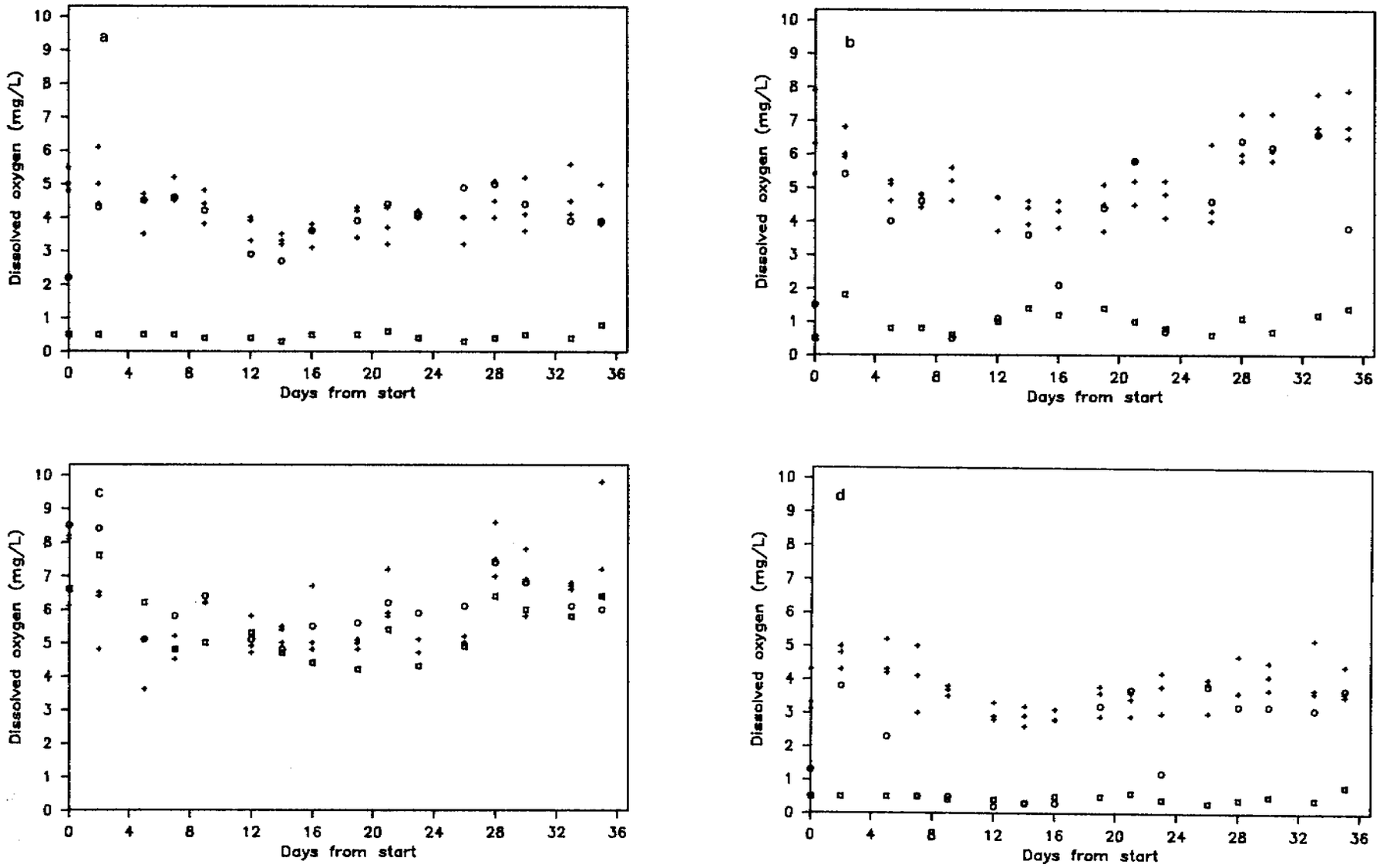

Figure 5. Concentration of dissolved oxygen at: (a) 10 cm depth, 0900 hours; (b) 80 cm depth, 0900 hours; (c) 110 cm depth, 1600 hours; and (d) 80 cm depth, 1600 hours in the enclosures and the billabong

□ open water; + enclosures containg billabong water only; o, enclosure with billabong water and sediment

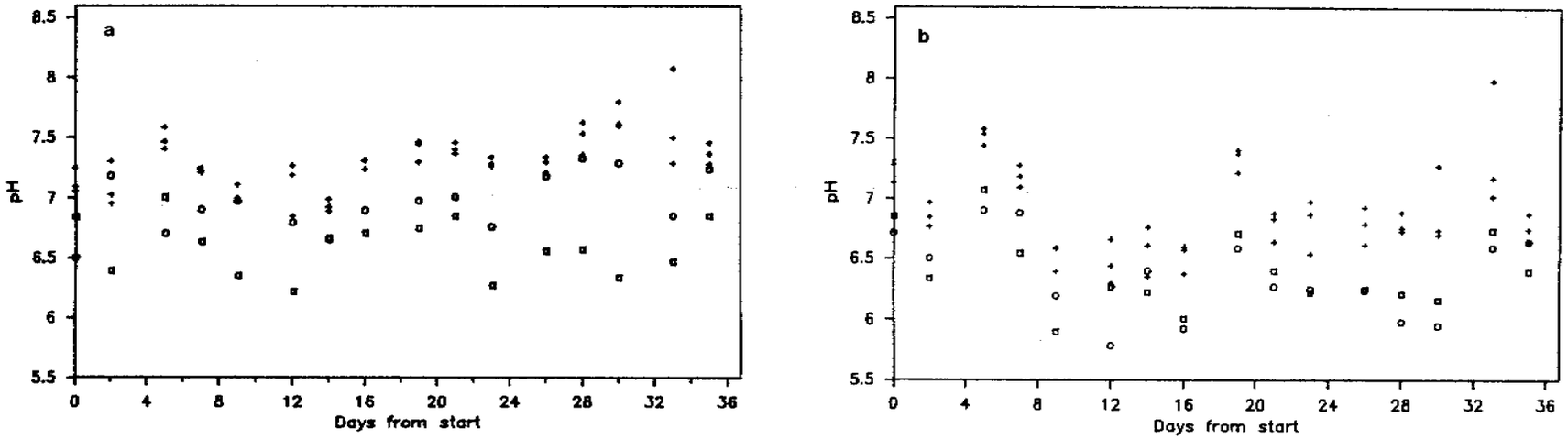

Figure 6. (a) Value of pH at: (a) 10 cm depth, 0900 hours; and (b) 80 cm depth, 0900 hours in the enclosures and the billabong
□ open water; + enclosures containg billabong water only; o, enclosure with billabong water and sediment

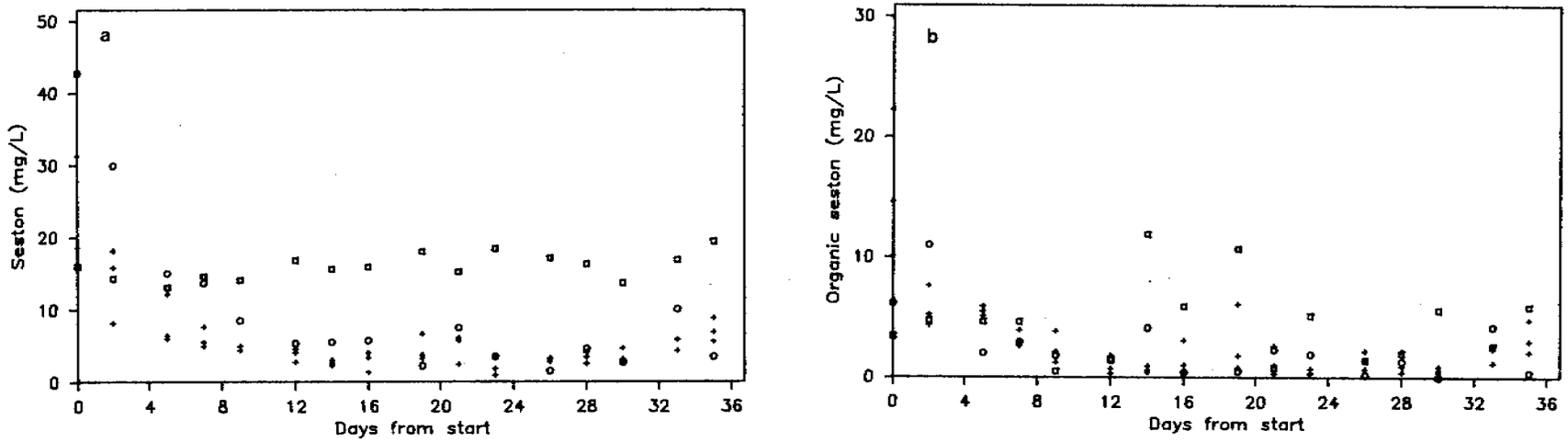

Figure 7. (a) Concentration of: (a) seston at 10 cm depth, 0900 hours; and (b) organic seston at 10 cm depth, 0900 hours in the enclosures and the billabong
□ open water; + enclosures containg billabong water only; o, enclosure with billabong water and sediment

Table 4. List of water quality variables which were not significantly different ($P < 0.05$) between the enclosures and the billabong

A[a]	B[b]	C[c]
Variable (depth, time)	Variable (depth, time)	Variable (depth, time)
Temp. (10 cm, 0900 h)	Temp. (10 cm, 0900 h)	Temp. (10 cm, 0900 h)
Temp. (80 cm, 0900 h)	Temp. (80 cm, 0900 h)	Temp. (10 cm, 0900 h)
Temp. (10 cm, 1600 h)	Temp. (10 cm, 1600 h)	Temp. (80 cm, 1600 h)
Temp. (80 cm, 1600 h)	Temp. (80 cm, 1600 h)	Temp. (80 cm, 1600 h)
DO (10 cm, 1600 h)	DO (10 cm, 1600 h)	DO (10 cm, 1600 h)
DO (10 cm, 0900 h)		
Organic seston (10 cm, 0900 h)	Organic seston (10 cm, 0900 h)	Organic seston (10 cm, 0900 h)
Inorganic seston (10 cm, 0900 h)		

[a] Between the three enclosures without sediment (Nos 2, 3, 4) and the enclosure with sediment (No. 1);
[b] Between the three enclosures without sediment and the billabong;
[c] Between the enclosure with sediment and the billabong.

without sediment (Nos 2, 3, 4) differed significantly from the enclosure containing sediment (No. 1) and from the billabong. As well, for the same variables, the enclosure containing sediment differed significantly from the billabong. Concentrations of DO in the billabong at 170 cm depth were similar to those at 80 cm depth.

Chlorophyll *a* concentrations (Fig. 8) in the three enclosures without sediment were different from the enclosure containing sediment and also from the billabong. As well, the enclosure containing sediment was different from the billabong. However, organic seston, which would have contained the chlorophyll *a*, and hence might be expected to follow a similar pattern of distribution, was not significantly different in these cases.

Similarity Index (SI) values between the diatom assemblages are given in Table 5 and the percentage relative abundances of diatom species from each diatometer sample are given in Table 6.

In terms of diatom assemblages (Table 5), the three enclosures without sediment were very similar to each other (SI = 89-94), but different from the enclosure containing sediment (SI = 42-51) and from the billabong (SI = 37-45). As well, the enclosure containing sediment was different from the billabong sample (SI = 43).

4 DISCUSSION

Replication measurements

Temperature. The temperature profiles measured at 0900 h in the enclosures and in the billabong were similar at both depths, 10 cm and 80 cm (Table 2). During the day, solar heating produced temporary thermal stratification, raising the temperature at 10 cm depth at 1600 h (in both enclosures and billabong) by approximately 4°C above that prevailing (*ca.* 26°C) in the lower layers (Table 2). In terms of temperature, the enclosures mimicked the billabong closely.

Table 5. Similarity Index (SI) values between the diatom assemblages that developed on glass microscope slides exposed for colonisation in the enclosures and in the open water of the billabong

	Enclosure number			
	1	2	3	4
1 (with sediment)	-			
2 (without sediment)	42	-		
3 (without sediment)	48	94	-	
4 (without sediment)	51	89	94	-
Billabong open water	43	37	41	45

Table 6. The percentage relative abundances of diatom species from each diatometer sample

A dash (-) indicates that the relative abundances of the species was less than 0.3%

	Enclosure No.				
Species	1	2	3	4	Open Water
Gomphonema parvulum	36.8	82.8	78.1	76.0	30.6
Eunotia pectinalis var. *minor*	44.5	1.9	3.0	3.2	1.5
Gomophonema gracile	2.3	13.4	12.6	8.8	3.4
Navicula radiosa	7.4	0.6	4.7	6.5	26.6
Nitzschia palea	0.3	1.0	0.7	1.6	28.1
Pinnularia stauroptera	-	-	-	-	5.2
Anomoeoneis exilis	0.6	-	-	-	-
Cymbela minuta	-	-	-	0.3	-
Eunotia camelus	2.6	-	-	-	-
E. flexuosa	0.3	-	-	-	0.3
E. lunaris	0.6	0.3	-	1.3	1.2
E. monodon	0.3	-	0.3	-	-
Eunotia sp. 4	0.3	-	-	-	-
E. rhomboidea	0.6	-	-	-	-
Frustulia rhomboides	0.6	-	0.7	0.6	-
Melosira granulata	1.0	-	-	-	-
Navicula halophila	0.6	-	-	-	-
Pinnularia braunii var. *amphicephala*	0.3	-	-	-	-
P. gibba var. *linearis*	0.3	-	-	1.0	-
P. microstauron	0.3	-	-	-	-
Stauroneis phoenicenteron	-	-	-	-	2.4
Stenopterobia intermedia	-	-	-	0.6	-
Sydnedra sp.	-	-	-	-	0.6

Dissolved oxygen. Except for surface readings taken at 0900 h, DO concentrations measured in the billabong were not replicated in the enclosures. The differences between the billabong and the enclosures were greater for DO concentrations than for other variables measured.

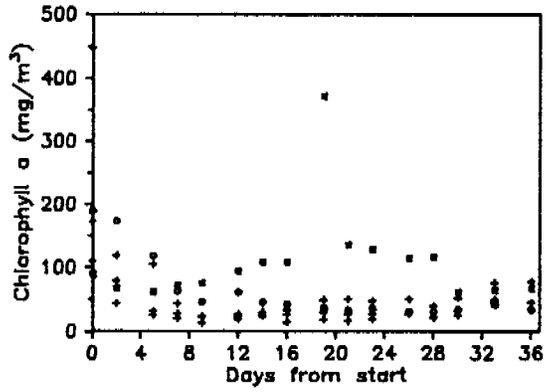

Figure 8. Concentration of chlorophyll *a* at 10 cm depth, 0900 h in the enclosures and the billabong

□ open water
+ enclosures containg billabong water only
o enclosure with billabong water and sediment

In the deep water of the billabong, at both 80 and 170 cm depth, the DO concentrations remained low, averaging < 1 mg/L, compared to the 2-6 mg/L range in the enclosures (Fig. 5, Table 2). During the day, the average DO concentrations in the surface water of the billabong increased, as a result of photosynthesis, to about 6 mg/L at 1600 h, similar to the levels within the enclosures (Table 2). The presence of sediment in an enclosure had little effect on DO concentrations near the surface but resulted in large fluctuations in DO concentrations at 80 cm depth. Sometimes the DO concentrations at 80 cm depth in this enclosure resembled the other enclosures, with DO concentrations of about 6 mg/L; at other times this enclosure resembled the surrounding waterbody with DO concentrations of less than 1 mg/L. In the billabong, DO concentrations measured at depths of 80 cm and 170 cm at 0900 h (Table 2) were very similar indicating that most of the billabong water, unlike the water in the enclosures, had low oxygen levels at the time of the experiment. These low oxygen levels were presumably due to the high oxygen-consuming capacity of the sediment micro-organisms and poor water circulation, a typical condition in Coonjimba Billabong and other permanent waterbodies at this time of year (Walker & Tyler 1984).

pH. The values of pH measured at 0900 h were highest in the three enclosures without sediment (Fig. 6; Table 2). The presence of sediment in an enclosure had the effect of increasing the similarity between the pH in the enclosure and in the open water, especially at 80 cm depth (Table 2). In the enclosures without sediment the pH sometimes rose above 8.0 (Fig. 6), more than one unit above the maximum observed in the billabong (Table 2; Table 3 shows historical pH values in Coonjimba Billabong). This is presumed to be due to the rapid carbon dioxide removal by high rates of primary production coupled with the low buffering capacity of the water and is a significant departure from Magela Creek conditions where pH values above 7.0 are rare (Morley et al. 1985, Walker & Tyler 1984).

Seston. Within 8-9 days from the start of the experiment the total seston concentrations in the enclosures had decreased to about one-third of the concentrations occurring in the billabong (Fig. 7*a*). The reduction was less marked with the other indices of suspended material, namely the absolute concentrations of organic seston and of chlorophyll *a* (Table 2), suggesting that inorganic particles tended to settle out in the enclosure but remained suspended in the billabong. All three measures are related to the biomass of planktonic algae. concentrations of organic seston (Fig. 7*b*) were very variable and the lack of any significant difference between concentrations in the enclosures and the open water is mostly due to this variability, a feature also observed by Gachter (1979) and Imboden et al. (1979). The reduction in organic seston that occurred during the first week was similar to, but less marked than, the reduction in total seston. Possible explanations for the reduction in seston concentrations in the enclosures are: (1) the small volume of the enclosures restricted water turnover and promoted settling of the suspended particles; and (2) nutrients were removed from the water column by the relatively high density of periphytic algae on the enclosure walls, causing certain elements to become limiting to the planktonic populations. Because seston was mostly organic (> 75%, Table 2), (1) was probably the most important explanation. Inorganic seston concentrations in the enclosures tended to be similar to those in the billabong (Table 2).

Representativeness measurements

Chlorophyll *a*. Chlorophyll *a* concentrations in all enclosures were similar but lower than found in the billabong (Table 2). During the third week, a prominent rise in the concentrations of organic seston and a corresponding peak in the chlorophyll *a* concentrations were measured in the billabong (Fig. 8). This effect, presumably caused by an algal bloom, was not observed in the enclosures.

Between days 14-26 there was 45 mm rainfall recorded at Jabiru East Meteorological Station. Measurement of the nutrient concentrations in this rainfall (Noller, unpublished work) using techniques previously described (Noller et al. 1985) showed the following nutrient inputs, calculated from the concentration data (billabong kg/ha; enclosures mg/0.33m^2 surface area): nitrate (as -N) (0.054; 13), ammonia (as -N) (0.023; 0.76), and phosphate (as -P) (< 0.0025; < 0.083). Following this rainfall, increases in nutrient concentrations in the enclosures were calculated to be: nitrate (as -N) 3.3%; ammonia (as -N) 0.6%; and phosphate (as -P) < 6%, by assuming that nutrient inputs from rainfall were the same at Coonjimba Billabong as those measured in rainfall at Jabiru East, approximately 1 km away, and that nutrient concentrations in billabong water, including enclosures, were the same as historical mean levels (Table 3). It is possible that sufficient nutrient input occurred to trigger the algal bloom. This bloom may also have been triggered by water runoff from land or may have resulted entirely from internal factors. The numbers and species of phytoplankton in Magela Creek are highly variable (Hart et al. 1985*b*, Kessell & Tyler 1982).

The peak in chlorophyll *a* concentrations (Fig. 8) in the open water of the billabong about the 18th day thus illustrates the complete independence in behaviour of the enclosure ecosystems from the ecosystem of the billabong as measured. No trace of a coincident rise was apparent in the enclosures which must have lacked the basis, or the stimulus, or both,

for the algal bloom to develop. Hence, in terms of chlorophyll *a* concentrations, the enclosures were not representative of the billabong (Table 2).

Diatom assemblage composition. The diatom assemblages that develop on glass slides are likely to be different from the assemblages found on natural substrates, but the effects of water conditions on diatom assemblages can be usefully studied without insisting that the assemblages are directly relatable to those on natural substrates. Many characteristic diatom assemblages occur on natural substrates: epilithic (on stone) epipelic (on sediment), epiphytic (on plants), and the diatom assemblage that colonises glass substrates may be considered as yet another assemblage, even though it is one which does not occur naturally.

The diatom assemblages on the diatometers consisted of acidophilic (preferring pH values below 7), halophobic (preferring low concentrations of dissolved ions) diatom species typical of Magela Creek. However, the assemblages from the diatometers exposed within the three enclosures without sediment were overwhelmingly dominated (76% to 83%) by one species, *Gomphonema parvulum* (Table 6). This suggests an unusual situation (probably a stressed one), since the species numbers were more evenly distributed in the assemblages on the diatometer from the enclosure containing sediment (two dominant species) and on the diatometer left in the billabong (three dominant species) (Table 6). The diatom assemblages developing on glass slides in Magela Creek floodplain billabongs are sometimes dominated by one or two species (McBride 1983), but the dominance of such a diatom assemblage in Magela Creek by *G. parvulum* has not been observed previously. Presumably, the open water sample represented a typical Coonjimba Billabong diatom assemblage for the time of year and the diatom assemblages observed in the enclosures were distorted by harsh regimes of water chemistry and physical conditions at the end of the Dry season. The diatom assemblages were also probably influenced by rain input.

The interpretation of SI values in the present study was based on the values obtained in similar studies elsewhere (McBride 1983). SI values relating specifically to replicate diatom assemblages were not found in the literature, but could be calculated from data given by Patrick (1968, table 2, p. 176) in which the diatom assemblages on eight sets of glass slides exposed under identical conditions in tanks supplied with stream water were compared. The average for several hundred SI between these assemblages was 83. McBride (1983) found a range of SI values from 75 to 89 between diatom assemblages from diatometers exposed 1-2 metres apart in the open water zone of floodplain billabongs downstream of the study area. In terrestrial communities, Bray & Curtis (1957) obtained an average SI of 82 for the mean of seven replicate counts on two communities of trees, herbs and shrubs. It is difficult to define an exact and universal range of SI values which should be expected between identical plant communities because the range is influenced by the type of ecosystem and the sample size. However, based on the values given above, the 75-90 range proposed by Kessel & Whittaker (1976) appears a reasonable general estimate and was adopted for use in this study.

The high SI values between the diatom assemblages in the enclosures containing billabong water without sediment (mean ± SE = 92 ± 2, n = 3) indicate that these communities were sufficiently similar to be considered replicates in phytosociological terms. However, a different assemblage developed on the diatometer in the surrounding waterbody compared to the diatometers in the enclosures, whether sediment was present (enclosure 1, SI = 43, n = 1) or absent (enclosures 2, 3, 4; SI mean ± SE) = 41 ± 2, n = 3). These data suggest that significant differences must exist between the billabong and enclosure habitats in the values of the water quality variables that affect primary producers. Hence, in terms of diatom assemblage composition, the enclosures could not be considered to be representative of the billabong.

Of the diatom species for which the autecology is known, only *Nitzschia palea* had significantly different populations in the enclosures and the open water, being considerably higher in the latter. This suggests that the water in the enclosures contained less nutrients

than the billabong water because *N. palea* favours eutrophic conditions (Lowe 1974). Nutrients are removed from the water column by periphytic algae and in the enclosures the higher ratio of colonisable surface area to water volume would produce a greater degree of removal. No data were available on nutrient concentrations in the enclosures, apart from the rain input described above, to determine the extent of this effect. However, nutrients in the rain input undoubtedly cause some of the observed differences.

5 CONCLUSIONS

In broad terms, the findings of this experiment were, that for enclosures of 200 L volume in a shallow tropical waterbody:

1) replication was good between identical enclosures containing only water, but not between these enclosures and an enclosure containing water and sediment;

2) enclosures containing only water had poor representativeness of the surrounding waterbody;

3) including sediment in an enclosure appeared to significantly affect most of the main water quality variables, but did not usefully improve the representativeness.

The conditions within enclosures are sufficiently reproducible to enable studies of the effects of added materials to be undertaken in isolation from existing waterbodies and when representativeness to the waterbody is not essential to the study. The potential value of such enclosure experiments lies in the ability of identical enclosures to replicate some biological variables, a feature not easily achieved in laboratory scale experiments.

An enclosure containing sediment as well as water seemed to behave more like the surrounding water for certain variables for some of the time, but the effects were not consistent. In particular, higher fluctuations of DO concentrations occurred in the enclosure containing sediment than in the other enclosures or the surrounding waterbody. For these reasons there seems little value in the inclusion of sediment in enclosures.

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