MACROINVERTEBRATE COMMUNITY STRUCTURE AND WATER QUALITY VARIATION IN AN EFFLUENT IMPACTED WETLAND (LAKE COLEMAN), VICTORIA, AUSTRALIA.

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ABSTRACT

Temporal and spatial variation in water quality and macroinvertebrate community structure were assessed in Lake Coleman, a shallow wetland adjacent to the Gippsland Lakes, Victoria, Australia. Littoral water quality and macroinvertebrate samples were collected annually in spring for 3 years following the cessation of a 30 year discharge of a treated effluent to the wetland. The discharged effluent contained highly coloured pulp and paper wastewaters as well as domestic and industrial effluents. Temporal changes in wetland water quality were related to the cessation of effluent discharge which resulted in reduced water colour and nutrient concentrations at discharge sites. Water quality was also affected by the inundation of the wetland by floodwaters in 1993 which lowered salinities across the wetland and also increased colour and nutrient concentrations at non-outfall sampling sites. Lake Coleman littoral macroinvertebrate species richness was lower than that reported for an adjacent, relatively unimpacted wetland, but was up to 3 times higher than in another local wetland impacted by sewage discharge. Macroinvertebrate community structure was variable over time and displayed no consistent pattern between sites. Change in macroinvertebrate species richness and densities were associated with wetland flooding. Further monitoring is required to assess long term changes to wetland macroinvertebrate community structure resulting from current management strategies.

Key Words: *Wetland, pulp, paper, effluent, sewage, water quality*

INTRODUCTION

Lake Coleman is a shallow wetland located at the western end of the Gippsland Lakes, Victoria (Fig. 1). It has a *Class A* wetland status and provides internationally significant habitat for migratory bird species (Heron 1989). The wetland consists of a mosaic of open water and reed beds (*Juncus usitatus, Cyperus eragrostis* and *Phragmites australis*) interspersed with stands of swamp paperbark (*Melaleuca ericifolia*). It has a wetted area of approximately 2,200 ha and an average depth of 0.3 m, with a maximum depth of 1 m (Robinson 1988). Lake Coleman has a very small catchment area (11,000 ha) and, prior to the 1950s, is believed to have been semi-permanent, being dry over winter one year in three (Robinson 1988; Anon. 1991). The wetland became permanent in 1958 with the commencement of wastewater discharge to its eastern end. This discharge, which continued until October 1992, contained highly coloured, treated pulp and paper mill effluent mixed with treated domestic and industrial wastewaters. Additional water has also been supplied to Lake Coleman via two man-made channels which were excavated between Lake Coleman and Lake Wellington in 1980 (Fig. 1). Channel water flows from Lake Wellington are brackish and have raised salinity levels in the north-west section of Lake Coleman (Robinson 1988).

Small scale biological surveys of Lake Coleman were carried out between 1975 and 1977 (Gippsland Water unpublished data) and a more extensive survey was carried out between 1986 and 1987 (Robinson 1988). These indicated that macroinvertebrate species richness and

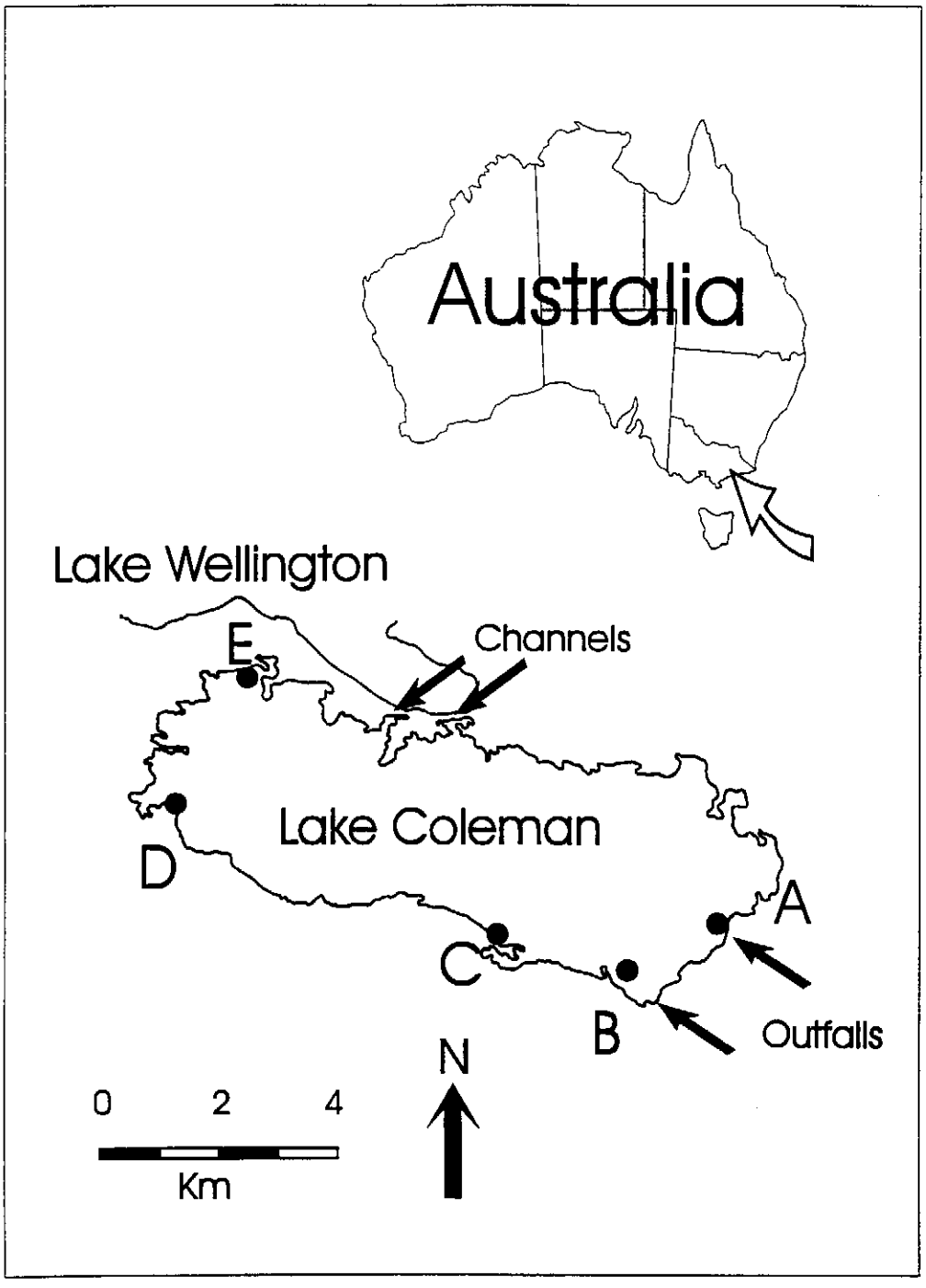

Figure 1: Lake Coleman sampling sites.

densities were depressed in Lake Coleman, both in the vicinity of the effluent discharge, and at the other end of the wetland, adjacent to Lake Wellington. This present study was established to monitor any short term changes in Lake Coleman water quality and macroinvertebrate community structure related to changing pollutant concentrations and wetland salinity following cessation of discharge of treated effluent to the wetland in October 1992.

METHODS

Sampling sites

Five sites around the perimeter of Lake Coleman were sampled for physico-chemical parameters and aquatic macroinvertebrates in September 1992, October 1993 and September 1994 (Fig. 1). Sampling site characteristics are detailed in Table 1. Lake Coleman was inundated with flood waters sourced from the Latrobe River and the wetland catchment in September 1993.

Water quality sampling

Water samples for physico-chemical analyses consisted of a single grab-sample collected from the water surface at each sampling site on each sampling occasion. Samples were analysed for colour (Shimadzu UV-Vis spectrophotometer), electrical conductivity (Philips PW9505 EC meter), pH (Philips PW9418/20 pH meter), dissolved oxygen (YSI Model 58 DO meter), nitrate and total phosphate (ion chromatography, Waters Chromatography) and suspended solids and chlorophyll *a* using appropriate standard methods (Anon. 1992).

Invertebrate sampling

Five replicate littoral samples were collected from each site on each sampling occasion using a hand-held sweep net with a mesh aperture of 250 μm. Each replicate was collected by moving the sweep net amongst emergent vegetation over a 10 m length of the littoral zone. This method has been found to be an effective means of integrating a range of micro-habitats (i.e. water column, upper sediments and vegetation) found in these environments (Cheal *et al.* 1993). Samples were preserved on site in buffered 5% formalin. Samples were washed over a 1 mm sieve in the laboratory and retained macroinvertebrates were sorted from detritus and sediments under magnification, counted, and with the exception of Amphipoda, Oligochaeta and Nematoda, identified to species level using available keys and a laboratory voucher system (Hawking 1993). Adult and larval beetles were treated as separate species.

Statistical analysis

Water quality data were standardised to *z*-scores and inter-relationships between parameters investigated using Principal Components Analysis (PCA). Cluster analysis was used to group sampling sites. Spearman rank correlations between water physico-chemical parameters and macroinvertebrate species richness and densities were also calculated.

Table 1: Lake Coleman sampling site characteristics

Site	Littoral water depth	Littoral sediments	Littoral vegetation	Habitat	Impacts
A	10 cm	sand	*Juncus usitatus*	Exposed	Effluent
B	10 cm	silt	*Phragmites australis* *Juncus usitatus*	Protected	Effluent
C	60 cm	silt	*Phragmites australis*	Protected	
D	10 cm	very fine silt	*Juncus usitatus*	Semi-protected	
E	5 cm	very fine silt	*Juncus usitatus*	Exposed	Saline water

Two factor analysis of variance (ANOVAs) by sampling site and time was used to investigate differences in macroinvertebrate abundance and species richness. Where significant interactions were present, simple main effects were analysed with one-way ANOVAs to compare species richness and macroinvertebrate densities between times for each sampling site separately and between sites for each sampling time separately, with a Bonferroni adjustment to significance levels for these *post-hoc* analyses (Kirk 1995). Tukey HSD multiple comparison tests were used to locate any significant differences in simple main effect analyses. Non-Metric Multidimensional Scaling (NMDS) using a Bray-Curtis distance matrix derived from root-root transformed means (Raffaelli *et al.* 1991) was used to discriminate between sampling sites over the survey period based on their faunal attributes (Gray *et al.* 1992). The significance of the NMDS results were tested using the ANOSIM procedure (Clarke and Green 1988; Clarke and Warwick 1994) and matching macroinvertebrate community structure with water quality characteristics was attempted using the BIOENV procedure (Clarke and Warwick 1994). Statistical analyses were carried out using the *PRIMER V4.0* (Clarke and Warwick 1994) and *SYSTAT V5.03* (Wilkinson 1990) computer packages.

RESULTS

Water Quality

Water quality data recorded at each site between September 1992 and September 1994 are presented in Table 2. In general, wetland waters were more highly coloured and nutrient rich, and lower in electrical conductivity and suspended solids concentrations in the vicinity of the two effluent discharges than at the western end of the wetland in 1992. Flood waters of 1993 lowered electrical conductivities at all sampling sites. Water samples collected in 1994 tended to have higher electrical conductivities and suspended solid concentrations and lower colour and nutrient concentrations. Highest phosphate concentrations were recorded from site A in 1992, and highest colour and suspended solids concentrations were recorded from site E in 1993. Highest salinities and lowest nutrient, suspended solids and colour concentrations were recorded from site C in 1994. Water samples were more alkaline at the western sampling sites located away from the outfalls.

The first two components of the analysis carried out on water quality data accounted for 68% of the variance in the data (Table 3). Principal Component I was highly correlated with pH, dissolved oxygen, particulates and colour and Component II with electrical conductivity, chlorophyll *a* and nutrients. The plots of the PCA sample scores separated sites with higher electrical conductivities from sites with lower electrical conductivities along a suspended solids gradient (Fig. 2). Groupings were not obviously related to sampling time or location.

Macroinvertebrates

A total of 46,300 individuals comprising 148 operational taxonomic units were collected from Lake Coleman over the three year sampling period. Species richness was highest for the Coleoptera (39 species) followed by Diptera (38 species) and Hemiptera (12 species). Macroinvertebrate species contributing more than 1% of total macroinvertebrate densities at each site on each sampling occasion are presented in Table 4. Percentage composition of the major invertebrate taxa varied between sites and over time (Fig. 3), although Hemiptera, Coleoptera, Amphipoda and Decapoda made up significant portions of the fauna at most sites on most sampling occasions. Macroinvertebrate densities were negatively correlated with total phosphate concentrations (r_s = -0.638, $0.01<P<0.05$) and colour (r_s = -0.566, $0.01<P<0.05$) and macroinvertebrate species richness was negatively correlated with total phosphate concentrations (r_s = -0.674, $0.001<P<0.01$). There was no significant correlation between water quality PCA factor scores and macroinvertebrate densities or species richness ($r_s<0.26$, $0.2<P<0.5$).

Species richness and macroinvertebrate densities differed significantly between sampling sites and times (Tables 5 and 6) and significant interactions were also present. Significant differences in macroinvertebrate densities and species

Table 2: Summary of Lake Coleman water quality data from September 1992 to September 1994

Date	Site	pH (units)	DO (mg l^{-1})	EC (mS m^{-1})	Colour (Pt. Co. Units)	NO_3 (mg l^{-1})	TP (mg l^{-1})	Chl *a* (mg l^{-1})	SS (mg l^{-1})
Sep92	A	8.3	10.8	590	420	0.230	1.500	0.0422	120
	B	8.2	11.3	750	320	0.110	0.780	0.0665	120
	C	8.0	11.1	920	210	0.088	0.140	0.0017	17
	D	7.9	11.0	970	210	0.092	0.350	0.1271	300
	E	7.5	9.4	1050	220	0.073	0.640	0.1054	780
Oct93	A	8.6	11.4	430	200	0.307	0.940	0.6713	160
	B	8.9	13.2	430	200	0.246	0.560	0.3663	120
	C	8.9	13.4	490	210	0.266	0.230	0.1813	44
	D	7.6	9.6	270	410	0.222	0.550	0.2201	490
	E	7.7	8.9	230	680	0.273	0.520	0.2358	810
Sep94	A	8.2	9.4	750	260	0.005	0.470	0.1281	240
	B	8.2	10.3	750	280	0.005	0.430	0.1200	180
	C	8.6	12.9	1200	120	0.005	0.066	0.0060	15
	D	7.8	9.4	820	280	0.593	0.350	0.0613	640
	E	7.9	8.8	850	270	0.289	0.700	0.1020	410

Table 3: Variable loadings from the principal components analysis of water quality data, September 1992 to September 1994.

Water Quality Variable	Principal Component	
	I	II
pH	-0.944	0.166
Dissolved oxygen	-0.924	-0.042
Suspended solids	0.872	0.191
Colour	0.634	0.534
Electrical conductivity	0.074	-0.911
Chlorophyll *a*	0.124	0.740
Nitrate	0.189	0.596
Total phosphate	0.125	0.556
Eigen values	3.21	2.24
% variance explained	38.2	29.9

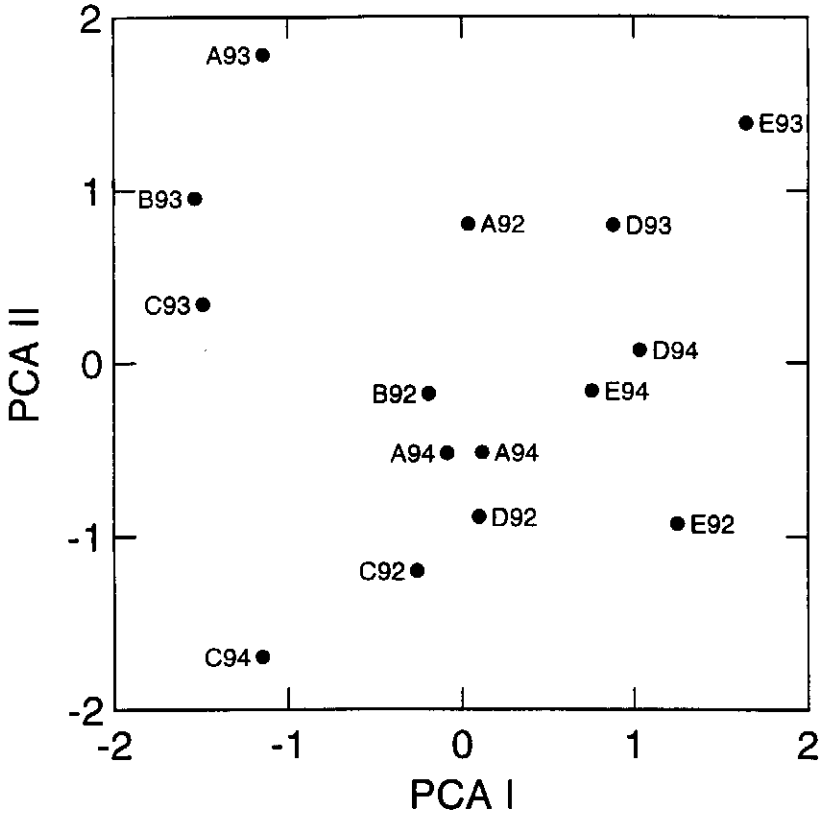

Figure 2: Principal component ordination of water quality data.

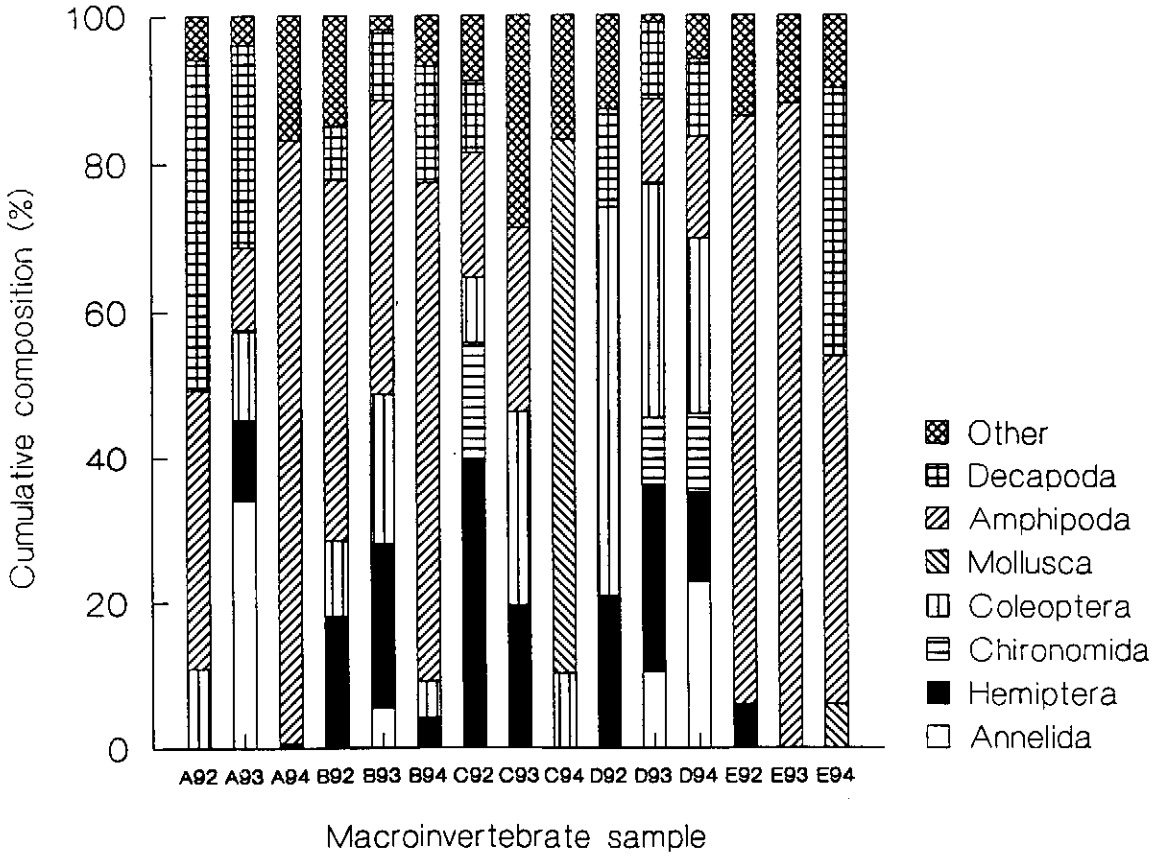

Figure 3: Cumulative percentage composition of major macroinvertebrate taxa at each site by sampling date.

Table 4: Percentage contribution of major species to total site macroinvertebrate density (1%<*<5%).

SAMPLING YEAR	1992					1993					1994				
SAMPLING SITE	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
NEMATODA															
Nematod spp.				*	*										
ANNELIDA															
Oligochaete spp.				*		24.3	6.8	*	17.0	*	*	*	*	*	*
Syllid sp. 1							*	*		22.5	*	*	*		
Boccardiella limnicola		*		*	*	*	*	*	*	*	*	*	*	*	*
MALACOSTRACA															
Paratya australiensis	49.3	48.2		*	13.8	11.3	19.9	5.4	8.2	30.8	42.9	33.9	*	*	32.0
Amphipod spp.	40.9	16.5	59.5	18.9	29.5	44.3	32.3	33.8	*	*	38.7	42.6	35.9	87.8	37.2
Cymodetta sp. A		*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sphaeroma sp. A	*	*			*	*	*			*	*				
Ostracod sp. 2			9.3	*			*	*					*		
Cumacean sp.1	*	*		*	*					*					
MOLLUSCA															
Hydrobia buccinoides	*	*	*	*	*			*		*	*		52.3		
Fluviolanatus amarus	*	*				*	*	*	*	7.5	*	*		*	*
Potomopygrus sp.								*		*		*	*	*	*
INSECTA															
Hydrophilidea sp. L2			*	*	*	*	*	*							
Micronecta robusta	*	24.1	*	15.8	9.9	*	18.0		5.7	*			*		
Sigara australis	*	*	*	*	6.8	*	*	7.7	*	5.4		*	*	*	*
Juvenile corixids			17.6			*	*	17.3	7.9	*	*	*		*	*
Juvenile hemiptera	*			9.6	*						*				
Anisops thienemanni	*			*	*	*	*		*		*	*		*	*
Anisops deani/nabilla	*	*		*	*	*	*	*	*		*	*	*		
Juvenile notonectids						*	*	*	24.9	*					
Ischnura aurora aurora						*	*	*	*	*			*	*	
Juvenile odonata								*	*			*	*		
Tanytarsus sp.			*	*		*	*	*	*	*					
Chironomus sp.1			*	*		*	*	*	9.4	*			*		
Chironomus februaris								*	*	*					*
Polypedilum oresitrophus			*				*								
Procladius sp.			*	*				*	*	*	*	*	*	*	8.4
Ceratopogonidae sp. M		*	*	*				*					*	*	
Diptera pupae			*	*		*		*	*				*		

Table 5: Results of anova of Lake Coleman macroinvertebrate densities (Data Log_{10} transformed prior to analysis).

Factor	*df*	MS	*F* ratio	*P*
Time	2	0.274	4.337	0.017
Site	4	2.503	39.673	<0.001
Interaction	8	0.311	4.934	<0.001
Residual	60			

Table 6: Results of anova of Lake Coleman species richness. (Data square-root transformed prior to analysis).

Factor	*df*	MS	*F* ratio	*P*
Time	2	7.527	27.088	<0.001
Site	4	13.868	49.913	<0.001
Interaction	8	1.045	3.761	0.001
Residual	60			

Table 7: Summary of ANOVAs comparing macroinvertebrate densities and species richness across sampling sites for each sampling year separately. All data log_{10} or square root transformed prior to analysis. $^{**}0.001<P<0.006$, $^{***}P<0.001$. Sites joined by a horizontal line were not significantly different.

Year	ANOVA *F* test, change in individual no. over time	Tukey HSD test (individuals)	ANOVA *F* test, change in species no. over time	Tukey HSD test (species)
1992	$F = 14.811^{***}$	A B E D C	$F = 49.886^{***}$	A B E D C
1993	$F = 5.622^{**}$	E B A D C	$F = 9.607^{***}$	A E B D C
1994	$F = 29.643^{***}$	B E A D C	$F = 15.833^{***}$	A E B D C

Table 8: Summary of ANOVAs comparing macroinvertebrate densities and species richness across sampling times for each sampling site separately. All data log_{10} or square-root transformed prior to analyses. $^{**}0.001<P<0.01$, $^{***}P<0.001$. Years joined by a horizontal line were not significantly different.

Site	ANOVA *F* test, change in individual no. over time	Tukey HSD test (individuals)	ANOVA *F* test, change in species no. over time	Tukey HSD test (species)
A	$F = 4.506$	1992 1994 1993	$F = 9.091^{***}$	1992 1994 1993
B	$F = 3.630$	1994 1992 1993	$F = 14.446^{***}$	1992 1994 1993
C	$F = 3.161$	1992 1993 1994	$F = 3.326$	1992 1994 1993
D	$F = 11.824^{***}$	1992 1993 1994	$F = 9.467^{***}$	1994 1993 1992
E	$F = 1.254$	1994 1993 1992	$F = 5..779^{**}$	1994 1992 1993

Table 9: Summary of Lake Coleman macroinvertebrate community indices, 1992 to 1994. All samples totaled over 50 m of the littoral.

Site	Total number of individuals			Total number of species		
	1992	1993	1994	1992	1993	1994
A	643	1620	1140	21	35	30
B	670	1500	640	19	49	26
C	6510	4290	11700	44	54	62
D	1620	2770	9990	57	61	39
E	1400	1140	812	28	38	19

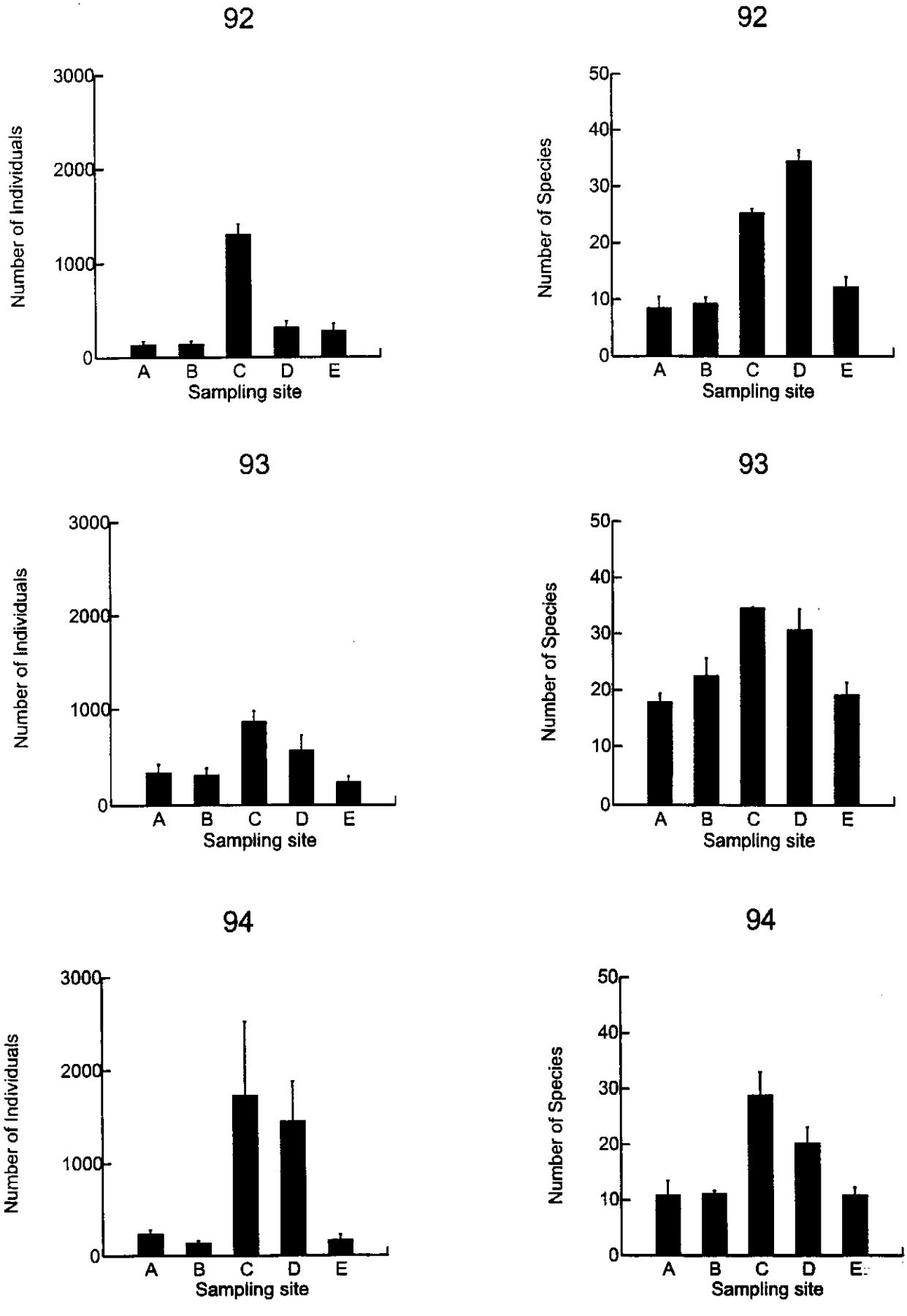

Figure 4: Macroinvertebrate species richness and densities (n=5, error bars=1 SEM)

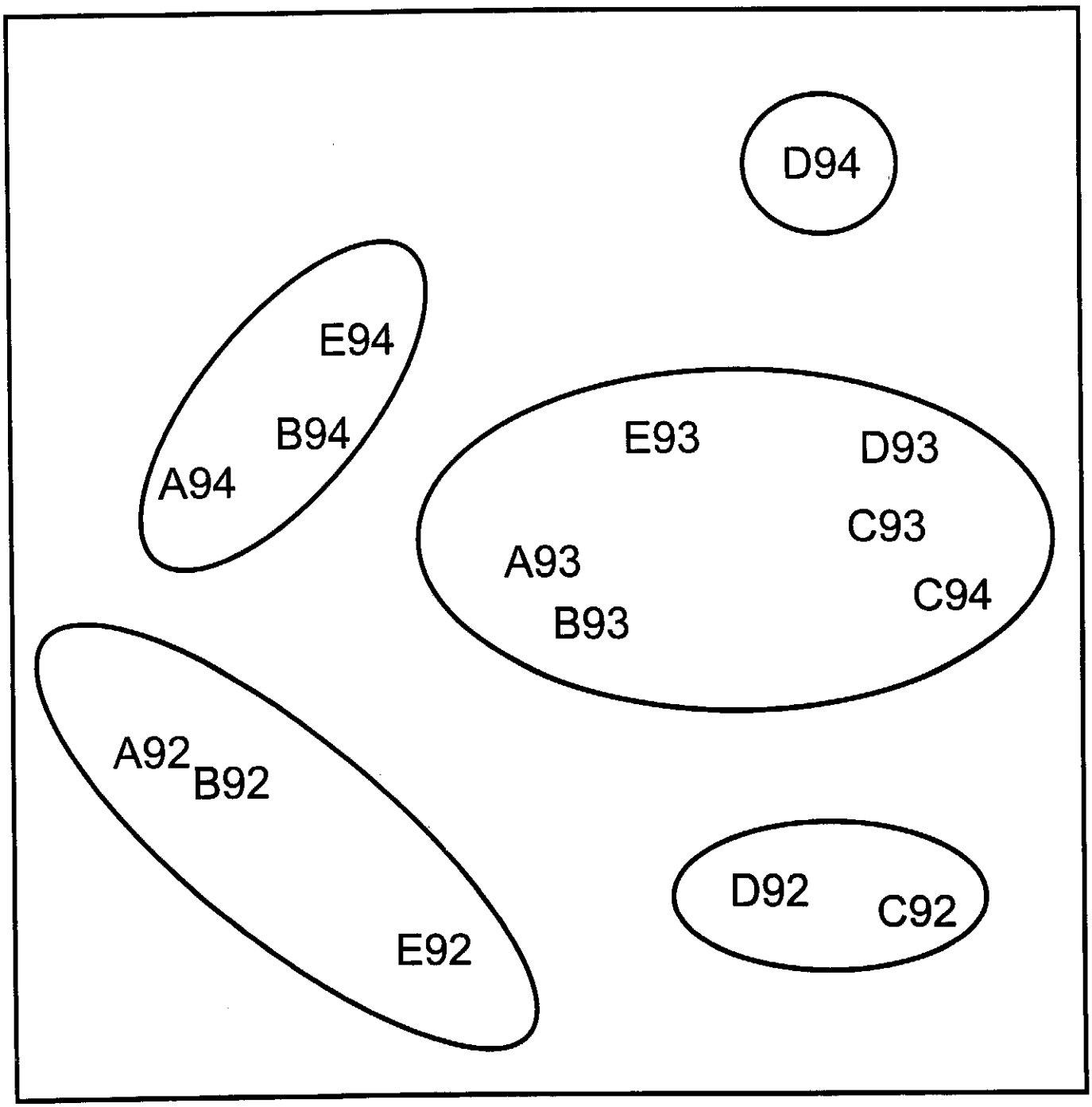

Figure 5: NMDS plot of macroinvertebrate data (stress=0.10)

richness existed between sites on each sampling occasion (Table 7). The greatest mean species richness and mean macroinvertebrate densities occurred at sites C and D on each sampling occasion (Fig. 4). The density of macroinvertebrates at site D varied significantly over time (Table 8), with highest densities being present at site C in all years. Species richness of the macroinvertebrate communities varied significantly over time at all sites (Table 8) with richness being highest at site D in 1992 and at site C in 1993 and 1994. The total number of species and individuals pooled for each site also varied over time at all sampling sites (Table 9). There was, however, no consistent pattern in trends between sites for these parameters.

A Multidimensional Scaling (NMDS) ordination of the macroinvertebrate data with site groups derived using cluster analysis is presented in Fig. 5. The plot showed no consistent site/time groupings although there was some separation of outfall sites (sites A and B) and site E from other sites along dimension 1 and separation of samples collected in 1992 from other times along dimension 2. Samples collected in 1993 formed a cluster discrete from other time/site groupings. An analysis of similarity (two-way ANOSIM, no replication; Clarke and Warwick 1994) confirmed that differences between sites were significant (R=0.487, P=0.011), but indicated that differences over time were non-significant (R=-0.050, P=0.531). There was no significant relationship between macroinvertebrate community structure and water quality identified using the BIOENV (Clarke and Warwick 1994) analysis (S_R = 0.267; electrical conductivity, nitrate and total phosphate).

DISCUSSION

Changes in Lake Coleman water quality over the three year sampling period reflect the impact of cessation of effluent discharge together with flood inundation of the wetland. Prior to the cessation of effluent discharge, water samples collected from eastern sampling sites (sites A and B) were dilute (low in salinity and suspended solids) and were relatively highly coloured and nutrient rich compared with samples collected from the western end of Lake Coleman. This water quality gradient across the wetland had been recorded in previous studies (Robinson 1988). Nutrient concentrations declined at the two outfall sites between 1992 and 1994 following cessation of effluent discharge and dilution by flood waters in September 1993. Flood waters lowered salinities at all sampling sites in 1993, but only lowered wetland water colour at the two outfall sites. The western sampling sites are fringed by *Melaleuca* woodlands. Leached humic substances released during decomposition of *Melaleuca* vegetation have been demonstrated to increase water colour (Wrigley *et al.* 1988) and it is likely that overland flood flows transported coloured compounds into the wetland at the western end of Lake Coleman in 1993. Water colour remained lower than 1992 levels at the two outfall sites in 1994, a consequence of dilution and photo-chemical degradation of effluent colour (Robinson 1988). As predicted by previous laboratory trials (Haynes *et al.* 1994), chlorophyll *a* concentrations tended to increase with decreasing water colour concentrations at outfall sites. Lake Coleman waters were hyper-eutrophic (i.e. contain >0.1 mg l^{-1} of phosphorus (Wetzel 1975)) over the sampling period. The observed increase in chlorophyll *a* concentration supports the contention that water colour is an important factor controlling primary productivity in Lake Coleman (Congdon 1986; Wrigley *et al.* 1988).

Littoral macroinvertebrate species richness and densities were lower at all Lake Coleman sampling sites than those reported for Dowd Morass, an adjacent, relatively un-impacted wetland (Robinson 1988). Species richness in Lake Coleman was however, up to three times greater than present in McLeod Morass, a nearby domestic sewage impacted wetland (Bibrowska and Robinson 1989). Macroinvertebrate species richness and densities were variable over the 3 year sampling program with highest densities and species richness present at sites C and D. The average species richness of the macroinvertebrate communities at the two outfall sites varied significantly over the sampling period. Changes in macroinvertebrate communities at these sites were associated with the 1993 floods and both species richness and densities

returned to 1992 (effluent discharge) levels in 1994. Flooding of wetlands has been associated with release of organic matter (Briggs and Maher 1985; Neckles *et al.* 1990) and subsequent enhanced wetland productivity. Lake Coleman is hyper-eutrophic, and it is more likely that dilution of water column contaminants (including nutrients) by flood waters contributed to macroinvertebrate community change at this time. This is supported by the negative correlation present between macroinvertebrate species richness and total phosphate concentrations and between macroinvertebrate densities and total phosphate concentrations and colour recorded over the survey period. Species richness was also highest at site E following flooding. Saline waters also depress wetland species richness (Hart *et al.* 1989) and the reduction in water column salinity by floods at site E in 1993 is likely to have influenced community structure at this time. In contrast, flooding did not significantly alter species richness at the remaining non-outfall sites, although highest species richness at site D was associated with the flood waters of 1993 (Table 9).

Further monitoring of wetland macroinvertebrate community structure and water quality is now required in order to gauge the success of present management strategies for the wetland.

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