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Invertebrate community structure related to physico-chemical parameters of permanent lakes of the south coast of Western Australia

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Abstract

The aquatic invertebrate fauna and a range of physical and chemical parameters were recorded in twenty-three permanent lakes within 20 km of the coast between Cape Naturaliste and Albany, Western Australia. Invertebrates were collected by qualitative sweeps, benthic cores and plankton trawls to sample all major habitats. A total of 209 invertebrate taxa were recorded, representing a rich faunal diversity. Multivariate analyses showed that invertebrate community structure was most closely associated with salinity and nutrient status of the lakes; however, all salinities were below the limnologically accepted 3 g l^{-1} upper limit for freshwater (Bayly & Williams 1973). Human activities are most likely responsible for the elevated nutrient levels recorded in some of the lakes.

Introduction

Lentic wetlands in the south-west of Australia, particularly lakes on the Swan Coastal Plain associated with urban development, have recently been the focus of much research. Wetlands on the Swan Coastal Plain today represent only about 30% of wetlands present prior to European settlement (Halse 1989) and many are now eutrophic due to urbanization and agriculture (Davis & Rolls 1987; Balla & Davis 1993; Davis *et al.* 1993).

In contrast, the permanent lakes along the south coast are less disturbed and have received little attention. Limnological studies on south coast lentic wetlands have mainly been restricted to temporary systems (Bayly 1982, 1992a; Christensen 1982; Pusey & Edward 1990a,b) although two permanent pools were included in the latter study. Recently, a survey of aquatic invertebrates in three lakes in the Two Peoples Bay area (Storey *et al.* 1993) outlined a highly diverse invertebrate fauna, with possible biogeographic links to south-western Tasmania. Establishing a database of physical, chemical and biological parameters in south-coast wetlands is essential for developing management procedures to deal with the impact of increased human activity. This study elucidates relationships between environmental parameters and invertebrate community structure for the lakes surveyed, and provides a database to assess the conservation value of the lakes to enable formulation of future management programmes.

Materials and Methods

Study sites

Twenty-three permanent lakes in the south of Western Australia were studied, all located on Vacant Crown Land within 20 km of the coast between Cape Naturaliste and Albany (Fig 1). Several of the lakes were not officially named and are therefore referred to as follows; the lake near the junction of Charley and Dunes Roads, Pemberton is Charley Lake; the lake north east of Windy Harbour is Windy Harbour Lake; for the group of lakes near Boat Harbour Road, Denmark, the eastern lake is Boat Harbour Lake 1, the western lake is Boat Harbour Lake 3 and the northern lake is Boat Harbour Lake 4.

Sampling regime

Fifteen lakes were sampled in 1991 during winter (25 June–2 July) and six of these, located across the geographical range of the survey, were re-sampled in spring (4–13 November), together with six additional lakes. Charley Lake and Lake Williams were sampled in early summer (18 & 19 December) because of forest quarantine restrictions; these were considered spring samples because typical hot/dry summer conditions had not commenced.

Environmental parameters

The physical and chemical parameters measured in the lakes, and the methods used are summarised in Table 1. Surface area of the lakes was estimated from enlarged photocopies of 1:50000 maps, using a Delta-T™ Area Meter. Temperature, dissolved oxygen and pH were measured from surface waters at each lake between 1030 and 1430 h. Depth was recorded along at least two transects for those lakes accessible to a boat. At these lakes, vertical profiles of dissolved oxygen and temperature were recorded to determine the extent of any stratification. The ratio of surface to bottom readings for temperature and dissolved oxygen was used as a measure of stratification in subsequent statistical analyses, where a ratio of one indicated no stratification.

Undisturbed water samples were taken for analyses for colour, turbidity, anions and cations. Salinity was calculated as the total concentration of the major cations (Mg, Ca, K and Na) and chloride in solution. These ions account for approximately 95% of the total soluble salts (TSS) for drainage basins

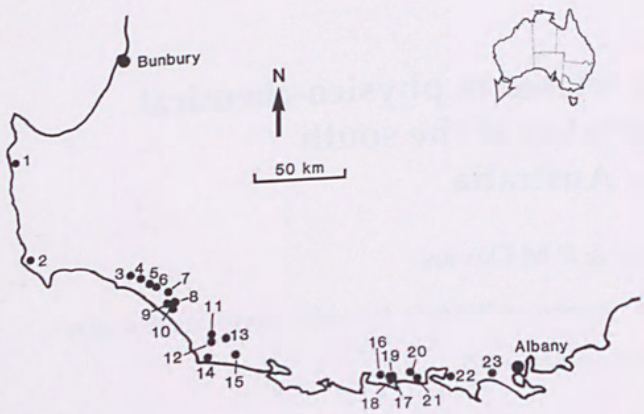

Figure 1. Map of locations of the lakes.

1. Quininup Lake	33 45' 48" S	115 00' 06" E
2. Lake Davies	34 13' 20" S	115 01' 58" E
3. Lake Quitjup	34 22' 58" S	115 35' 40" E
4. Lake Jasper	34 24' 40" S	115 40' 59" E
5. Lake Wilson	34 25' 39" S	115 43' 00" E
6. Lake Smith	34 25' 45" S	115 43' 26" E
7. Charley Lake	34 30' 21" S	115 49' 28" E
8. Yeagarup Lake	34 32' 43" S	115 52' 14" E
9. Neanup Lake	34 32' 47" S	115 51' 32" E
10. South Yeagarup Lake	34 33' 08" S	115 51' 58" E
11. Doggerup Lake	34 43' 03" S	116 03' 36" E
12. Lake Samuel	34 43' 55" S	116 03' 26" E
13. Lake Florence	34 44' 03" S	116 05' 57" E
14. Windy Harbour Lake	34 50' 00" S	116 02' 25" E
15. Lake Maringup	34 50' 00" S	116 11' 55" E
16. Owingup Lake	34 59' 56" S	117 03' 57" E
17. Boat Harbour Lake 1	35 01' 01" S	117 05' 59" E
18. Boat Harbour Lake 3	35 01' 01" S	117 05' 17" E
19. Boat Harbour Lake 4	35 00' 53" S	117 05' 46" E
20. Lake 12046	34 59' 56" S	117 13' 23" E
21. Lake Williams	35 01' 00" S	117 16' 03" E
22. Lake Saide	35 02' 34" S	117 28' 24" E
23. Lake Powell	35 01' 14" S	117 44' 16" E

on the south coast of Western Australia (Loh *et al.* 1983). Water samples for total nitrogen and phosphorus determinations were filtered in the field through a 0.22 μm Millipore™ filter using a 50 ml syringe. Samples for chlorophyll (a) determinations were taken by filtering a measured volume (approx. 1 l) of water through a Whatman™ GF/C filter, and the retained cells, containing chlorophyll, were stabilized with a few drops of a saturated magnesium carbonate solution. The filter was folded, blotted between gauze swabs and placed in a plastic bag on ice, out of the light, before being stored frozen in the laboratory. Chlorophyll (a) was then measured using the method described in Strickland & Parsons (1968). At each lake, a 10 cm deep core-sample of the benthic material was collected in a vertical-sided vial with 13.2 cm^2 lid opening. In the laboratory, the percent organic content was determined after drying at 40 °C and ashing in a muffle furnace at 450 °C for approximately eight hours.

Invertebrates

The methodologies for collecting fauna were designed to sample the major aquatic habitats and maximise the number of species recorded from each lake. Six random replicate benthic samples were taken with a 72 cm^2 core sampler to 10 cm depth from each lake. Samples were immediately preserved in 5% formalin. In the laboratory, the organic fraction was separated from the sediment by water elutriation and washed through a 250 μm sieve. The fauna was removed from the organic fraction using a dissecting microscope. All individuals were identified to the lowest taxon possible, usually species, either by the use of keys or by matching specimens to a voucher collection at the Aquatic Research Laboratory, Department of Zoology, The University of Western Australia. The Calanoida, Ostracoda and Cladocera

Table 1

Environmental parameters, methods of measurement and units of precision.

Parameter	Method / Apparatus	Precision	Acronym
Lake surface area	Estimated from 1:50000 map		SA
Temperature	Mercury thermometer & Yeo-Kal 602 Hamon salinity / temperature bridge	0.5°C 0.5°C	Temp
Dissolved oxygen	Nester portable meter	0.1 mg l^{-1}	DO
pH	Kane-May KM 7001 portable pH meter	0.1 pH unit	pH
Depth	Graduated line	0.05 m	Depth
Colour	UV-VIS spectrophotometer	5 APHA units	Col
Turbidity	Nephelometric method	0.1 NTU	Turb
Anions & cations	Atomic absorption spectrophotometer	0.4 mg 1^{-1}	chemical symbols
Salinity	Sum of anion & cation concentrations		Sal
Total nitrogen	Auto analyser	0.01 mg l^{-1}	N
Total phosphorus	Auto analyser	0.01 mg l^{-1}	P
Chlorophyll (a)	Spectrophotometer	0.01 μg l^{-1}	Chloro
Benthic organic matter	Gravimetric method	0.01%	BOM

were forwarded to specialist taxonomists for identification. We include within *Calamoecia tasmanica* (Smith) *s.l.* the two forms *C. tasmanica* and *C. tasmanica subattenuata* described from Western Australia (Bayly 1992b). An estimate of abundance for each species was made according to the following categories; < 50 (rare), 50–500 (common) and > 500 (abundant) individuals.

A standard Freshwater Biological Association (FBA) D-net with 110 µm mesh was used to collect two-minute qualitative sweep samples from the substrate and amongst the macrophytes from the littoral margin of each lake. Samples were preserved in 5% formalin. In the laboratory, the fauna was removed from the organic matter in the samples, identified and categorised as for the benthic samples.

Plankton was sampled with a 110 µm mesh net, attached to a standard FBA D-net frame, held just below the water surface. Two samples were taken from each lake, using a standardised 50 m trawl for biomass determination and a shorter trawl for identification of the plankton species. Each sample was preserved in 5% formalin. Biomass was determined after drying the samples to constant weight at 40 °C. The taxa were identified and abundance categories estimated as for the benthic samples.

Data analyses

Multivariate analyses are useful techniques to outline patterns in complex biological phenomena (Gauch 1982) and these patterns are generally correlated to underlying environmental gradients (Wright *et al.* 1984; Furse *et al.* 1984; Moss *et al.* 1987). Principal components analysis (PCA) was used to ordinate the pattern of co-occurrence of the physical, chemical and morphological parameters measured for the lakes. This technique was used to reduce the complex dataset to a few, underlying 'factors' and to eliminate redundancies inherent in the data (Noruss 1986). This analysis was performed using the SPSS/PC$^+$ advanced statistics procedure 'FACTOR'.

The total species information from each lake was classified by a polythetic divisive multivariate technique (**T**wo-**W**ay **IN**dicator **SP**ecies **AN**alysis; **TWINSPAN**, Hill 1979a). Subsequent groupings formed by TWINSPAN were correlated to environmental parameters by **M**ultiple **D**iscriminant **A**nalysis (**MDA**; Noruss 1986) using the SPSS/PC$^+$ version DSCRIMINANT. This analysis was performed between each TWINSPAN division. **DE**trended **COR**respondence **ANA**lysis (**DECORANA**, Hill 1979b) was used to ordinate the lakes on the basis of invertebrate community structure. DECORANA orders samples along an axis of similarity, where the lakes closest together on each axis have a more similar invertebrate community structure than those further apart.

Results

Environmental parameters

The 23 lakes studied ranged in surface area from 0.13 ha (Quininup Lake) to over 400 ha (Lake Jasper), with the majority of the lakes less than 100 ha in surface area (Table 2). The deepest lakes were Yeagarup and Jasper, both over 10 m (Table 2). Most of the lakes with larger surface area were shallow, ranging between about 0.8 m and about 1.3 m for Lake Powell and Owingup Swamp respectively.

Water colour was highly variable between lakes, ranging from < 5 APHA units at Quininup Lake to 740 APHA units at Lake Williams. The lakes were visually classified in this study as clear, brown and black corresponding to three APHA unit categories where clear is < 100, brown 100–300 and black > 300 (Table 3).

The pH ranged from 4.4 at Lake Florence to 8.6 at Lake Davies (Table 2). The values for pH were highly negatively correlated with colour (correlation coefficient $r = -0.83$, $n = 29$, $p < 0.001$). The low pH values probably reflected high humic/tannic content of darker waters (Table 3). The majority of these dark-water lakes lie on acid peat flats, a source of humic material. Lake colour was also correlated with water temperature ($r = 0.51$, $n = 29$, $p < 0.01$), probably due to dark water absorbing more solar radiation than clear water. Water temperatures between lakes ranged from 9.2–15°C in winter to 12.3–24°C in spring (Table 2). Temperature stratification (Table 2), with colder hypolimnetic water, which is the normal condition for deep water lakes, was recorded in Charley and Yeagarup Lakes in spring. In contrast, lakes Maringup and Jasper were stratified in winter, with warmer hypolimnetic water, which was interpreted as heating of the bottom sediments and hypolimnetic water by solar radiation in these clear-water lakes.

Salinity categories for the lakes were based on the classification for potable surface water by the Water Authority of Western Australia (1989a). The majority of the lakes were fresh; however Boat Harbour Lake 3, Lake Saide and Lake Powell were classified as marginal and Lake Davies and Owingup Swamp as brackish (Table 3).

On the basis of nutrient status (Wetzel 1975) Windy Harbour, Williams, Saide and Powell, were classified as eutrophic (Table 3). The other lakes were either oligo-mesotrophic or meso-eutrophic. Lakes sampled in winter usually had higher levels of phosphorus, probably from run-off of winter rainfall, elevating them into the meso-eutrophic category. The typical ratio of total nitrogen to total phosphorus (N:P) within the tissue of aquatic algae and macrophytes is 7:1 (Wetzel 1975). In Quininup Lake, Lake Smith, Neanup Swamp, and Boat Harbour Lake 3, the N:P ratios in the water were greater than 70:1 and therefore phosphorus was more likely the limiting nutrient. In contrast, for Lake Williams and, in winter, Lake Powell, the ratio was less than 4:1, indicating that nitrogen was the more probable limiting nutrient.

Turbidity measured in nephelometric turbidity units (NTU) ranged widely (Table 3), showing no obvious association with individual lakes. Turbidity and chlorophyll (a) were correlated ($r = 0.61$, $n = 29$, $p < 0.01$); high turbidity probably reflected the abundance of algal cells. Values for chlorophyll (a) ranged from 0.19 $\mu g\ l^{-1}$ in Yeagarup in late spring to 14.41 $\mu g\ l^{-1}$ in Lake Saide in winter (Table 3). Lower values for chlorophyll (a) were consistently recorded during spring. Based on the classification of Wetzel (1975) using chlorophyll (a) levels, the trophic status of most of the lakes was classified as oligotrophic and only lakes Powell, Saide, 12046, Boat Harbour 1, Boat Harbour 4, Windy Harbour and Owingup Swamp were classified as meso-eutrophic.

Benthic organic matter ranged from 0.16% in Lake Wilson to 87% in Boat Harbour Lake 1 (Table 3). The wide range reflects both differences in the nature of the catchments and

Table 2

Environmental information collected for each lake/occasion. W = winter, S = spring, ** = not recorded.

Lake	Season	SA (km^2)	Max. depth (m)	Temp surface (°C)	Temp ratio[1]	DO surface ($mg\ l^{-1}$)	DO ratio[1]	pH ($mg\ l^{-1}$)	Na ($mg\ l^{-1}$)	K ($mg\ l^{-1}$)	Ca ($mg\ l^{-1}$)	Mg ($mg\ l^{-1}$)	Cl ($mg\ l^{-1}$)	Cation Dominance
Quininup Lake	S	0.0013	**	18.0	1	**	1	8.30	131.73	4.3	48.50	17.01	200.65	Na >Ca > Mg > K
Lake Davies	W	0.0116	4.3	13.1	1	11.1	1.12	8.64	474.74	11.7	30.46	84.56	814.64	Na > Mg >Ca > K
Lake Davies	S	0.0116	4.5	17.0	1	11.4	1	8.60	424.86	9.8	32.46	78.25	720.70	Na > Mg >Ca > K
Lake Quitjup	W	0.7261	1.4	12.2	1	12.4	1	7.53	70.81	1.6	1.60	6.80	113.79	Na > Mg >Ca = K
Lake Jasper	W	4.3751	10.1	10.7	0.88	12.5	2.78	7.52	67.59	2.1	8.42	6.32	107.41	Na > Ca >Mg > K
Lake Wilson	W	0.1731	1.7	12.0	1	12.5	1.19	5.55	51.73	1.2	1.20	4.62	84.02	Na > Mg >Ca = K
Lake Smith	W	0.0450	1.6	13.2	1	12.4	1	4.70	45.29	0.6	< 0.40	3.89	72.32	Na > Mg > K > Ca
Lake Smith	S	0.0450	1.6	16.0	1	11.1	1	4.50	31.27	0.7	< 0.40	2.67	48.92	Na > Mg > K> Ca
Charley Lake	S	0.0260	6.4	24.0	1.33	7.8	13.00	6.50	39.31	0.8	1.30	3.30	72.32	Na > Mg >Ca > K
Yeagarup Lake	W	0.1697	10.8	11.5	1	13.8	1	7.05	34.49	0.9	6.01	3.65	54.59	Na > Ca >Mg > K
Yeagarup Lake	S	0.1697	10.1	15.2	1.27	12.8	1	6.80	33.11	1.0	5.21	3.40	57.78	Na > Ca >Mg > K
Neanup Swamp	S	0.0833	**	16.0	1	**	1	6.40	34.71	1.1	8.02	2.92	54.24	Na > Ca >Mg > K
South Yeagarup Lake	S	0.0610	**	12.3	1	**	1	6.70	26.21	1.0	43.69	3.65	41.12	Ca > Na >Mg > K
Doggerup Lake	W	0.0831	**	10.8	1	12.3	1	**	34.26	1.1	< 0.40	3.40	52.82	Na > Mg > K> Ca
Doggerup Lake	S	0.0831	2.5	18.0	1	9.8	1	5.20	36.09	0.8	< 0.40	2.92	58.49	Na > Mg > K > Ca
Lake Samuel	S	0.0667	1.1	17.5	1	11.2	1	4.70	36.32	0.7	< 0.40	3.40	62.75	Na > Mg > K > Ca
Lake Florence	S	0.1044	1.5	18.0	1	10.4	1	4.40	35.40	0.9	< 0.40	2.92	51.76	Na > Mg > K> Ca
Windy Harbour Lake	W	0.0186	0.35	9.2	1	13.7	1	6.47	82.07	2.0	4.41	9.96	124.43	Na > Mg > Ca > K
Lake Maringup	W	1.3602	4.6	9.7	0.8	12.0	1	7.58	64.14	1.9	26.05	7.29	102.81	Na > Ca > Mg > K
Lake Maringup	S	1.3602	4.8	15.8	1	11.5	1	7.90	54.49	1.7	22.04	6.08	86.85	Na > Ca > Mg > K
Owingup Swamp	S	1.7886	1.3	19.5	1	11.2	1	7.40	340.48	1.5	17.64	58.08	717.15	Na > Mg > Ca > K
Boat Harbour Lake 1	W	0.2507	0.6	13.5	1	12.5	1	8.00	150.12	4.1	29.26	18.71	245.31	Na > Ca > Mg > K
Boat Harbour Lake 3	W	0.4235	0.8	14.5	1	12.2	2.09	8.10	241.40	6.2	48.10	27.70	407.32	Na > Ca > Mg > K
Boat Harbour Lake 4	W	0.1097	**	12.5	1	12.4	1	8.05	149.66	5.6	20.44	23.09	246.02	Na > Mg > Ca > K
Lake 12046	W	0.1014	4.9	10.3	1	12.9	1	7.70	182.31	16.9	22.04	16.77	250.63	Na > Ca > K > Mg
Lake Williams	S	0.0211	2.9	21.5	1	8.0	1.60	5.80	139.78	46.9	7.30	13.30	235.74	Na > K> Mg > Ca
Lake Saide	W	0.4125	1.1	13.0	1	12.7	1	8.40	150.35	6.6	99.80	22.60	245.31	Na > Ca > Mg > K
Lake Powell	W	1.3973	0.7	15.0	1	11.8	1	8.10	291.51	10.1	29.66	28.92	492.05	Na > Ca > Mg > K
Lake Powell	S	1.3973	0.9	19.0	1	11.0	1	7.10	211.05	6.2	25.25	22.36	363.72	Na > Ca > Mg > K

[1]Ratio of surface to bottom readings.

Table 3

Environmental information collected for each lake/occasion. W = winter, S = spring, * = below detection.

Lake	Season	Salinity (mg/1)	Salinity Category[1]	Colour (APHA units)	Colour classification[2]	Turb (NTU)	Chloro (a) ($\mu g\ l^{-1}$)	N (mgl^{-1})	P (mgl^{-1})	Trophic status[3]	BOM (%)
Quininup Lake	S	403	fresh	< 5	clear	0.3	0.58	5.80	< 0.01	oligo-mesotrophic	2.47
Lake Davies	W	1417	brackish	10	clear	0.4	0.64	1.10	0.01	meso-eutrophic	1.92
Lake Davies	S	126	brackish	10	clear	0.4	1.53	0.83	< 0.01	oligo-mesotrophic	1.29
Lake Quitjup	W	195	fresh	110	brown	0.9	0.42	0.56	0.01	meso-eutrophic	0.73
Lake Jasper	W	192	fresh	15	clear	0.8	2.56	0.69	0.01	meso-eutrophic	1.16
Lake Wilson	W	143	fresh	170	brown	0.7	1.07	0.46	0.02	meso-eutrophic	0.16
Lake Smith	W	122	fresh	380	black	0.4	0.43	0.70	0.01	meso-eutrophic	1.24
Lake Smith	S	84	fresh	530	black	0.9	0*	0.70	< 0.01	oligo-mesotrophic	3.44
Charley Lake	S	117	fresh	310	black	0.4	0.97	0.64	0.01	meso-eutrophic	11.25
Yeagarup Lake	W	100	fresh	180	brown	3.0	0.41	0.55	0.01	meso-eutrophic	3.62
Yeagarup Lake	S	91	fresh	260	brown	0.7	0.19	0.55	< 0.01	oligo-mesotrophic	2.24
Neanup Swamp	S	101	fresh	240	brown	0.8	0.80	0.73	< 0.01	oligo-mesotrophic	0.18
South Yeagarup Lake	S	116	fresh	100	brown	2.6	0*	0.43	< 0.01	oligo-mesotrophic	44.82
Doggerup Lake	W	92	fresh	300	black	0.4	0.53	0.52	0.01	meso-eutrophic	17.31
Doggerup Lake	S	99	fresh	330	black	0.4	0.20	0.55	0.01	meso-eutrophic	0.43
Lake Samuel	S	104	fresh	470	black	1.1	1.78	0.79	0.01	meso-eutrophic	66.04
Lake Florence	S	101	fresh	630	black	0.7	0.39	0.89	0.01	meso-eutrophic	1.42
Windy Harbour Lake	W	223	fresh	340	black	0.9	4.84	1.00	0.05	eutrophic	72.20
Lake Maringup	W	202	fresh	20	clear	0.3	0.62	0.61	0.01	meso-eutrophic	7.40
Lake Maringup	S	171	fresh	55	clear	0.3	0.40	0.48	< 0.01	oligo-mesotrophic	17.10
Owingup Swamp	S	113	brackish	220	brown	0.6	3.59	0.69	0.01	meso-eutrophic	0.61
Boat Harbour Lake 1	W	448	fresh	70	clear	0.4	3.24	0.92	0.01	meso-eutrophic	87.10
Boat Harbour Lake 3	W	731	marginal	20	clear	0.5	2.45	1.40	0.01	meso-eutrophic	43.82
Boat Harbour Lake 4	W	445	fresh	65	clear	0.6	4.82	0.83	0.01	meso-eutrophic	44.68
Lake 12046	W	489	fresh	110	brown	1.7	3.72	0.82	0.02	meso-eutrophic	46.42
Lake Williams	S	443	fresh	740	black	0.3	1.07	1.70	0.43	eutrophic	0.37
Lake Saide	W	525	marginal	80	clear	1.3	14.41	0.90	0.04	eutrophic	1.22
Lake Powell	W	852	marginal	220	brown	12.0	12.71	1.50	0.47	eutrophic	0.87
Lake Powell	S	629	marginal	190	brown	3.1	3.29	0.97	0.12	eutrophic	1.60

[1]Based on the Water Authority of Western Australia (1989a) classification for surface water; fresh = 500 $mg\ l^{-1}$ TSS, marginal = 500-1000 $mg\ l^{-1}$ TSS, brackish = 1000-5000 $mg\ l^{-1}$ TSS.

[2]Classification according to colour measurements in APHA units; < 100 = clear, 100-300 = brown, > 300 = black.

[3]Based on Wetzel (1975); oligo-mesotrophic = 5-10 $\mu g\ l^{-1}$ P & 250-600 $\mu g\ l^{-1}$ N, meso-eutrophic = 10-30 $\mu g\ l^{-1}$ P & 300-1100 $\mu g\ l^{-1}$ N, eutrophic = 30-100 $\mu g\ l^{-1}$ P & 500-15000 $\mu g\ l^{-1}$ N.

the patchy distribution of organic material within each lake as shown for the six re-sampled lakes (Table 3).

Factor analysis of the environmental data using principal components (PCA) indicated seven major factors (Table 4). The factors are numbered in decreasing amount of variation explained and therefore considered of decreasing 'importance'. Factor 1 showed the co-occurrence of depth with stratification and low nitrogen levels. Factor 2 showed co-occurrence of all cations and anions measured, except potassium, and salinity, illustrating that in the lakes with relatively elevated salinities, no single cation was responsible. Additionally, the lakes with elevated salinity had low colour. Factor 3 was a gradient generally of parameters that were different seasonally; temperature, dissolved oxygen and colour. Factor 4 showed the association of elevated phosphorus with chlorophyll and high turbidity (Table 4). Factor 5 showed that lakes with high pH, calcium, nitrogen and chlorophyll also had low colour levels. Factor 6 showed a gradient of nutrient levels (nitrogen, phosphorus and potassium) and colour. Factor 7 was a gradient of the association of lake size with low levels of benthic organic matter. A total of 85.9% variation in environmental parameters was explained by these seven factors. The identification of these seven underlying factors greatly simplified the large data array, collapsing the information into co-occurring parameters. In subsequent analyses identifying gradients in the ordinations of invertebrate community structure, factors, rather than individual variables, were correlated with axes scores.

Invertebrates

A total of 209 taxa belonging to 6 phyla were recorded from the lakes, and the occurrence of the taxa in the lakes is shown in Appendix 1. The number of invertebrate species collected from each lake ranged from 18 in Lake Davies to 55 and 56 species in lakes Charley and South Yeagarup, respectively. Stepwise multiple regression analysis, with hierarchical inclusion of the number of species recorded in each lake against factor scores (Table 4), showed that Factors 2, 3 and 5 were significantly correlated ($p < 0.05$, F-value = 5.7,

Table 4

Factor scores calculated for the environmental variables and the percentage of variation explained by each Factor. A principal components analysis of the physico-chemical conditions associated with each site shows the pattern of co-occurrence of variables. The parameters highlighted in **bold** were considered 'significant', *i.e.* loading on any axis at > +0.30 or < -0.30 (Child 1970).

Parameter	F1	F2	F3	F4	F5	F6	F7
SA	0.163	0.007	-0.166	0.237	0.163	-0.247	**0.685**
Season	-0.134	-0.054	**0.916**	-0.153	-0.024	-0.026	0.034
Depth	**0.559**	-0.056	-0.154	**-0.302**	-0.014	0.245	**0.598**
Temp (surface)	0.106	0.100	**0.908**	-0.004	-0.003	0.201	0.057
Temp (bottom)	**0.900**	0.133	0.261	0.060	-0.032	0.103	0.151
Temp (ratio)	**0.945**	0.072	0.035	0.029	0.035	0.062	0.150
DO (surface)	**0.806**	0.117	**-0.425**	0.045	-0.268	-0.027	0.027
DO (bottom)	**0.871**	0.130	-0.183	0.094	0.058	-0.090	-0.120
DO (ratio)	**0.877**	0.014	0.122	0.012	0.079	-0.018	0.039
pH	**0.310**	0.225	0.161	0.097	**0.786**	-0.049	-0.026
Col	0.204	**-0.352**	**0.469**	0.123	**-0.584**	**0.336**	-0.196
Turb	-0.007	0.069	-0.045	**0.880**	0.024	0.017	0.154
Na	0.103	**0.963**	-0.022	0.117	0.155	0.119	0.027
K	0.100	0.253	0.105	0.172	-0.056	**0.824**	-0.097
Ca	-0.201	**0.335**	-0.170	0.213	**0.702**	0.072	-0.090
Mg	0.072	**0.981**	0.005	-0.037	0.117	0.025	0.017
Cl	0.110	**0.970**	0.026	0.116	0.125	0.073	0.049
Sal	0.093	**0.965**	0.002	0.121	0.169	0.107	0.030
Chloro	0.126	0.184	-0.249	**0.751**	**0.340**	0.041	-0.098
N	**-0.426**	0.063	0.131	-0.101	**0.475**	**0.553**	0.137
P	0.098	0.086	0.138	**0.735**	-0.126	**0.593**	0.082
BOM	0.032	-0.112	-0.293	-0.046	0.145	-0.071	**-0.735**
% variation explained	25.9	19.4	13.1	9.8	6.9	6.1	4.7

cumulative variation explained $r^2 = 0.41$). This indicated the importance of salinity, where lakes with lower salinities had higher species richness (Fig 2), and to a lesser extent, season, pH and nitrogen levels.

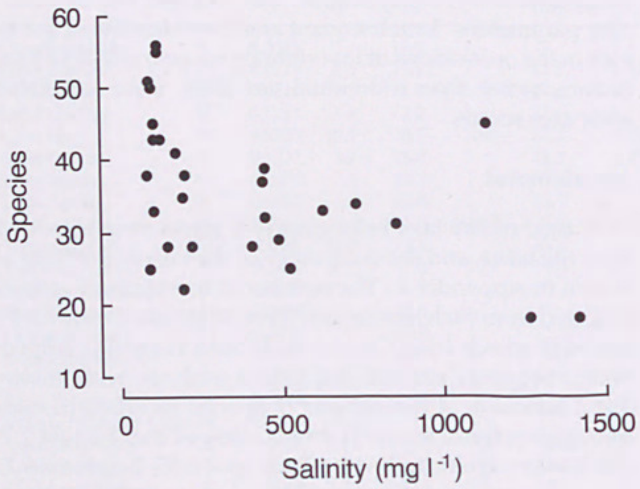

Figure 2. Regression analysis of total species richness *vs* salinity. The regression was significant $F_{(1,27)} = 7.63$, $p = 0.01$, $r = -0.47$, $n = 29$.

Zooplankton biomass was variable between lakes, ranging from zero in Doggerup Lake in winter to 678.5 mg in Lake Powell in winter (Appendix 1). The highest biomass values were recorded from lakes 12046 and Powell and consisted mainly of *Daphnia carinata* King.

TWINSPAN analysis of the total species data-set was taken to two levels and indicator species for each division are shown in Fig 3. The first and most important division separated Powell, Quininup, Davies, Owingup, Boat Harbour 3 and Saide from the other lakes (division 1 and 2; Fig 3). This division was attributed primarily to salinity, based on the results of multiple discriminant analyses (Table 5). One TWINSPAN level two division separated lakes Saide and Powell from Quininup, Davies, Owingup and Boat Harbour 3 (division 3 and 4; Fig 3) and was associated with

Table 5

Discriminant analyses, using factor scores from PCA, on TWINSPAN (presence/absence) groupings. Discriminant analysis was performed at each TWINSPAN division, terminating at level two of the classification analysis. The table illustrates percent correct classification, the most important factors (entered stepwise) for discriminating between groups, and Wilk's Lambda. All significance levels shown were $p < 0.05$. The values in brackets indicate the direction of the correlation between factor scores and TWINSPAN groupings.

Groups	% correct	Variables	Interpretation	Lambda
1/2	100	F2	high salinity	0.46 (-)
		F5	high pH/nitrogen	0.32 (-)
		F4	high phosphorus	0.27 (-)
		F7	large size	0.23 (+)
3/4	100	F4	high phosphorus	0.36 (-)
		F2	high salinity	0.28 (+)
		F1	stratified	0.22 (+)
5/6	95	F5	high pH/nitrogen	0.63 (-)
		F1	stratified	0.37 (+)
		F3	high temperature	0.26 (+)
		F2	high salinity/low colour	0.23 (-)

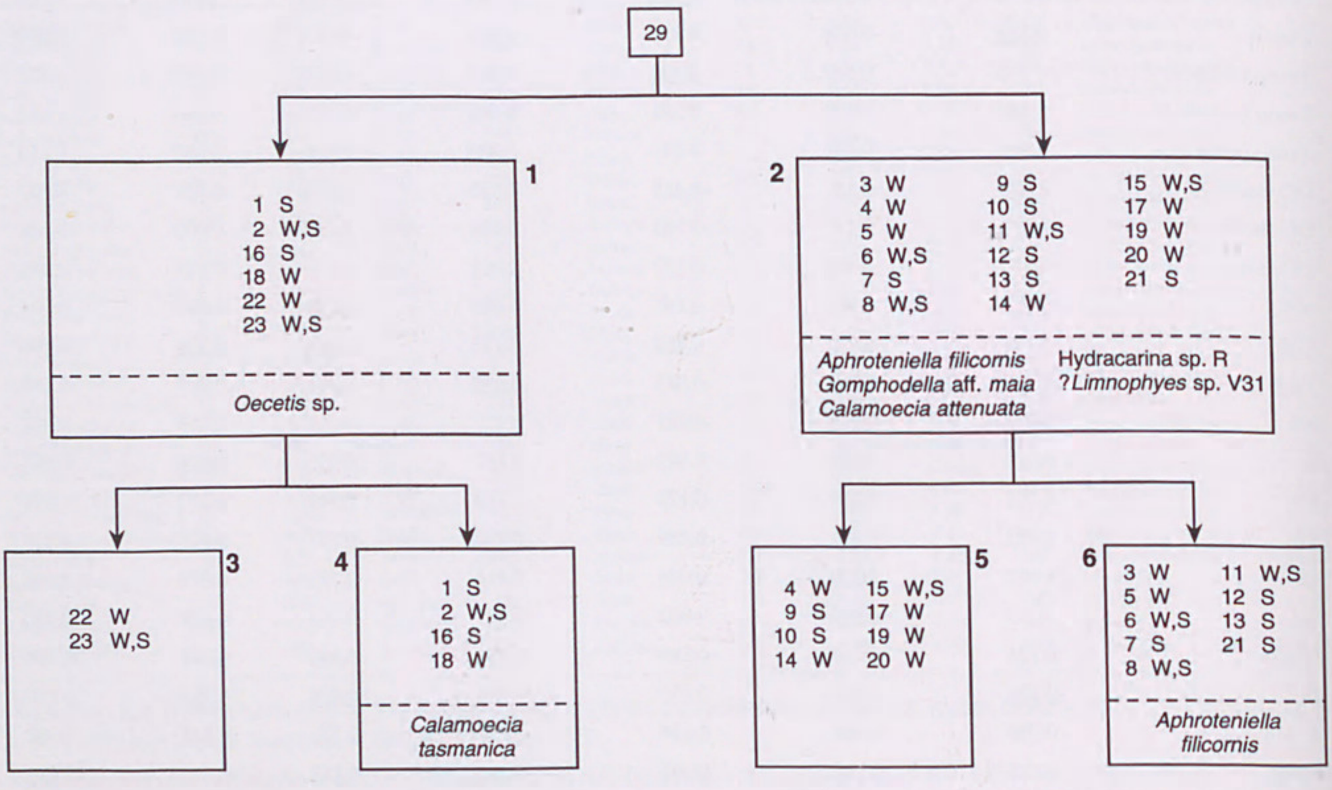

Figure 3. Dendrogram showing TWINSPAN classification of the lakes using the total species list. Indicator species are shown at the bottom of the boxes. Lake numbers as in Figure 1. W = winter, S = spring.

phosphorus levels (Table 5). The second level two division of other lakes (division 5 and 6; Fig 3) was associated with pH and nitrogen levels (Table 5).

Ordination by DECORANA on the total species data-set is presented in Figure 4. Along axis one, the obvious separation is of lakes Powell and Saide from the other lakes. Axis one was a gradient of pH, salinity and phosphorus concentration. These variables explained 32, 27 and 16% of the total respectively (Table 6).

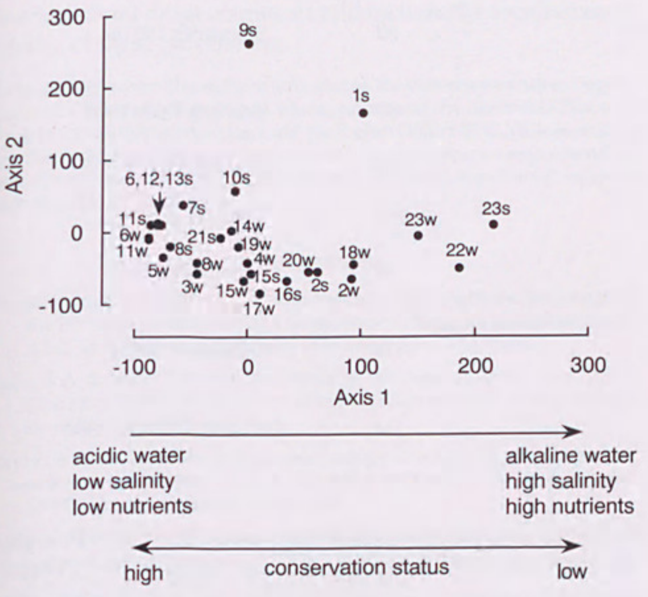

Figure 4. Axis 1 by axis 2 plot of DECORANA scores using total species for each lake. w = winter, s = spring. Lake numbers as in Figure 1.

Table 6

Results of stepwise multiple regression analysis, with hierarchical inclusion of DECORANA axes scores against environmental parameters. The cumulative variation explained (r^2) by each variable and F-values are presented. All factors where the F-values were significant at $p < 0.05$ are shown in the table.

Dependent variable	Factor	Interpretation	r^2	F-value
Axis 1 scores	F5	pH/nitrogen	0.32	12.6
	F2	salinity	0.59	18.8
	F4	phosphorus	0.76	25.8
Axis 2 scores	F1	depth/stratification	0.47	24.1
	F3	season	0.69	28.4

Discussion

The permanent lakes of the south coast of Western Australia contained a highly diverse invertebrate fauna, totalling 209 taxa. However, the total taxa count would have been higher if the Nematoda and Annelida could have been identified to species. An interesting feature of the fauna was the number of species that previously had been recorded in lotic habitats in Western Australia. Five of the dragonfly species; *Austrogomphus lateralis* (Selys), *Hemigomphus armiger* (Tillyard), *Lathrocordulia metallica* (Tillyard), *Hesperocordulia berthoudi* (Tillyard) and *Synthemis cyanitincta* (Tillyard) are considered to be stream species (Watson 1962). Within the Chironomidae, 14 species; *Paramerina levidensis* (Skuse), ?*Zavrelimyia* sp. V20, *Ablabesmyia* sp. V37, Orthocladiinae sp. V43, *Cricotopus annuliventris* (Skuse), ?*Limnophyes* sp. V31, *Thienemanniella* sp. V19, *Dicrotendipes* sp. V47, *Nilothauma* sp., *Riethia* sp. V4, *Riethia* sp. V5, *Harnischia* sp. VCD10, *Stempellina ?australiensis* Freeman and *Aphroteniella filicornis* Brundin have been recorded only from upland streams of the jarrah and karri forests (Edward 1986; Storey & Edward 1989). The Trichoptera, except Leptoceridae sp. F, sp. H and sp. I, the Amphipoda *Perthia acutitelson* Straškraba and the Dytiscidae beetle *Sternopriscus browni* Sharp have been recorded in upland streams of the northern jarrah forest (Aquatic Research Laboratory 1988; Bunn *et al.* 1986; Storey *et al.* 1990).

The provisionally identified *Glacidorbis* sp., from South Yeagarup Lake, is of interest because the only previous representative from Western Australia, *Glacidorbis occidentalis* Bunn & Stoddart, is highly associated with intermittently flowing streams (Bunn *et al.* 1989). The genus is known from both lotic and lentic waters in eastern Australia (Ponder 1986).

The species richness of the fauna was high, in both a regional and State context, to the extent that many of the lakes could be considered environments with high conservation significance. Species richness of invertebrates provides a useful comparison for different aquatic systems, with more diverse systems being considered 'healthier' than less diverse ones (Magurran 1988). Table 7 shows a comparison of species richness for invertebrates from different biogeographic regions of Western Australia. Species richness was high for lakes from both the Swan Coastal Plain and the south coast regions. The permanent lakes of the Swan Coastal Plain were characterised by nutrient enrichment to an extent where many were eutrophic, and the lakes were sampled on more than one occasion (Davis *et al.* 1993), which would have substantially increased the total species list. Sampling in summer/autumn would be likely to increase the total number of species for the south coast lakes. The major differences in species composition were that only about 30% of the identified species were shared by lakes in the two regions, with high numbers of species of Coleoptera in the Swan Coastal Plain lakes and high numbers of species of Chironomidae in the south coast lakes.

Multivariate classification of the lakes on the basis of invertebrate community structure and subsequent correlation with environmental parameters illustrated a tight coupling. Multiple discriminant analyses using TWINSPAN groupings produced an approximately 98% correct classification, suggesting that a model can be derived where by the type of invertebrate community can be predicted with a very high degree of accuracy, given a set of environmental parameters collected during winter/spring. Any departure from this predictive success could indicate some level of disturbance.

The most important environmental parameters, determined by multiple discriminant analyses to be significantly associated with invertebrate community structure, were

Table 7

Species richness of invertebrates recorded from a range of methodologically similar studies of lentic systems in Western Australia.

System	Catchment	Lakes	Seasonal sampling	Species richness	Reference
South coast lakes	mostly undisturbed	23	limited	209	this paper
Two Peoples Bay Lakes (south coast)	mostly undisturbed	3	yes	123	Storey *et al.* 1993
Robe River pools (Pilbara)	mostly undisturbed	10	limited	80	Streamtec 1991a
Swan Coastal Plain lakes	urban	5	yes	87	Davis & Rolls 1987
Swan Coastal Plain lakes	urban	6	yes	176	Balla & Davis 1993
Swan Coastal Plain lakes	urban	41	yes	253	Davis *et al.* 1993
Tamworth Lake (Swan Coastal Plain)	rural	1	no	48	Streamtec 1992
Collie wetlands	semi-disturbed rural	2	no	31	Streamtec 1991b
Swamphen Lake (Capel)	disturbed, revegetated	1	no	44	Cale & Edward 1990

levels of salinity, pH and nutrient status. All the lakes had salinities well below 3 g l^{-1} considered the upper limit for biological freshwater (Bayly & Williams 1973). However, the higher salinities, with a maximum of 1626 mg l^{-1} at Lake Davies in winter, appeared sufficient to cause a localised loss of some, presumably less-tolerant, species. Differences in the geologies and origins of the lakes, particularly recent past connections to the sea, however, also need to be considered.

Two of the indicator species determined by the TWINSPAN analysis were associated with dark coloured, acidic water. *Aphroteniella filicornis,* which is usually found in the lower order streams throughout Australia, has been recorded in perched acid, dune lakes on Fraser Island, Queensland (Cranston & Edward 1992). In this study, it only occurred in the acid dark-water lakes. The most commonly collected species of Ostracoda was *Gomphodella* aff. *maia* De Dekker which was mainly associated with the black-water acidic lakes.

The Trichoptera *Oecetis* sp., was an important indicator species for the separation of lakes Quininup, Davies, Owingup, Boat Harbour 3, Saide and Powell from the other lakes in the TWINSPAN analysis. This genus is common in eutrophic lakes of the Swan Coastal Plain (Balla & Davis 1993) and in lower rivers of the northern jarrah forest (Storey *et al.* 1990). Lakes Powell, Saide, Owingup and Boat Harbour 3 had both elevated salinity and nutrients and contained fauna more typical of the eutrophic lakes of the Swan Coastal Plain including the species *Daphnia carinata, Triplectides australis* Navas, *Sarscypridopsis aculeata* (Costa), *Austrochiltonia subtenuis* (Sayce), *Palaemonetes australis* Dakin, *Chironomus occidentalis* Skuse and *Polypedilum nubifer* (Skuse) (Balla & Davis 1993; Pinder *et al.* 1991). *Candonocypris novaezelandiae* (Baird) is often associated with eutrophic water (De Deckker 1981) and was only recorded from lakes 12046 and Powell. The high zooplankton biomass in Lakes 12046 and Powell consisted mainly of *Daphnia carinata* and this species was also the dominant species of Cladocera in the eutrophic lakes on the Swan Coastal Plain (Davis & Rolls 1987; Davis *et al.* 1993). Multivariate analyses showed that the structure of the invertebrate fauna of lakes Powell and Saide was highly associated with nutrient enrichment. Past and present land practices within the catchments of these lakes may have degraded water quality and subsequently adversely affected composition of the invertebrate fauna. The absence of *Calamoecia* from lakes Saide and Powell may reflect human activity in these eutrophic lakes. However, the geological history of the lakes should also be considered, as the only record of the euryhaline estuarine species *Gladioferens imparipes* Thompson was from Lake Powell, indicating a recent past connection with the sea. Lake Saide is associated with farming activities, particularly, in the past, with potato production. Lake Powell receives large nutrient inputs *via* Five and Seven Mile creeks, of secondary treated sewage from the Timewell Road Treatment Plant, Albany (Water Authority of Western Australia 1989b). Human activity should therefore be considered as a possible cause of elevated nutrient status for all of the eutrophic lakes.

Growns *et al.* (1993), using multivariate analysis of invertebrate data from 33 wetlands on the Swan Coastal Plain, found that the majority of wetlands could be grouped on the basis of nutrient status and colour, and concluded that low nutrient levels and highly coloured waters were the probable state of wetlands prior to European settlement. If this conclusion is correct, then many of the dark-water lakes of the south coast would have a high conservation status.

Analysis of the total species dataset by DECORANA (Fig 4) showed a gradient of putative conservation status of the lakes, from 'high' quality, having low scores on axis one (*e.g.* lakes Doggerup, Smith, Wilson, Quitjup, Williams and Maringup), through 'intermediate' quality lakes (those in the centre of the axis and including Boat Harbour Lake 3, Lake Davies, Owingup Swamp and Lake 12046) to 'low' quality, having high axis one scores (*e.g.* lakes Powell and Saide). This nominal conservation status of the lakes, based on invertebrate community structure, was reiterated on the important underlying gradients. pH, salinity and phosphorus concentration respectively are the most important environmental parameters describing the above pattern. Future management programmes should include the routine monitoring of these parameters.

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Appendix 1. Species richness and list of taxa identified from the benthic, sweep and zooplankton samples and zooplankton biomass (dry weight) in a standard 50 m trawl. W = winter, S = spring. * = open water inaccessable. Numbers represent abundance categories for each species in any of the samples; 1 = < 50, 2 = 50–500, 3 = > 500 individuals. An 'A' after the taxa = adult—Coleoptera only. Lake numbers as in Figure 1.

	1S	2W	2S	3W	4W	5W	6W	6S	7S	8W	8S	9S	10S	11W	11S	12S	13S	14W	15W	15S	16S	17W	18W	19W	20W	21S	22W	23W	23S
Species richness (total taxa)	28	18	18	35	22	28	43	38	55	33	25	45	56	51	50	33	43	28	38	41	45	32	34	39	29	37	25	31	33
Zooplankton biomass (mg)	30.6	81.9	47.8	143.9	57.6	86.6	18	72.8	20.2	83.1	11.9	31.3	*	0	24.2	67.5	18.8	7.4	117	34.5	24.3	43.4	39.4	35.1	764.3	68.9	16.5	679	587
CNIDARIA																													
Hydra sp.	2											1	1													1			
PLATYHELMINTHES																													
TEMNOCEPHALOIDEA																													
Temnocephala sp.						1																		1					
TURBELLARIA																													
Dugesiidae sp. 1																												1	
NEMATODA																													
Nematoda spp.	2	1	1	1	3	2	1	1	1	1	1	2	2	2	1	1	1	2	2	1	1	1	1	1	1	3	1	2	1
MOLLUSCA																													
BIVALVIA																													
Bivalva sp. 1																					1								
Bivalva sp. 2																												1	
Westralunio carteri Iredale											1								1				1						
GASTROPODA																													
?*Glacidorbis* sp.													1																
Ferrissia petterdi (Johnston)	1			1									1						1	2		1	1						
Gastropoda sp. 1	3																												
Gastropoda sp. 2																			1	1									
?*Physastra*													1					1	1		1		1				1	1	2
ANNELIDA																													
OLIGOCHAETA																													
Oligochaeta spp.	3	2	1	1	3	1	1	1	2	2	1	1	1	1	1	1	2	1	2	1	2	1	2	2	2	1	1	2	1
HIRUDINEA																													
Richardsonianidae sp. 1																			1	1	2	1							1
Glossiphoniidae sp 2				1																									
ARTHROPODA																													
ARACHNIDA																													
Hydracarina sp. C									1																				
Hydracarina sp. D										1																			
Hydracarina sp. E								1							1	1													
Hydracarina sp. F						1	1	1	1					1	1	1	1			1		1			1	1			
Hydracarina sp. G	1				1			1							1	1	1	1		1		1	1		1	1			
Hydracarina sp. I						1			1					1	1		1		1						1				
Hydracarina sp. J									1			1					1												1
Hydracarina sp. L														1															
Hydracarina sp. O														1															
Hydracarina sp. Q														1			1												
Hydracarina sp. R					1	1	1	1				1	1	1	1	1	1		1	1					1	1			
Hydracarina sp. S							1	1																1	1				
Hydracarina sp. T				1		1	1	1	1	1									1										
Hydracarina sp. U												1																	
Hydracarina sp. V																		1											
CRUSTACEA																													
Cladocera																													
Biapertura nr. *setigera* Brehm	1								1			1	1				1	1			1			1					
Bosmina meridionalis Sars					3									1					3										
Chydorus sp. Leach	1				2		1	1	1			1	1	1	1	1					1			1					
Neothrix cf. *armata* Gurney							1	1				2	1		1														
Daphnia carinata King																					1				3			3	3
Alonella sp.				1	1		1	1					1		1		1	1			1								
Cladocera undescribed genus V13									1							1	1							1					
Cladocera ?genus V16									1																				
Cladocera ?genus V17									1																				
Cladocera ?genus V18																						1							
Cladocera ?genus V15																													2
Graptoleberis testudinaria Sars												2					1	1											
Camptocercus cf. *australis* Sars													1		1									1					
Ostracoda																													
Newnhamia fenestra King									1			2																	
Cypretta baylyi McKenzie									1			2	1																
Newnhamia sp. 295													1																
Sarscypridopsis aculeata (Costa)	3												1										1	1	1			2	2
Limnocythere mowbrayensis Chapman			1															1											
Candonopsis tenuis (Brady)				1		1			1	1			1	1					2	1	1	1		1					
Gomphodella aff. *maia* De Deckker				1		1	1	1	2	1				2	1		2		1			3		1		1			
Cyprididae undescribed genus										1		2								1	1	1		1		1			
Alboa worooa De Deckker												1							2	1	1	2							
Ilyodromus sp. 255														1	1	1		1								1			
Paralimnocythere sp. 262																		1								1			
Candonocypris novaezelandiae (Baird)																									1			2	1

	1S	2W	2S	3W	4W	5W	6W	6S	7S	8W	8S	9S	10S	11W	11S	12S	13S	14W	15W	15S	16S	17W	18W	19W	20W	21S	22W	23W	23S
Species richness (total taxa)	28	18	18	35	22	28	43	38	55	33	25	45	56	51	50	33	43	28	38	41	45	32	34	39	29	37	25	31	33
Zooplankton biomass (mg)	30.6	81.9	47.8	143.9	57.6	86.6	18	72.8	20.2	83.1	11.9	31.3	*	0	24.2	67.5	18.8	7.4	117	34.5	24.3	43.4	39.4	35.1	764.3	68.9	16.5	679	587
Copepoda																													
Cyclopoida																													
Cyclopoida spp.	1	1	1	1	1	1	1	1	1	1		1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	2	1
Harpactacoida																													
Harpactacoida spp.		1	1		1		1	1				1	2	1	1		1	1		1	1		2	1		1		3	1
Calanoida																													
Calanoida sp.																											2		
Calamoecia tasmanica (Smith) s.l.	3	3	2	3		3	3	3		3	3	2	1	1	3	3	3	1	3	3	3	3	3	2	3	3			
Calamoecia attenuata Fairbridge					3	1	1		3	1	3	2	1	1			3			3				1	1	3			
Hemiboeckella searli Sars								2																					
Hemiboeckella andersonae Bayly											1		1		1									1	1				
Gladioferens imparipes Thompson																													1
Isopoda																													
Phreatoicidea																													
Phreatoicidea sp. A																					1					1			
Amphipoda																													
Amphipoda sp. A															1		1												
Amphipoda sp. B																							1						
Gammaridae																													
Perthia branchialis (Nicholls)																								2					
Perthia acutitelson Straskraba	1			1		1	1		1			1	1		1	1	1	1	2	1	1			1		2			
Ceinidae																													
Austrochiltonia subtenuis (Sayce)	3	3	2	1			1	1	2	2		1		1					2	1	2	1	2			3	2	3	1
Decapoda																													
Parastacidae																													
Cherax sp. (immature)															1								1						
Cherax quinquecarinatus (Gray)				1	1		1	1	1							1	1	1	1	1				1					
Cherax tenuimanus (Smith)		1				1				1			1																
Cherax destructor Clark																					1					1			
Palaemonidae																													
Palaemonetes australis Dakin		3	3	3	2					1			2						1	3	2	2	2	1			2	3	3
INSECTA																													
Ephemeroptera																													
Leptophlebiidae																													
Leptophlebiidae sp.						1																							
Neboissophlebia occidentalis Dean							1		1																				
Bibulmena kadjina Dean							1			1							1												
Baetidae																													
Cloeon sp.	1											1																	
Caenidae																													
Tasmanocoenis tillyardi (Lestage)				1			1	1			1	1	1	1	1	1			1	1					1	2	1	1	
Odonata																													
Odonata sp.							1							1															
Aeshnidae																													
Aeshna brevistyla (Rambur)									1			1	1															1	
Libellulidae																													
Orthetrum caledonicum (Brauer)																					1						1		
Austrothemis nigrescens (Martin)													1										1						
Corduliidae																													
Lathrocordulia metallica (Tillyard)													1																
Hesperocordulia berthoudi (Tillyard)								1																					
Hemicordulia australie (Rambur)									1																				
Procordulia affinis (Selys)												1		1						1	1								
Synthemidae																													
Synthemis cyanitincta (Tillyard)															1														
Gomphidae																													
Austrogomphus lateralis (Selys)				1																									
Hemigomphus armiger (Tillyard)																	1												
Austrogomphus collaris Hagen													1							1									
Lestidae																													
Austrolestes annulosus (Selys)	1											1																	
Megapodagriidae																													
Austroagrion cyane (Selys)												1															1		
Coenagriidae																													
Coenagriidae sp.																												1	
Hemiptera																													
Corixidae																													
Micronecta sp.															1											1	1	1	2
Agraptocorixa sp. A		1																									1	1	
Sigara sp.																											1		1
Agraptocorixa sp. B																												1	
Veliidae																													
Veliidae sp. 2												1																	
Notonectidae																													
Notonectidae sp.												1																	
Anisops sp.	2											1													1			1	2
Notonecta sp.												1																	

	1S	2W	2S	3W	4W	5W	6W	6S	7S	8W	8S	9S	10S	11W	11S	12S	13S	14W	15W	15S	16S	17W	18W	19W	20W	21S	22W	23W	23S
Species richness (total taxa)	28	18	18	35	22	28	43	38	55	33	25	45	56	51	50	33	43	28	38	41	45	32	34	39	29	37	25	31	33
Zooplankton biomass (mg)	30.6	81.9	47.8	143.9	57.6	86.6	18	72.8	20.2	83.1	11.9	31.3	*	0	24.2	67.5	18.8	7.4	117	34.5	24.3	43.4	39.4	35.1	764.3	68.9	16.5	679	587
Nepidae																													
Ranatra sp.												1																	
Diptera																													
Chironomidae																													
Paramerina levidensis (Skuse)						1	1	2	1	1		1	1	1	1	1	1	1	1	1		1	1	1		1		1	1
Procladius paludicola Skuse							1		1											1	1			1					
Procladius villosimanus Kieffer														1		1												1	1
?*Zavrelimyia* sp. V20							1		1						1	1													
Macropelopia dalyupensis Freeman		1	1											1				1				1							
Macropelopia sp. VSCL50																1													
Ablabesmyia sp. V37													1	1		1													
Coelopynia pruinosa Freeman				1										1														1	1
Orthocladiinae sp. VSCL3	1																												
Orthocladiinae sp. VSCL7		1																											
Orthocladiinae sp. VSCL20				1					1		1									1	1								
Orthocladiinae sp. VSCL36										1													1	1			1		
Orthocladiinae sp. VSCL38											1		1						1	1									
Orthocladiinae sp. VSCL43														1	1	1													
Orthocladiinae sp. V43													1							1					1				
Cricotopus annuliventris (Skuse)																					1								
Corynoneura sp.	1											1	1																
Limnophyes pullulus (Skuse)	1			1				1	1		1	1	1		2	1	1	1	1		1	1	1			1			1
?*Limnophyes* sp. V31				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
?*Limnophyes* sp. VSCL45																						1							
Thienemanniella sp. V19									1					1	2	2	2												1
Stictocladius sp. VSCL24							1										1												
Dicrotendipes sp. V47	1						1	1		1	1		2	1	1	1	1	1	1	1	1	1	1	1		1			
Dicrotendipes ?*conjunctus* Walker			1																										1
Kiefferulus martini Freeman																								1					
Kiefferulus intertinctus Skuse																								1			1	1	
Cryptochironomus griseidorsum Kieffer			1	1	1			1			1	1	1	1	1					1				1		1	1	1	
Nilothauma sp.				1			1	1									1												
?*Stenochironomus* sp.						1																							
Stenochironomus sp. VSCL14				1							1															1			
Stenochironomus sp. VSCL31				1					1		1																		
Riethia sp. V5									1	1	2			1	1	1	1												
Riethia sp. V4									1	1				2	1	1	1									1			
Polypedilum sp. VSCL8		1	1	1	1	1			1	1	1	1	1	1	1			1	1	1	1	1				1			
Polypedilum sp. VSCL16				2						1				1	1														
Polypedilum sp. VSCL 33									1		1		1	1	1	1	1							1				1	
Polypedilum nubifer (Skuse)																											1		
Chironomus occidentalis Skuse																						1					1		
Chironomus aff. *alternans* Walker										1	1		2			1				1			1						
Cladopelma curtivalva Kieffer									1				1			1					1	2	1	1					
Harnischia sp. VCD10						1		1		1	1			1	1		1									1			
Chironomini ?genus VSCL27								1																					
Chironomini ?genus VSCL34									1	1	1	1	1	1		1													
Chironomini ?genus VSCL35												1	1											1					
Tanytarsini ?genus										1	1									1									
Tanytarsus sp VSCL5	2		1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	1	2	1	1	1				1	1
Tanytarsus sp. VSCL9		1	1		1														1	1	1								
Tanytarsus sp. VSCL18				2		1	1		1	1					1														
Cladotanytarsus sp. VSCL10	1	1	1	1	1				1	1	1							1	1	2	2	1	1	1	1		1		
Stempellina ?*australiensis* Freeman				1				1	1			1		1												1			
Aphroteniella filicornis Brundin				2		1	1	1	1	1	1			1	1	1	1									1			
Ceratopogonidae																													
Ceratopogonidae sp. B						1	1							1	1		1				1	1		1	1	1	1		
Ceratopogonidae sp. F							1																						
Ceratopogonidae sp. G					1					1																		2	2
Ceratopogonidae sp. K									1										1					1					
Ceratopogonidae sp. L				1			1																	1					
Ceratopogonidae sp. N							1											1						1					
Ceratopogonidae sp. O																			1	1					1				
Ceratopogonidae sp. P							1														1		1						
Tipulidae																													
Limoniinae sp. A																	1				1		1		1				
Limoniinae sp. B	1											1																	
Limoniinae sp. F													1																
Empididae																													
Empididae sp. A					1									1															
Empididae sp. B													1																
Tabanidae																													
Tabanidae sp. A			1																	1		1							
Dolichopodidae																													
Dolichopodidae sp. A																									1				
Culicidae																													
Culicidae sp.	1																												

	1 S	2 W	2 S	3 W	4 W	5 W	6 W	6 S	7S	8 W	8 S	9 S	10 S	11 W	11 S	12 S	13 S	14 W	15 W	15 S	16 S	17 W	18 W	19 W	20 W	21 S	22 W	23 W	23 S
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Ephydridae																													
Ephydridae sp. A																						1							
Trichoptera																													
Ecnomidae																													
Ecnomidae sp.						1																							
Ecnomina ?trulla Neboiss							1	1	1					1			1												
?Ecnomus sp.				1		1	1	1						1	1														
Ecnomus pansus Neboiss						1													1										
Ecnomus turgidus Neboiss																								1					1
Leptoceridae																													
Leptoceridae spp.		1					1			1				1			1	1			1	1				1			
Lectrides parilis Neboiss																			1							1			
Triplectides sp. B																											1		
Notoperata tenax Neboiss													1		1														
Notalina sp. A																										1			
Oecetis sp.		1																			1		1			1		1	1
Triplectides australis Navas																												1	1
Leptoceridae sp. C			1						1				1						1										
Leptoceridae sp. F						1	1	1	1					1	1	1			1						1	1			
Leptoceridae sp. H								1										1							1				
Leptoceridae sp. I													1		1		1												
Hydroptilidae																													
Hydroptilidae sp.										1			1	1			1												
Acritoptila globosa Wells							1	1	1					1	1														
Hellyethira sp. B					1								1								1	1		1					
Atriplectididae																													
Atriplectides ?dubius Mosley														1															
Polycentropodidae																													
Polycentropodidae sp.									1												1								
Plectronemia eximia Neboiss														1															
Coleoptera																													
Dytiscidae																													
Sternopriscus ?browni Sharp															1		1			1									
Sternopriscus sp. A																													
Liodessus sp.															1														
Megaporus sp.													1																
Homeodytes scutellaris (Germar)			1									1																	
Homeodytes sp.								1																					
Sternopriscus browni Sharp A	1	2		1	1		1	1	1			1	1		1						1						1	1	
Sternopriscus marginata Watts A				1	1		1								1										1				
Rhantus sp. A																							1						
Liodessus inornatus (Sharp) A																					1		1		1				
Necterosoma darwini (Babington) A																							1						
Antiporus femuralis (Boheman) A									1								1									1			1
Megaporus howitti (Clark) A																													1
Megaporus solidus (Sharp) A	1	2																					1				1		
Homeodytes scutellaris (Germar) A																					1								
Lancetes lanceolatus Clark A													1							1			1						1
Liodessus dispar (Germar) A	1								1														1				1		
Megaporus sp. A										1																			
Helodidae																													
Helodidae									1			1	1					1	1			1	1		1			1	
Gyrinidae																													
Macrogyrus sp. A																			1	1									
Hydrophilidae																													
Hydrophilidae sp. 6																													
Hydrophilidae sp. 1 A	2								1														1						
Hydrophilidae sp. 2 A									1												1								
Hydrophilidae sp. 3 A																					1								
Hydrophilidae sp. 9 A																									1				1
Hydrophilidae sp. 11 A																											1		1
Carabidae																													
?Carabidae sp. A																									1				