Hydrobiologia **267**: 269–289, 1993.
S. H. Hurlbert (ed.), Saline Lakes V.

Saline lakes of the Paroo, inland New South Wales, Australia

B. V. Timms
Sciences Department, Avondale College, Cooranbong, N.S.W., 2265, Australia

Key words: saline lakes, water chemistry, flora, fauna, biogeography

Abstract

Twenty-five lakes from fresh to crystallizing brine in the semi-desert of northwestern New South Wales, Australia, were studied regularly for 27 months. The lakes are small, shallow and ephemeral. Chemically waters are mainly of the NaCl type. Seventy-four species of invertebrate occur in saline waters (>3 g l^{-1}) with crustaceans such as *Parartemia minuta*, *Apocyclops dengizicus*, *Daphniopsis queenslandensis*, *Diacypris* spp. and *Reticypris* spp. dominant, particularly at higher salinities. The insects *Tanytarsus barbitarsis* and *Berosus munitipennis* are also important in meso- and hypersaline lakes. They are joined in hypo- and mesosaline waters by many others, including more beetles, odonatans, trichopterans, pyralids, notonectids, and corixids. Species richness declines with increasing salinity. There is a prominent inland faunal component mainly of crustaceans, including *P. minuta*, *D. queenslandensis*, *R. walbu*, *Trigonocypris globulosa* and *Moina baylyi*.

Introduction

Salt lakes abound in Australia and after three decades of study much is known (see De Deckker, 1983; Williams, 1981a, 1990, for bibliography). However, lake distribution and knowledge of them is regionally uneven, so that in New South Wales (hereafter NSW) there are not many salt lakes (<50?) and the only data on them are a few chemical analyses (Johnson, 1980; Williams *et al.*, 1970). Most athalassic saline lakes in NSW lie in the north-west, particularly in a horseshoe-shaped cluster 100–150 km west of Bourke in the Paroo district (Fig. 1). They exhibit a range of salinities from fresh to crystallizing brine, and relative permanency from almost permanent except in major droughts to quite episodic with water present for only a few weeks following unusual rains.

This study aims to provide information on geomorphology, water chemistry and biota for comparative purposes with other Australian saline lakes. In this respect, their isolation is of significance as the Paroo lies *ca* 800 km north of the main cluster of saline lakes in southern Australia, *ca* 900 km southwest of Lake Buchanan in tropical Queensland, and *ca* 800 km east of episodic Lake Eyre. Each of these areas has a characteristic biota (Timms, 1987; Williams 1984, 1990). The central question is to which of these lake systems are the Paroo lakes most closely related?

Methods

The study area (Fig. 1) was visited 12 times regularly over 27 months commencing July 1988. Sometimes lakes were not visited due to logistic impediments or they were dry. Most were sampled by wading, but in those of depth >0.75 m

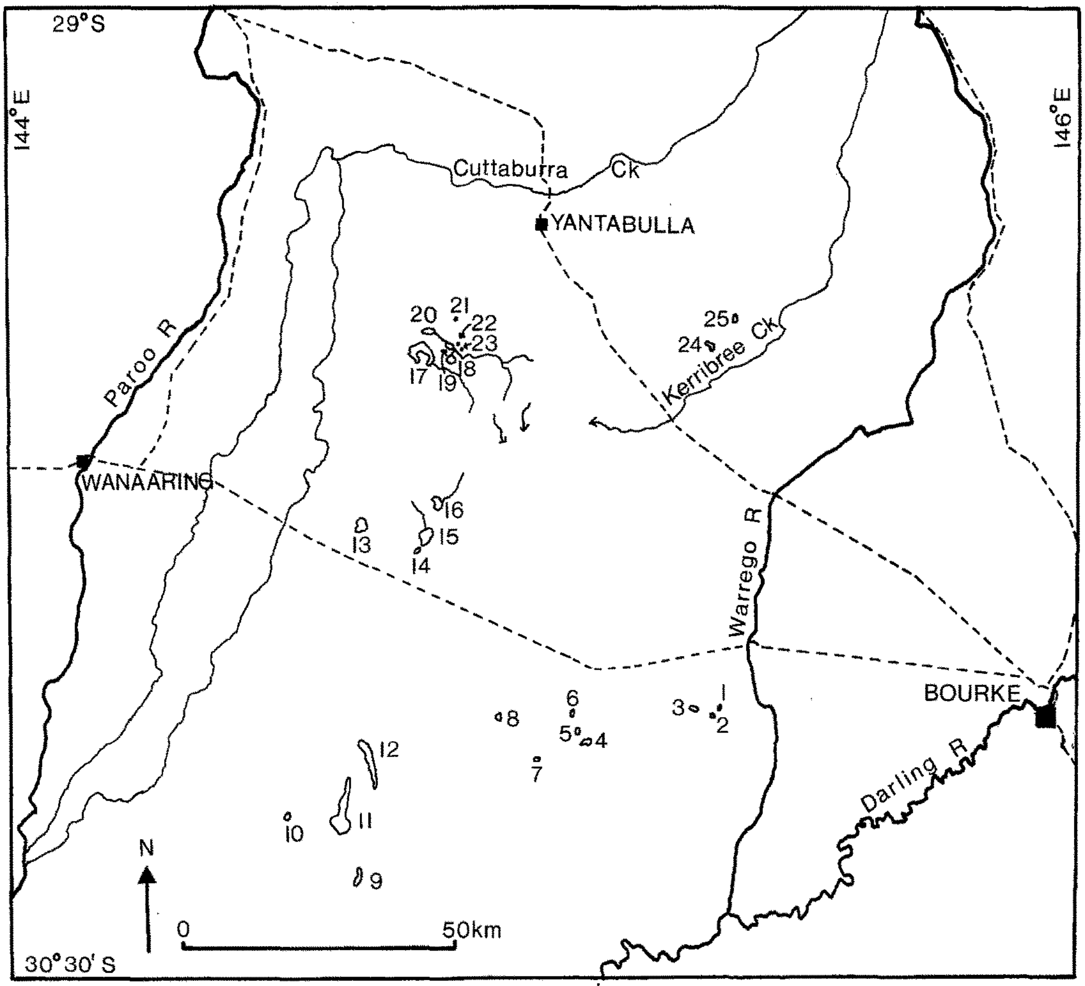

Fig. 1. Map of the Paroo district of northwest N.S.W. The code to lake numbers is in Table 1.

sampling was from a canoe. From stations near mid-lake, water temperature (by a mercury thermometer), light penetration (with a Secchi disc), and pH (by a Hanna Instruments HI 8424 meter) were determined. A water sample was taken for later determination of total dissolved solids (hereafter TDS) by gravimetry. Duplicate samples of 200 ml volume if <5 g l^{-1}, 100 ml if 5.1–20 g l^{-1}, 50 ml if 21–100 g l^{-1} and 20 ml if >101 g l^{-1}, were dried at 105 °C until consecutive weighings were consistent. Time taken varied from *ca* 24 hours for low salinity samples and 72 hours for high salinity samples. Turbidity was measured with a Hach Environmental Laboratory DR/EL1. Ionic analyses were made on samples collected mainly in July, 1989; Na, K, Ca and Mg were measured by atomic spectrophotometry, Cl by potentiometric tritration against $AgNO_3$, HCO_3 by tritration against 0.01N HCl to a pH 4.5, and SO_4 by the turbidimetric $BaSO_4$ method. Accuracy of all procedures was $\pm 2.5\%$ or better.

Plankton was collected with a conical net of 30.5 cm diameter and mesh size 159 μm towed at constant speed for one minute (rarely up to 5 minutes if plankton was sparse) from lake edge towards the middle. Generally this caught $>10\,000$ plankters which were preserved in 4% formalin. In the laboratory, each collection was totally examined under a microscope and species identified and listed.

Littoral and epibenthic animals were caught with a rectangular pond net 20 cm by 8 cm and of 1 mm mesh. One man-hour was spent on each occasion using this net. All taxa caught were listed in the field, and representative specimens of each preserved in Carnoys solution for later identification. Generally almost all taxa listed for a lake were caught in the first 10–30 minutes, but in fresher lakes a few additional species were sometimes recovered in the last 30 minutes. Such additional species were rare in the more saline lakes. This method then did not necessarily catch all species present in a lake, but is a compromise as to achieve full representation would take many hours and may not be absolutely achievable. Furthermore it is probable, based on the accrual of additional species in the last 30 minutes of each man-hour, that species lists were most representative in saline lakes and least so in fresher lakes.

Often in the text TDS is loosely referred to as salinity, which is the sum of the seven major ions (Table 3). However salinity is equal to only *ca* 0.8 of the TDS values recorded (Tables 3 and 4), perhaps because of the presence of dissolved organic matter. The lake salinity classification scheme of Hammer (1986) is used because it is universally known and easily described – freshwater (0–0.5 g l^{-1}), subsaline (0.5–3 g l^{-1}), hyposaline (3–20 g l^{-1}), mesosaline (20–50 g l^{-1}) and hypersaline (> 50 g l^{-1}).

Results

Geomorphology

The lakes lie in a sandy plain at *ca* 100 m above sea level, are mostly < 250 ha in area and < 1 m deep (Table 1, Fig. 1). Most arose by deflation by strong southwest and northwest winds, though damming by dunes is often important. Lunette dunes on the eastern shores point to the importance of deflation. These dunes typically consist of a high outer dune of cemented gypsum and one or more lower unconsolidated dunes near the present lake shore. Lake floors are generally of gypsiferous clays.

Some lakes lie on palaeodrainage channels still occasionally but inefficiently used so that ponding and flooding occur. The best example (Johnson, 1980) is the chain consisting of Lake South Nichebulka, Avondale Salt Lake, and Lake Utah on Kerribree Creek. Lake Utah is generally the terminal basin, though water can terminate in the other lakes in drier years (e.g. in 1988), or rarely flow beyond Utah (e.g. in 1974, B. O'Malley, pers. com.). Lake Nichebulka may connect to this system, but did not during 1988–90, and Lake Burkanoko is the terminus on what appears to be a tributary now well isolated by dunes.

Bell Creek northwest of Kerribree Creek provides a smaller example of a old drainage system now dammed to form a terminal lake, here Lower Bell Lake. The two lakes upstream, Gidgee and Middle Bell, are regularly connected (each winter, 1988–90), while water from nearby Horseshoe Lake may reach there by a tortuous route as it did in 1974 (A. Davey, pers. com.). Another example is the unnamed valley leading to the Warrego River in the eastern part of the study area. It carries Lakes Willeroo and Yandaroo, neither of which has overflowed in living memory. Gypsum Lake is probably part of this system but is now isolated by dunes. The final case is Lake Pirillee, which occupies an indistinct waterway leading to upper Kerribree Creek – it connected with this creek in the 1989 and 1990 floods (W. Hann, pers. com.). Lake Strathern seems to lie on a dammed isolated tributary of this system.

Many lakes (Nos. 5–10, 13, 21–23) lie isolated on the sand plain, and Taylors Lake lies just beyond the junction of exposed bed rock and the sand plain. This lake and Nos. 1, 2, and 21 have a high proportion of their drainage from this rock, whereas the remainder gain much water from the sand plain, via channels (e.g. Lake Burkanoko), overland flow (e.g. Ballymere), seepage (e.g. Bells Bore Lake) or in any combination of these.

The lakes varied widely in reliability with respect to water presence (Table 2), both among themselves and secularly (A. Davey, W. Davis, pers. coms.) Only two, Willeroo and Yandaroo, always contained water, though both are known

Table 1. Some physiographic features of lakes of the Paroo.

Lake[1]	Lat & Long.	Elevation[2] (m)	Area (ha)	Max. depth (m)	Geomorphological type[3]
1. 'Gypsum'	30° 07′ S 145° 22′ E	115	35	<0.5	Deflated and dammed
2. Yandaroo	30° 07′ S 145° 21′ E	115	56	<1.0	Dammed on old water course
3. Willeroo	30° 05′ S 145° 17′ E	115	113	<2.5	Dammed on old water course
4. Taylors	30° 07′ S 145° 04′ E	100	62	<2.0	Deflated and dammed
5. 'Ballymere'	30° 06′ S 145° 02′ E	100	32	<0.5	Deflated
6. 'Barakee'	30° 05′ S 145° 02′ E	100	90	<0.2	Deflated
7. Mere	30° 11′ S 144° 59′ E	115	68	<0.5	Deflated
8. 'Kings Bore'	30° 06′ S 144° 55′ E	95	151	<0.5	Deflated
9. 'near L. Pelora'	30° 21′ S 144° 39′ E	90	250	<0.5	Deflated
10. 'Flowing Bore'	30° 15′ S 144° 31′ E	90	150	<0.5	Deflated
11. Utah	30° 15′ S 144° 38′ E	90	1900	<0.2	Deflated; old water course
12. 'Avondale Salt'	30° 09′ S 144° 39′ E	90	520	<0.5	Old water course; deflated
13. 'Rainbar'	29° 48′ S 144° 40′ E	95	190	<0.5	Deflated
14. 'Sth Nichebulka'	29° 51′ S 144° 47′ E	95	54	<1.0	Old water course
15. Nichebulka	29° 49′ S 144° 48′ E	95	322	<0.1	Deflated
16. Burkanoko	29° 46′ S 144° 49′ E	95	280	<1.5	Deflated
17. Horseshoe	29° 32′ S 144° 46′ E	110	746	<0.5	Deflated
18. 'Gidgee'	29° 33′ S 144° 50′ E	110	185	<1.5	Deflated
19. 'Middle Bell'	29° 31′ S 144° 49′ E	110	32	<1.0	Old water course; deflated
20. 'Lower Bell'	29° 30′ S 144° 48′ E	110	160	<1.0	Dammed and deflated
21. 'Freshwater Bw'	29° 29′ S 144° 50′ E	115	19	<1.5	Dammed and deflated
22. 'Bells Bore'	29° 31′ S 144° 50′ E	115	24	<0.1	Deflated
23. 'Woolshed'	29° 32′ S 144° 51′ E	110	4	<0.2	Deflated
24. Pirillee	29° 32′ S 145° 18′ E	115	150	<2.0	Old water course; deflated
25. 'Strathern'	29° 28′ S 145° 19′ E	115	146	<0.5	Deflated; old water course

[1] Names in apostaces are not officially approved by the Geographical Names Board, but are used by local people.
[2] Determined to the nearest 5 m.
[3] The origin of most lakes is complex. The dominant mode is given first, followed, if appropriate by formative process of secondary importance.

to dry in major droughts. Some dry periods must be long, as dead trees stand in Willeroo. Taylors Lake is almost permanent, but the remainder are ephemeral. Generally they fill from autumn rains and water persists till spring (or to summer in some cases). The most reliably filled lakes are Gidgee and Middle Bell while Rainbow, near Pelora, and Woolshed Lakes are the most transient (Table 2). Many lakes have truncated inner lunettes and wave-built beaches 1–2 m above levels observed in 1988–90. These probably relate to a record filling in 1974. At the other extreme in dry years (eg. 1984–86) all lakes in the Bell system remained dry as did probably most others. In these years Taylors and Willeroo became ephemeral (A. Davey & W. Davis, pers. com.).

Water chemistry

In most lakes the dominant ions are Na and Cl (Table 3). The exceptions are the least saline lakes: Lakes Willeroo and Yandaroo are dominated by Na and HCO_3, Lake Gypsum by Na and SO_4, and Lake Strathern by Ca and SO_4. Relative ion importance largely relates to salinity. Potassium reached *ca* 5 equivalent per cent in the fresh lakes, but rarely approached a value of 0.5 in the saline lakes. Bicarbonate was most important in the fresh lakes, though in a few saline lakes its contribution reached 20 per cent, with figures <5 per cent more common. The relative importance of NaCl increased with salinity (Table 3). The ratios Na/Ca and Mg/Ca both increased sig-

Table 2. Seasonal variation in the presence of water and its TDS ($g\,l^{-1}$) in some lakes in the Paroo.

Lake / Date	July 1988	Oct 1988	Dec 1988	Feb 1989	April 1989	June 1989	July 1989	Sept 1989	Nov 1989	Feb 1990	May 1990	Oct 1990
1. 'Gypsum'	?	–	–	–	–	0.79	1.42	4.31	–	–	0.27	1.05
2. Yandaroo	?	0.17	0.14	0.37	0.54	0.21	0.14	0.19	0.24	1.12	0.18	0.27
3. Willeroo	?	0.44	0.12	0.23	0.26	0.15	0.12	0.14	0.17	0.24	0.09	0.17
4. Taylors	?	2.29	1.67	2.77	3.62	2.06	2.55	2.83	4.87	–	0.67	1.61
5. 'Ballymere'	?	?	–	–	–	1.94	3.95	10.12	–	–	0.48	1.42
6. 'Barakee'	?	166.8	–	–	–	42.6	110.5	–	–	–	23.0	127.2
7. Mere	?	4.14	9.6	81.9	–	17.8	71.4	–	–	–	4.7	27.1
8. 'Kings Bore'	?	33.5	186.5	–	–	22.2	39.0	76.0	–	–	22.9	108.2
9. 'near Pelora'	14.1	–	–	–	–	–	–	–	–	–	11.2	–
10. 'Flowing Bore'	29.1	–	–	–	–	16.1	52.4	–	–	–	30.8	–
11. Utah	46.4	–	–	–	–	88.9	263.8	–	–	–	55.5	–
12. 'Avondale Salt'	18.5	–	–	–	–	?	?	?	–	–	9.3	69.0
13. 'Rainbar'	8.4	–	–	–	–	–	–	–	–	–	–	–
14. 'Sth Nichebulka'	6.6	?	–	–	–	6.7	19.3	83.7	–	–	4.0	24.6
15. Nichebulka	68.9	?	–	–	–	95.7	232.1	–	–	–	53.8	361.0
16. Burkanoko	13.4	?	–	–	–	31.5	–	–	–	–	5.6	22.6
17. Horseshoe	30.0	174.0	–	–	–	77.6	–	–	–	–	13.2	31.0
18. 'Gidgee'	?	14.1	51.6	–	–	4.6	9.1	13.4	45.8	–	5.2	18.7
19. 'Mid Bell'	5.3	14.8	151.7	–	–	11.0	26.5	144.4	–	–	5.8	37.5
20. 'Lower Bell'	6.7	15.8	122.9	–	–	32.3	–	–	–	–	8.3	34.5
21. 'Freshwater'	?	6.9	–	–	–	1.29	1.54	2.55	–	–	0.3	0.47
22. 'Bells Bore'	61.7	–	–	–	–	46.6	186.6	–	–	–	28.8	–
23. 'Woolshed'	?	–	–	–	–	19.9	–	–	–	–	16.2	–
24. Pirillee	?	?	?	?	?	?	1.07	1.30	1.93	–	?	1.28
25. 'Strathern'	?	?	?	?	?	?	?	5.2	–	–	?	8.2

Code – = dry; ? = unknown.

nificantly with salinity ($r = 0.65$, and $r = 0.67$ respectively, both significant at $P < 0.001$).

Because of seasonal and secular salinity variations, it is difficult to assign the lakes to salinity classes (Table 4). Assignment based on mean TDS, adjusted to salinity, is probably the most simple and results in a division into 2 freshwater lakes, 5 subsaline, 7 hyposaline, 5 mesosaline and 6 hypersaline lakes. Salinity varied widely in most lakes during 1988–90 (Tables 2 & 5) with coefficients of variation generally between 50 and 125%. This variability was unrelated to salinity ($r = -0.09$, $n = 15$, $P > 0.10$).

All lakes are alkaline, with mean pH between 8.2 and 10.0 (Table 5). Highest individual readings occurred on late sunny afternoons (e.g. a pH of 11.0 in Lake Pirillee) and lowest ones in hypersaline lakes in early mornings (e.g. 7.6 in Lake Barakee).

Some physical variables

Minimum-maximum water temperatures were 8–21 °C in winter, and 25–39 °C in summer, with individual values naturally strongly influenced by time of day when measurements were made.

Most lakes had clear waters of low turbidity (Table 5). The exception was Freshwater Lake which had turbid waters typical of local freshwater pans. The two freshwater lakes and some of the subsaline and mesosaline lakes had slightly opaque waters (Table 5). Given such clear waters, Secchi disc readings could not be obtained for most lakes; only values for opaque to turbid lakes are given (Table 5). These reinforce the differences in turbidities between fresh and saline lakes. Only in the freshwater lakes are there enough data to interpret seasonal variations; these

Table 3. Chemical features of some lakes in the Paroo. [determined on samples collected in July 1989, except for No. 23 (June 1989) and No. 25 (Sept 1989)].

Lake No. and Name	TDS ($mg\,l^{-1}$)	Salinity[1] ($mg\,l^{-1}$)	Aspect reported[2]	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
3 Willeroo	125	123	A	0.019	0.004	0.008	0.004	0.021	0.004	0.063
			B	49.4	6.6	23.2	20.8	34.9	4.6	60.5
2 Yandaroo	162	158	A	0.013	0.003	0.009	0.004	0.025	0.006	0.081
			B	59.4	4.1	19.6	16.9	33.0	5.5	61.5
21 'Freshwater'	664	420	A	0.074	0.002	0.036	0.016	0.110	0.064	0.118
			B	51.3	3.2	27.7	20.8	48.4	21.1	30.5
24 Pirillee	1068	974	A	0.270	0.006	0.044	0.022	0.398	0.170	0.064
			B	73.9	1.0	13.7	11.4	71.0	22.3	6.7
1 'Gypsum'	1424	1004	A	0.120	0.008	0.100	0.052	0.116	0.496	0.112
			B	35.0	1.6	33.7	29.7	21.2	66.9	11.9
4 Taylors	2250	1600	A	0.37	0.01	0.11	0.05	0.76	0.24	0.06
			B	61.6	0.4	20.5	17.5	78.3	18.1	3.6
5 'Ballymere'	3952	3460	A	1.12	0.01	0.09	0.06	1.76	0.36	0.06
			B	83.7	0.2	7.7	8.4	85.5	12.8	1.7
25 'Strathern'	5180	3630	A	0.38	0.02	0.50	0.17	0.58	1.86	0.12
			B	29.6	0.9	44.6	24.9	28.7	68.0	3.3
19 'Mid Bell'	5340	4180	A	0.96	0.02	0.28	0.16	2.18	0.48	0.10
			B	60.1	0.3	19.8	19.8	84.1	13.7	2.2
14 'Sth Nichebulka'	6620	4910	A	1.26	0.01	0.26	0.14	2.34	0.84	0.06
			B	69.8	0.2	15.6	14.4	78.1	20.7	1.2
20 'Lower Bell'	6760	5420	A	1.19	0.02	0.44	0.18	2.24	1.06	0.14
			B	57.1	0.5	24.9	17.5	73.5	23.9	2.6
13 'Rainbar'	8400	6000	A	1.36	0.02	0.50	0.18	2.82	1.04	0.08
			B	59.3	0.6	25.3	14.8	77.4	21.2	1.4
18 'Gidgee'	9012	7560	A	1.76	0.04	0.44	0.32	4.20	0.56	0.16
			B	61.3	0.3	17.2	21.2	89.4	8.8	1.8
16 Burkanoko	13423	9500	A	2.25	0.05	1.00	0.35	3.95	0.10	1.80
			B	64.5	0.3	16.4	18.8	73.9	1.3	24.8
9 'near Pelora'	14060	11450	A	2.50	0.05	0.90	0.45	5.60	0.15	1.80
			B	56.8	0.3	23.6	19.3	79.8	1.3	18.9
12 Avondale Salt	18540	16270	A	4.85	0.02	0.5	0.55	9.6	0.1	0.65
			B	75.2	0.1	8.9	15.8	94.5	0.7	4.8
23 'Woolshed'	19880	15500	A	4.3	0.1	0.7	0.5	8.0	0.2	1.7
			B	69.8	0.4	13.8	16.0	85.3	1.1	13.6
10 'Flowing Bore'	29090	19300	A	5.2	0.1	0.5	0.9	10.6	0.3	1.7
			B	68.9	0.3	8.2	22.6	88.2	1.5	10.3
17 Horseshoe	30040	25400	A	7.6	0.1	0.6	0.8	14.7	0.1	1.5
			B	77.6	0.2	6.8	15.3	92.4	0.5	7.1
8 'Kings Bore'	39080	33300	A	9.9	0.1	0.5	1.5	18.5	0.2	2.6
			B	74.2	0.2	4.7	20.9	90.0	0.7	9.3
11 Utah	46450	36900	A	12.5	0.1	0.5	0.9	21.6	0.2	1.1
			B	85.0	0.2	3.4	11.4	95.8	0.6	3.6
22 'Bells Bore'	61750	59000	A	19.4	0.2	0.8	2.0	34.8	0.8	1.0
			B	80.0	0.2	4.2	15.6	92.8	1.1	6.1
15 Nichebulka	68920	58000	A	18.2	0.2	0.8	2.2	35.2	0.4	1.0
			B	77.8	0.2	4.3	17.7	97.5	0.6	1.9
7 Mere	71440	69000	A	21.4	0.2	1.6	3.2	35.4	0.6	6.6
			B	80.2	0.3	6.6	12.9	87.1	0.9	12.0
6 'Barakee'	110480	85200	A	24.8	0.4	3.2	2.8	50.8	1.2	2.0
			B	73.1	0.3	11.1	15.5	96.8	0.5	2.7

[1] Determined by summing the values for the seven major ions measured.
[2] A = absolute amount in ($g\,l^{-1}$).
B = relative amount as equivalent percent of total cations or anions.

Table 4. Lake salinity classification and ionic ratios.

Class[1]	Lake No.	Ranking according to salinity on July 89[2]			Ranking according to mean TDS × 0.8[3]	
		Salinity ($g\,l^{-1}$)	Na/Ca^{2+}	Mg^{2+}/Ca^{2+}	Lake No.	Salinity ($g\,l^{-1}$)
Fresh ($<0.5\,g\,l^{-1}$)	3	0.12	2.13	0.89	3	0.15
	2	0.16	3.03	0.86	2	0.26
	21	0.42	1.85	0.75		
Subsaline (0.5–$3.0\,g\,l^{-1}$)	24	0.97	5.39	0.83	24	1.12
	1	1.00	1.04	0.75	1	1.26
	4	1.60	3.00	0.85	21	1.76
					4	1.99
					5	2.86
Hyposaline (3.0–$20\,g\,l^{-1}$)	5	3.46	10.87	1.09	25	5.36
	25	3.63	0.66	0.59	13	6.72
	19	4.18	3.04	1.00	9	10.08
	14	4.91	4.47	0.93	23	14.48
	20	5.42	2.29	0.70	16	14.64
	13	6.00	2.43	0.58	18	16.24
	18	7.56	3.56	1.23	14	19.28
	16	9.50	3.91	1.15		
	9	11.45	2.40	0.82		
	23	15.50	5.05	1.16		
	12	16.27	8.45	1.78		
	10	19.30	8.40	2.78		
Mesosaline (20–$50\,g\,l^{-1}$)	17	25.40	11.41	2.27	12	23.12
	8	33.30	15.79	4.54	7	24.72
	11	36.90	25.00	3.33	10	25.68
					20	29.44
					19	39.78
Hypersaline ($>50\,g\,l^{-1}$)	15	58.00	18.09	4.17	8	55.84
	22	59.00	19.05	3.70	17	58.56
	7	69.00	12.16	1.96	22	64.72
	6	85.20	6.59	1.39	6	75.20
					11	90.96
					15	129.84

[1] Classification as per Hammer (1986).
[2] See Table 3.
[3] Mean TDS calculated from Table 2 and multiplied by the average ratio (0.8) of Salinity/TDS in Table 3.

showed maximal values in winter/spring and minimal values after first filling and in summer.

Flora

Almost all lakes had well-vegetated central and marginal areas, except for a month or two after first filling. Only the claypan-like Freshwater Lake never developed vegetation, while most of the hypersaline lakes had sparse vegetation when less saline, but no live plants at high salinities. *Vallisneria?gigantea* Graebner was dominant in the two freshwater lakes; other common species included *Ludwigia peploides* (Kunth.) Raven, *Myriophyllum verrucosum* Lindl., *Chara* sp., and *Nitella* sp. The

Table 5. Some physicochemical features of the lakes.

Lake	Total dissolved solids		Mean pH	Mean turbidities (FTU)	Secchi disc value (cm)	
	Mean* ($g\,l^{-1}$)	Coefficient of variation			Range	Mean
3 Willeroo	0.19	52	9.1	20	23–150	80
2 Yandaroo	0.32	90	9.4	36	12–120	53
24 Pirillee	1.40	27⁺	10.0	1	b	–
1 'Gypsum'	1.57	101	9.0	17	10–45	24
21 'Freshwater'	2.20	113	9.0	1202	1–12	7
4 'Taylors'	2.49	47	9.6	6	b	–
5 'Ballymere'	3.58	108	9.2	16	b–17–20	18
25 'Strathern'	6.7	32⁺	9.0	7	b	–
13 'Rainbar'	8.4	0⁺	9.5	5	b	–
9 'near Pelora'	12.6	16⁺	9.5	12	b	–
12 'Avondale Salt'	16.8	100⁺	9.2	10	b–20	20
23 'Woolshed'	18.1	14⁺	8.9	2	b	–
16 Burkanoko	18.3	61⁺	9.5	5	b	–
18 Gidgee	20.3	90	9.4	5	b	–
14 'Sth Nichebulka'	24.1	125	9.2	16	b–15–35	25
7 Mere	30.9	105	9.3	10	b	–
10 'Flowing Bore	32.1	47⁺	8.8	2	b	–
20 'Lower Bell'	36.8	119	8.9	2	b	–
19 'Mid Bell'	49.6	124	8.8	6	b	–
8 'Kings Bore'	69.8	87	8.9	9	b	–
17 Horseshoe	73.2	100	8.8	9	b	–
22 'Bells Bore'	80.9	89⁺	8.9	9	b	–
6 'Barakee'	94.0	64	8.3	9	b	–
11 Utah	113.7	90⁺	8.2	5	b	–
15 Nichebulka	162.3	81	8.4	9	b	–

* Calculated from Table 2.
⁺ Based on less than 5 values, so not used in correlation.
b: Bottom visible from lake surface.

latter three species (including *C. fibrosa* in Lake 5), together with *Lepilaena* sp. (*L. bilocularis* T. Kirk. in Lake 4) dominated in the subsaline lakes. *Lepilaena* sp., with a salinity range of 1–40 g l^{-1} dominated in hyposaline and some mesosaline lakes, and *Ruppia* sp. (*R. megacarpa* Mason in Lakes 11, 15, 16 and 19) dominated in many mesosaline and all hypersaline lakes, with a salinity range of 22–108 g l^{-1}. The charophyte *Lamprothamnion papulosum* (Wallr.) J. Gr. also occurred in the range 5–71 g l^{-1}, but generally was not conspicuous.

Phytoplankton was not studied, but blooms of blue-green algae were observed in the two freshwater lakes in both summers.

Fauna

The lake fauna is listed in Tables 6 (Crustacea), 7 (Insecta) and 8 (miscellaneous groups). Several taxa could not be identified to species level because of incomplete taxonomic knowledge (e.g. Conchostraca), or they were new to science and not yet formally named (e.g. the alonid chydorids), or it was impractical to do so regularly (e.g. *Diacypris*, *Reticypris*). Some details are provided below.

Anostraca

Seven species were encountered (Table 6). Of these, four *Branchinella* spp. were restricted to

Table 6. Crustacea of the Paroo lakes.

Species	Salinity range ($g\,l^{-1}$)	Number of records	Lakes from which recorded[1]
Anostraca			
Branchinella australiensis (Richters)	0.3 → 11.2	10	1, 4, 5, 9, 12, 21
Branchinella nichollsi buchananensis Geddes	1.9 → 11.2	10	5, 7, 9, 12, 14, 16, 19
Branchinella spp.[2]	0.3 → 2.1	7	1, 4, 5, 21
Parartemia minuta Geddes	8.4 → 255.0	34	6–8, 10–12, 15–20, 22, 23
Notostraca			
Triops australiensis Spencer and Hall	0.3 → 19.3	13	1, 4, 5, 9, 12, 14, 21
Conchostraca			
Cyzicus sp.	0.2 → 5.2	18	1, 2, 4, 5, 7, 21, 25
Limnadia sp. a	0.2 → 11.2	19	1, 2, 4, 5, 7, 14, 16, 18–21, 25
Limnadia sp. b	0.2 → 0.5	3	1, 2, 4
Lynceus sp.	0.5	1	5
Cladocera			
Daphnia carinata King	0.11 → 17.8	43	1–5, 7, 14, 18–21, 24, 25
Daphniopsis queenslandensis Sergeev	4.57 → 71.4	45	6–10, 12, 14, 16–20, 23
Ceriodaphnia cornuta Sars	0.14 → 0.69	4	3, 5, 21
Ceriodaphnia aff. '*dubia*' Richard	0.18 → 1.94	5	2, 3, 5, 24
Ceriodaphnia aff. '*quadrangula*' (O. F. Muller)	0.14	1	3
Simocephalus vetulus elizabethae (King)	0.17 → 0.19	2	2
Moina australiensis Sars	0.79 → 1.94	2	1, 5
Moina baylyi Forro	22.3 → 51.6	2	8, 18
Moina micrura Kurz	0.47 → 0.54	2	2, 21
Diaphanosoma unguiculatum Gurney	0.14 → 0.33	4	2, 21
Latonopsis australis Sars	0.44 → 0.48	2	3, 5
New Aloniae 3 spp.	2.21 → 18.7	16	4, 7, 16, 18–20
Other chydorids[3]	0.11 → 19.9	22	1–5, 7, 14, 18–21, 24
Echinisca carinata Smirnov	0.2 → 15.9	26	2–4, 7, 13, 14, 18–21, 24
Macrothrix ?breviseta Smirnov	0.2 → 0.4	5	2, 3
Copepoda			
Boeckella triarticulata Thomson	0.09 → 10.1	46	1–5, 7, 19–21, 24, 25
Calamoecia canberra Bayly	0.17 → 0.79	7	1, 2, 5, 21
Calamoecia lucasi Brady	0.09 → 1.29	9	2–4, 21
Apocyclops dengizicus (Lepeschkin)	4.0 → 69.0	41	4, 7, 9, 13, 14, 16, 18–20, 23
Metacyclops platypus Kiefer	13.3 → 77.6	11	6, 8, 10–12, 15, 17, 18, 22
Microcyclops sp.	108.0 → 144.4	3	8, 19, 20
Microcyclops varicans (Sars)	0.9 → 0.67	14	2–5
Schizopera spp.	4.57 → 177.5	5	7, 12, 18, 19
Ostracoda			
Bennelongia sp.	0.14 → 5.3	2	3, 19
Cypretta sp;	0.14 → 9.6	8	1–5, 7, 14, 17–21, 24, 25
Diacypris spp.[4]	5.2 → 263.8	57	6–8, 10–12, 15–20, 22, 23
Heterocypris n. sp.	0.3 → 33.5	30	4, 13, 14, 16–18
Reticypris spp.	5.2 → 122.9	24	7–10, 12, 14, 16–20, 23
Cyprinotus n. sp.	0.17 → 24.6	32	1, 2, 4, 5, 7, 9, 14, 16, 18, 20, 24, 25
Trigonocypris globulosa De Deckker	2.2 → 122.9	34	4, 5, 8, 10, 12–14, 16–20, 23, 25
Mytilocypridini gen. nov.	14 → 122.9	18	5, 14, 16–20, 23
Decapoda			
Cherax destructor Clark	0.1 → 0.3	5	3

[1] Key to lake numbers given in Table 1.

[2] *B. arborea* Geddes, *B. lyrifera* Linder, *B. occidentalis* (Dakin), and *B. pinnata* Geddes.

[3] Includes at east 9 species, the most salt tolerant being *Biapertura rigidicaudis* Smirnov at 19.9 g/L followed by *Dunhevedia crassa* King at 14.0 g/L.

[4] Includes *D. dictyote* De Deckker, *D. dietzi* (Herbst) and *Diacypris* n. sp.

[5] Includes *R. herbstii* McKenzie and *R. walbu* De Deckker.

Table 7. Insects of the Paroo Lakes.

Species	Salinity range ($g\,l^{-1}$)	Number of records	Lakes from which recorded[1]
Ephemeroptera			
Cloeon sp.	0.1 → 4.8	20	2–4, 24
Tasmanocoenis tillyardi (Lestage)	0.1 → 2.2	8	2–4
Odonata			
Diplacodes bipunctata (Brauer)	0.1 → 22.7	20	1–5, 16, 18, 19, 24, 25
Diplacodes haemotodes (Burmeister)	0.1 → 1.9	8	2, 3
Hemianax papuensis (Burmeister)	0.1 → 8.2	6	23, 24 25
Orthetrum caledonicum (Brauer)	0.1 → 24.6	7	2–4, 7, 14, 18
Austrolestes annulosus (Selys)	0.1 → 37.5	37	2–5, 14, 16, 18–21, 24
Xanthagrion erythroneurum Selys	0.1 → 0.5	12	2, 3
Hemiptera – Notonectidae			
Anisops ?calcaratus Hale	1.0	2	3, 24
Anisops gratus Hale	0.1 → 24.6	24	1–5, 7, 14, 21
Anisops stahi Kirkaldy	0.1 → 1.9	4	2–5
Anisops thienemanni Lundbald	0.1 → 24.6	71	1–5, 7, 14, 18–21, 24
Anisops sp.	3.6	1	4
– Corixidae			
Agraptocorixa eurynome Kirkaldy	0.1 → 18.7	36	1–5, 7, 14, 18–21, 24
Agraptocorixa hirtifrons Hale	0.1 → 27.1	19	1–5, 18, 20
Agraptocorixa parvipunctata Hale	0.1 → 6.7	24	1–5, 7, 14, 18, 19, 21, 24
Micronecta spp.	0.1 → 53.8	81	1–7, 9, 10, 12–21, 24, 25
Sigara truncatipala Hale	0.1 → 10.1	5	2, 5
Sigara sp. (females only)	0.1 → 19.3	8	2, 7, 14, 18, 25
– Naucoridae			
Naucoris congrex Stal	0.1 → 0.3	3	2, 3
– Nepidae			
Ranatra dispar Montandon	4.1	1	7
Trichoptera			
Oecetes ?australis Banks	0.1 → 0.2	3	2
Oecetes sp.	0.1 → 4.8	6	3, 4, 21
Notolina sp.	0.1 → 10.1	11	2–5
Triplectides ?australicus Banks	0.1 → 13.3	37	1–4, 7, 18, 21, 24
Lepidoptera			
Pyralidae	0.1 → 37.5	14	2, 4, 7, 14, 16, 18, 19, 24
Diptera – Chironomidae			
Coelopynia pruinosa Freeman	0.4	1	21
Procladius paludicola group	0.2 → 26.5	8	1, 5, 18, 19, 21
?*Cricotopus* sp.	0.1 → 1.9	9	2–5
Chironomus tepperi Skuse	0.1 → 13.3	47	1, 4, 5, 7, 9, 13, 14, 17–21, 24, 25
Dicrotendipes sp.	0.1 → 1.3	6	2–4
Polypedilum nubifer Skuse	0.1 → 2.0	14	2–5
Tanytarsus barbitarsis Freeman	11.2 → 255.0	22	6–8, 10–12, 16, 17, 19, 22, 23

Table 7. (Continued).

Species	Salinity range (g l)$^{-1}$	Number of records	Lakes from which recorded[1]
– Culicidae			
Anopheles annulipes Walker	0.1 → 11.2	11	1–3, 5, 9, 24
Anopheles amictus Edwards	0.1	1	2
Aedes sp. near *sagax* (Skuse)	11.2	1	9
Culex australicus Dobrotworsky & Drummond	0.2 → 0.5	2	5
– Others			
Ceratopogonidae	0.1 → 33.5	9	2, 5, 8, 13, 18, 19
Stratiomyidae	0.1 → 1.4	4	1–3, 5
Coleoptera – Haliplidae			
Haliplus fuscatus Clark	0.1	1	3
– Dytiscidae			
Allodessus bistrigatus (Clark)	0.1 → 24.6	15	2, 3, 5, 14, 16, 18–21, 24
Antiporus gilberti Clark	0.1 → 24.6	25	1–5, 18, 21, 24, 25
Cybister tripunctatus Olivier	0.2 → 1.1	2	2, 3
Necterosoma penicillatum (Clark)	0.1 → 37.5	9	4, 7, 14, 16–19, 21
Megaporus howitti Clark	0.1 → 24.6	28	1–5, 14, 16, 18, 21, 24, 25
Sternopriscus multimaculatus (Clark)	0.1 → 27.1	43	1–5, 7, 9, 12, 14, 16–18, 19, 21, 24, 25
Rhantus suturalis MacLeay	0.2 → 5.6	6	2, 3, 16, 21
Eretes australis (Erichson)	0.2	1	2
Hydaticus variegatus Watts	0.2 → 53.8	12	3, 4, 8, 14, 15, 17–19
Hydaticus consanguineus Aube	0.1	1	3
– Hydrophilidae			
Berosus approximanus Fairmaire	0.1 → 24.6	12	1, 3–5, 14, 16, 18
Berosus macumbensis Blackburn	0.3 → 9.1	9	1, 5, 18, 21
Berosus munitipennis Blackburn	0.1 → 149.4	52	1–10, 12, 14, 16–21, 24, 25
Berosus nutans MacLeay	0.2 → 0.3	2	3
Enochrus sp. (nr. *andersoni* Blackburn)	0.2 → 1.3	2	2, 24
Helochares australis (Blackburn)	1.1	1	2
Limnoxenus macer (Blackburn)	0.5 → 1.3	2	21, 25
Paroster sp.	1.9	1	5

[1] Key to lake numbers given in Table 1.

fresh and subsaline waters, and *B. australiensis* was only occasionally found in hyposaline pans. *B. nichollsi* was more characteristic of these pans; it was identified as the subspecies *buchananensis*, known previously only from Lake Buchanan, central north Queensland (Geddes, 1981). *Parartemia minuta* was the characteristic anostracan of the meso- and hypersaline lakes, as in other inland saline lakes (Timms, 1987; Williams & Kokkinn, 1988), though its salinity range is widest in the Paroo.

Notostraca

Triops australiensis was found regularly in sub- and hyposaline waters in autumn and early winter collections. At these higher salinities individuals were only about half the size as those in the nearby freshwater pans. Notostracans have not previously been recorded for specific Australian saline lakes, though Williams (1981b) mentions their occasional presence in mildly saline waters. The upper salinity limit is the highest for Australia and is similar to that for *Lepidurus lynchi* in western Canada (Hammer, 1986).

Table 8. Miscellaneous animals of the Paroo Lakes.

Number of species	Mean salinity range ($g\,l^{-1}$)	Salinity records	Lakes from which recorded[1]
Hirudinea			
– unidentified leech	0.2	2	2
Rotifera[2]			
Brachionus plicatilis Muller	6.7 → 76.0	16	7, 8, 12–14, 16–20
Hexarthra cf. *fennica* (Levander)	0.2 → 76.0	30 +	4, 6–8, 11, 13–20, 22–24
Asplanchna sp.	0.1 → 5.2	4 +	2, 3, 18, 21
Keratella tropica (Apstein)	0.1 → 6.8	1 +	20
Arachnida – Hydracarina			
Arrenurus spp.			
(inc. *A. balladoniensis* Halik)	0.1 → 10.1	14	1–5, 24
Diplodontus spp.	10.1	1	5
Eylais spp.	0.1 → 13.2	28	1–5, 16–18
Hydrachna spp.	0.1 → 19.3	23	1–4, 7, 14, 18–21, 24
Limnesia spp.	0.2 → 0.3	2	2, 3
Piona cumberlandensis (Rainbow)	0.3	1	3
Mollusca – Gastropods			
Glyptophysa aliciae Reeve	0.1 → 1.1	9	2, 3
Isidorella newcombi Adams & Angas	0.1 → 4.7	24	2–5, 7, 21, 24
Physa sp.	0.1 → 4.9	7	2–4
Amphibia			
Tadpoles of *Limnodynastes* and *Notoden* or *Neobatrachus*	0.1 → 9.3	13	1–3, 5, 12, 18, 21, 24, 25
Pisces			
Leiopotherapon unicolor Gunther	0.1 → 0.3	6	3
Cyprinus carpio Linnaeus	5.5	1	16

[1] Key to lake numbers given in Table 1.
[2] Lakes Willeroo and Yandaroo not listed.

Conchostraca

Clam shrimps are not usually found in saline waters, but two species regularly enter hyposaline lakes to 11.2 $g\,l^{-1}$ (Table 6). Only Geddes *et al.* (1981) mention conchostracans in Australian saline lakes, with an upper salinity limit of 4.8 $g\,l^{-1}$. Three of the four species listed were very common in temporary fresh waters in the area (unpublished data), though *Limnadia* sp.a seemed to be characteristic of the hyposaline pans. It occurred in autumn and winter, whereas *Cyzicus* was found in all seasons.

Cladocera

Of the 26 species encountered (Table 6), only a few were common and widespread. *Daphniopsis queenslandensis*, an inland form of a genus characteristic of mesosaline lakes, was generally found in winter-spring and is the most salt tolerant cladoceran in the Paroo (to 71 $g\,l^{-1}$). The other halobiont is *Moina baylyi*, now known to be widespread in inland mesosaline waters (Williams & Kokkinn, 1988). Usually it occurred in spring and summer and rarely was found with *Daphniopsis*. Compared to data for L. Eyre (Bayly, 1974; Williams, 1990), *D. queenlandensis* has a wider salinity range in the Paroo, and *M. baylyi* a narrower range.

A further 7 species entered mesosaline waters. *Daphnia carinata*, and to a lesser degree *Echinisca carinata*, were the most common, but the most interesting are new alonid chydorids being described by Frey (1991). All penetrate salinities as high as or higher than those from which they have been recorded elsewhere in Australia.

Copepoda

Eight taxa were found, with *Boeckella triarticulata* the most common in fresh to hyposaline waters, *Microcyclops varicans* in fresh waters and *Apocyclops dengizicus* and *Metacyclops platypus* prominent in hypo- to hypersaline lakes. An unknown species of *Microcyclops* was restricted to quite hypersaline lakes. The harpacticoid *Schizopera* sp. was the most euryhaline, with an upper salinity limit of 177.5 g l^{-1}, but it was not very widespread.

The penetration of the widespread *B. triarticulata* into hyposaline lakes is typical throughout Australia, though the field salinity range is less in the Paroo (Bayly, 1969; De Deckker & Geddes, 1980). The absence of the halobionts, *Calamoecia clitellata* and *C. salina*, is more significant, as these are characteristic species of southern and western saline lakes, but not apparently in the eastern inland (De Deckker & Geddes, 1980; Geddes *et al.*, 1981; Timms, 1987; Williams, 1981a, 1984, 1990). The cyclopoids are wide ranging in southern and inland Australia and the salinity ranges in the Paroo are about equivalent. *Schizopera* occurs in other saline waters in Australia (R. Hamond, pers. com.).

Ostracoda

Eleven species occurred in the collections, four of them new (Table 6). This fauna is about as rich as in L. Eyre (Williams, 1990), but not as diverse as in lakes nearer the coast (e.g. 16 species in southeast South Australia, De Deckker & Geddes, 1980; 20 species in southwest Western Australia, Geddes, *et al.*, 1981). *Diacypris* spp. were the most widespread, and between them had a remarkably wide salinity range, but were most common at higher salinities (> 50 g l^{-1}). *Reticypris* spp. generally ocurred at intermediate salinities (20–80 g l^{-1}), *Heterocypris* sp. at lower salinities (3–20 g l^{-1}) and *Cyprinotus* at even lower salinities (3–10 g l^{-1}). Both *Trigonocypris globulosa* and a new mytilocyprinid occurred over a wide range of salinities and in fact had wider salinity ranges than reported elsewhere. These two species, together with *Reticypris walbu* and perhaps the new species, are components of an ostracod fauna characteristic of inland Australia (P. De Deckker, pers. com.), while the remainder occur in saline lakes over much of Australia.

Ephemeroptera

Mayflies are not regarded as saline lake inhabitants (Hammer, 1986), and this is their first mention for Australian saline lakes. *Tasmanocoenis tillyardi* and particularly *Cloeon* sp. were relatively common in the more persistent subsaline waters, and penetrated some hyposaline lakes, but only to 4.8 g l^{-1} (Table 7).

Odonata

Six species were recorded (Table 7), but more were probably present judging from the adults caught hawking near the lakes and from literature records. The damselfly *Austrolestes annulosus* was most frequently encountered; it had an upper salinity of 37.5 g l^{-1}, the maximum recorded for an odonate (Hammer, 1986). Three other species, all dragonflies, entered hyposaline waters, but to a lesser extent.

Other Australian studies report fewer odonates, generally of different taxa, and with lower salinity tolerances. The most similar are the Eyre Peninsula lakes, where both damselfly and dragonfly nymphs occur to 26.7 g l^{-1} (Williams, 1984).

Hemiptera

Waterbugs, particularly *Anisops* spp., *Agraptocorixa* spp., and *Micronecta* spp. were common components in most hyposaline and mesosaline lakes (Table 7). All three genera were usually represented by adults and juveniles, and so are halophilic. *Anisops thienemanni*, the dominant notonectid, was found all year, but its congeners were largely confined to the cooler months. Of the three species of *Agraptocorixa*, *A. hirtifrons* typically occurred in more saline waters, but was largely restricted to cooler months. *Agraptocorixa eurynome* was found all year round. *Micronecta* spp., though quite euryhaline, were generally found below 10 g l^{-1} (67 of 81 records), but with 11 occurrences at 10–30 g l^{-1} and 3 at 31–54 g l^{-1}.

Compared to other Australian salt lake districts, notonectids and corixids are more important and generally have higher salinity limits in the Paroo (De Deckker & Geddes, 1980; Geddes *et al.*, 1981; Timms, 1987; Williams, 1981a; Williams & Kokkinin, 1988). This confirms a singular observation by Ettershank *et al.* (1966) that some hemipterans can live in quite saline waters in inland NSW, more so than in southern Victoria. However, species richness and composition is about the same for at least the Victorian lakes, though is much more diverse than for other inland lakes studied.

Trichoptera

Although 3 of the 4 species found entered hyposaline waters (Table 7), only *Triplectides?australis* was common. It inhabited cases constructed from a variety of materials, including sheep dung, and was found in all seasons, whereas the others had characteristic cases and were encountered mainly in the cooler months.

Caddises are not common in saline lakes in Australia or elsewhere (Hammer, 1986). The Paroo fauna is the richest yet in Australia, though salinity ranges do not match the figures for *Oecetes?australis* in Victoria (Bayly & Williams, 1966; Timms, 1981).

Pyralidae

Moth larvae became more common in hyposaline lakes as the study progressed (1 record in 1988, 4 in 1989, 9 in 1990) and were most noticeable in spring when food plants (*Lepilaena* sp. and *Ruppia* sp.) grew. Their upper salinity record of 37.5 g l^{-1} is almost double that recorded for pyralids in Victoria (Williams, 1981a), the only other region where their presence has been recorded in salt lakes.

Chironomidae

Seven species were recorded (Table 7), though certainly more occur as the benthos was not sampled adequately. Two species predominate: *Chironomus tepperi* which occurred mainly in hyposaline pans in spring and *Tanytarsus barbitarsis* which lived in meso- and hypersaline waters at all seasons. Both are widespread, *C. tepperi* in temporary fresh waters (Edward, 1964), and *T. barbitarsis* in saline lakes in Victoria (Timms, 1983; Williams, 1981a), southern South Australia (Kokkinn, 1986), L. Eyre (Williams & Kokkinn, 1988) and L. Buchanan where it was wrongly recorded as *Rheotanytarsus* sp. (Timms, 1987). For both species, the upper salinity limits in the Paroo are the highest known.

Culicidae

Mosquito larvae occurred occasionally, but mainly in the hyposaline pans in spring. More than 4 species listed (Table 7) may be involved, as the dominant species, *Anopheles annulipes*, is a species complex and other species are known in the arid zone after flood rains (E. Marks, pers. com.).

Species richness is about the same in the Paroo saline lakes as in some other Australian areas, but upper salinity tolerances may be less, for Williams (1981a) reports *Aedes vigilax* from western Victorian saline lakes at 23 g l^{-1}.

Ceratopogonidae

These are not an important component of the plankton or littoral of the Paroo lakes (though they could be common in the benthos), whereas many Australian studies show them to be common in hypersaline lakes. Interestingly, they are not in L. Eyre (Williams & Kokkinn, 1988) and are unimportant in L. Buchanan (Timms, 1987), two other inland lakes. The salinity range in the Paroo is much narrower than in southern Australia.

Coleoptera

Nineteen species were recorded, 11 in saline waters (Table 7). *Berosus munitipennis* was the most common and euryhaline species, with many records to 149 g l^{-1} and one supplementary collection at 255 g l^{-1} from Barton's Creek which flows into Horseshoe Lake. This species is widespread in Australia and common in inland saline lakes (Timms, 1987; Timms & Watts, 1987; Watts, 1978; Williams & Kokkinn, 1988). Seven species (Table 7) were common in mesosaline waters. Many breeding populations of a hydrophilid, probably *B. munitipennis*, were found in salinities from 3–255 g l^{-1}, and some breeding dytiscids, possibly *Necterosoma penicillatum*, occurred in waters to 19 g l^{-1}.

The Coleoptera fauna of the Paroo region is somewhat less diverse than in Victorian salt lakes around Colac (19 species, Timms & Watts, 1987) but is largely of similar composition. The main differences are the prominence of the inland species *Hydaticus variegatus*, the abundance and wider salinity range of *Antiporus gilberti*, and scarcity of *Enochrus* sp. (near *andersoni*) in the Paroo. On the other hand, the Paroo fauna is much more diverse than that of either L. Eyre (Williams & Kokkinn, 1988) or L. Buchanan (Timms, 1987), probably because these large lakes offered a much more homogeneous environment than the numerous and variable lakes of the Paroo.

Rotifera

Only two species, the ubiquitous *Brachionus plicatilis* and *Hexarthra* cf. *fennica*, were common in the Paroo lakes, though there were a few others in hyposaline lakes, and many in the two freshwater lakes (Table 8). Few studies of Australian saline lakes consider rotifers, but those that do (e.g. Williams, 1981a) stress the importance of *B. plicatilis* and *H. fennica*. Salinity ranges for these species in the Paroo are the highest for Australia, but are below maximum ranges (*ca* 100 g l^{-1}) recorded for the world (Hammer, 1986).

Hydracarina

Water-mites were common in the freshwater lakes and in subsaline and some hyposaline lakes. Six genera are involved, with *Eylais* and *Hydrachna* the most widespread and salt tolerant (Table 8). Water-mites are not mentioned in other Australian studies, but elsewhere they are known from waters of similar salinities (Hammer, 1986).

Gastropoda

Of the three species found (Table 8), *Glyptophysa aliciae* and *Isidorella newcombi* are widespread in inland waters and *Physa* sp. is introduced. The latter two taxa occur in mildly hyposaline waters. *G. aliciae* and *Physa* were restricted to the nearly permanent waterbodies, but *I. newcombi* lived as well in three other lakes which dried regularly for many months. It seems the adults aestivate among plant roots and debris. A significant omission from the gastropod fauna, as well as that of L. Eyre (Williams & Kokkinn, 1988), is *Coxiella salina*. It apparently cannot survive severe and prolonged drying (Williams & Mellor, 1991).

Amphibia

Two species of tadpoles were found in fresh to hyposaline lakes (Table 8). From adults found near these lakes, the species involved were probably *Limnodynastes tasmaniensis* and *Notoden bennettii*. Tadpoles are not mentioned as being in even low salinity waters in other Australian studies or overseas (Hammer, 1986).

Pisces

Despite a variety of fish living in inland Australia (Glover & Sim, 1978), only two occurred in the Paroo lakes, probably because almost all lakes are ephemeral and there is virtually no access to permanent water even in flood. However this did not prove a major barrier to the European carp, as juveniles appeared in the isolated Burkanoko system in 1990 (though not in the two previous years).

Community structure

Momentary species richness, *i.e.* the number species collected on given visit to a lake, decreases with increasing salinity, with the relationship being more or less linear when TDS is scaled logarithmically (Fig. 2). The use of a log TDS scale has the further advantage of clearly show-

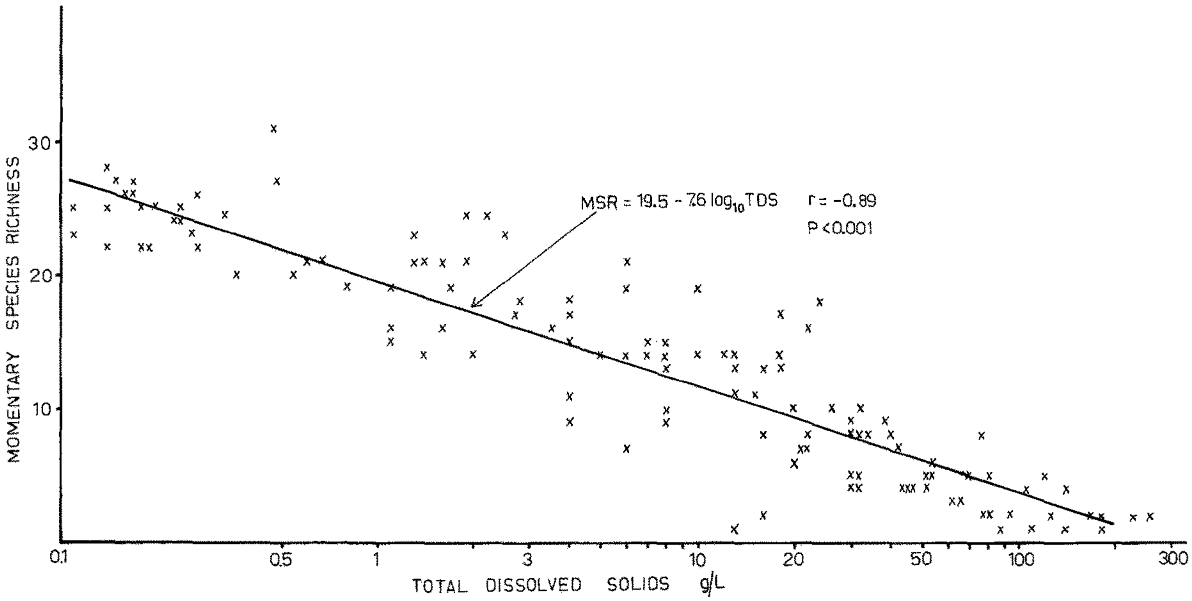

Fig. 2. Relationship between momentary species richness and salinity in the Paroo lakes.

ing patterns on species richness at low salinities. The slope is the same everywhere, *i.e.* between 0.1 and 1.0, 1 and 10, and between 10 and 100 g l^{-1}. There are no indication of boundaries, say at 3 g l^{-1} (the so-called fresh-salt water boundary, Williams, 1981a) or beyond 50 g l^{-1}.

It should be noted that although Fig. 2 is based on 133 data points, really there are 25 independent sets of data points (each set representing a lake), so that any limited segment of the salinity range could be strongly influenced by 'atypical' lakes.

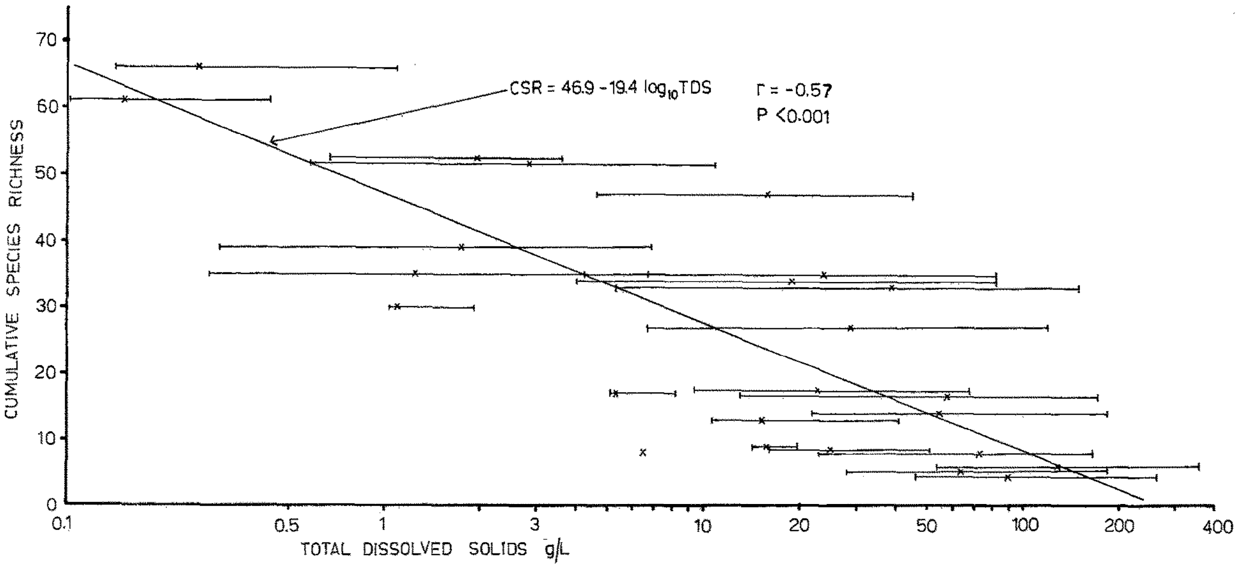

Fig. 3. Relationship between cumulative species richness and salinity in the Paroo lakes. Range and arithmetic mean are given for each lake.

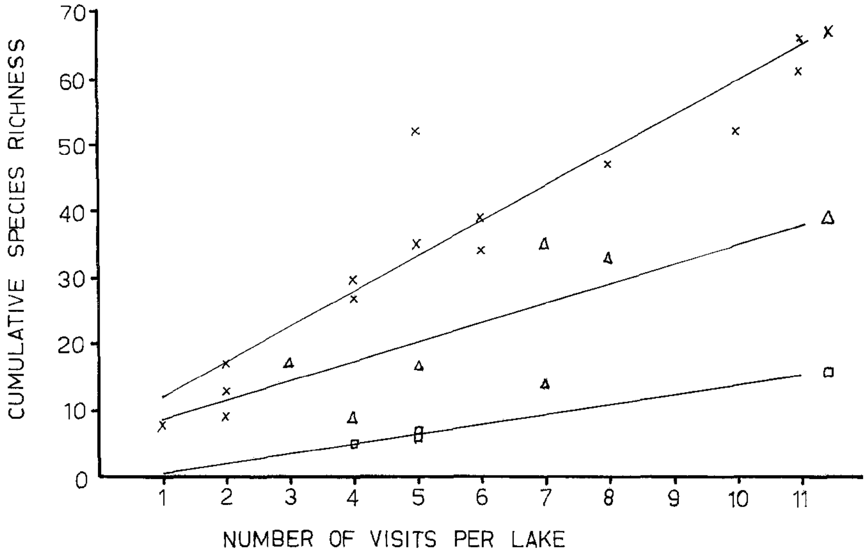

Fig. 4. Relationship between cumulative species richness and the number of visits to each lake. Salinity of lakes indicated as follows: *x*, $<20\ g\,l^{-1}$; △, $21–60\ g\,l^{-1}$; □, $>61\ g\,l^{-1}$. Regression equations differ according to salinity range: (i) $0–20\ g\,l^{-1}$ $y = 6.45 + 5.26\,x$; (ii) $21–60\ g\,l^{-1}$ $y = 0.41 + 3.73\,x$; (iii) $>61\ g\,l^{-1}$ $y = -1.0 + 1.50\,x$.

Table 9. Taxonomic representation at various salinities

Lake	Mean salinity ($g\,l^{-1}$)	Cumulative number of species	Proportion of		
			Crustaceans	Insects	Others
Willeroo	0.15	61	25	59	16
Yandaroo	0.26	66	27	58	15
Pirillee	1.1	30	23	60	17
'Gypsum'	1.3	35	37	51	12
'Freshwater'	1.8	39	38	51	10
Taylors	2.0	52	35	54	11
'Ballymere'	2.9	52	38	52	10
'Strathern'	5.4	17	41	53	6
'Rainbar'	6.7	8	38	38	25
'near Pelora'	10.1	13	54	46	0
'Woolshed'	14.5	9	78	11	11
Burkanoko	14.6	27	44	41	15
'Gidgee'	16.2	47	38	49	13
'Sth Nichebulka'	19.3	34	41	50	9
'Avondale'	23.1	17	59	24	17
Mere	24.7	35	46	43	11
'Flowing Bore'	25.7	9	67	33	0
'Lower Bell'	29.4	27	56	30	14
'Middle Bell'	39.8	33	48	42	10
'Kings Bore'	55.8	14	57	29	14
Horseshoe	58.6	17	53	35	12
'Bells Bore'	64.7	5	60	20	20
'Barakee'	75.2	7	57	29	14
Utah	91.0	5	60	20	20
Nichebulka	129.8	6	50	33	17

Table 10. Prominent animals in the Paroo lakes.

	Fresh (<0.5 g l⁻¹)	Subsaline (0.5–3.0 g l⁻¹)	Hyposaline (3.0–20 g l⁻¹)	Mesosaline (21–50 g l⁻¹)	Hypersaline (>51 g l⁻¹)
Dominant	*Micronecta* spp, *Anisops thienemanni* *Anisops gratus* *Austrolestes annulosus* *Boeckella triarticulata*	*B. triarticulata* *Micronecta* spp. *A. thienemanni*	*Daphniopsis queenslandensis* *Apocyclops dengizicus*	*D. queenslandensis* *A. dengizicus*	P. minuta *Diacypris* spp.
Subdominant	mites *Triplectides ?australicus*	*Agraptocorixa* spp. *A. gilberti* *M. howitti*	*S. multimaculatus* *A. thienemanni* *Trigonocypris globulosa* *Micronecta* spp. *Diacypris* spp.	*Parartemia minuta* *S. multimaculatus* *B. munitipennis* *Reticypris* spp. *A. thienemanni* *Micronecta* spp.	*A. dengizicus* *H.* cf. *fennica* *B. plicatilis*
Common	*Agraptocorixa* spp. *Megaporus howitti* *Sternopriscus multimaculatus* *Daphnia carinata* *Microcyclops varicans* *Chironomus tepperi* *Isidorella newcombi* *Allodessus bistrigatus* *Xanthagrion erythroneurum* *Antiporus gilberti* *Diplacodes bipunctata* *Cloeon* sp.	*Cyprinotus* sp. *D. carinata* *T. ?australicus* *C. tepperi* *S. multimaculatus* *Cyzicus* sp. *A. annulosus* *Calamoecia* spp. *Branchinella* spp.	*Brachionus plicatilis* *D. carinata* *Heterocypris* sp. *Agraptocorixa* spp. *Berosus munitipennis* *Limnadia* sp. a *M. howitti*	*Hexarthra* cf. *fennica* *Necterosoma penicillatum* *D. carinata*	*D. queenslandensis* *Tanytarsus barbitarsis*

Cumulative species richness, *i.e.* total number of species caught in each lake over the study period, also decreases significantly with increasing salinity (Fig. 3). In both cases there is considerable variability at any given salinity due to many factors including lake size and efficiency of sampling effort. Figure 4 partly illustrates the latter by indicating that lakes with low sampling effort tend to have lower species numbers. The slope is steepest for the less saline lakes though clearly the true relationship between species richness and number of visits is not linear. In an analysis of partial correlations, when this relationship is removed, the correlation coefficient between cumulative species richness and $\log_{10}$ salinity increases from −0.57 to −0.68. This still does account for the unmeasured influence of the relatively less efficient sampling effort in freshwater lakes as described earlier.

As salinity increases crustaceans become more important in lake communities and insects less important (Table 9), the change occurring in the 10-20 $g\,l^{-1}$ range. Although there is no overall detectable change in the 'other taxa' category, its components change, as mites and gastropods are only present at lower salinities while rotifers dominate at higher salinities.

These changes in dominant classes with increased salinity is even more apparent when the prominent animals in each salinity class is examined (Table 10). A variety of insects dominate at lower salinities, while at higher salinities a less diverse array of crustaceans is dominant.

Discussion

The saline lakes of the Paroo are small, ephemeral and their basins arose by deflation or damming due to wind action. They contrast with most other Australian saline lakes, which are large, isolated, episodic lakes of tectonic origin (e.g. Lakes Eyre, Buchanan), episodic playas in relictual drainage systems (as in inland Western Australia), smaller but clustered permanent to semi-permanent lakes of volcanic origin (e.g. western Victoria) or ephemeral but reliably filled small lakes near the coast (e.g. southeast South Australia). Perhaps the closest geomorphological and hydrological analogues of the Paroo lakes are the smaller lakes in southwest Western Australia studied by Geddes *et al.* (1981), and those away from the coast on the Eyre Peninsula, South Australia (Williams, 1984). Both of these analogues however, lie in relatively more benign climatic zones than the Paroo (Gaffney, 1975), and so contain water more reliably. Furthermore the Paroo lakes tend fill first, if at all, in autumn, rather than in winter, so imposing a different seasonal regimen than in southern Australia.

Nevertheless, despite their different physical characteristics, the Paroo lakes are typical desert saline lakes in that they exhibit wide temperature and salinity fluctuations and have quite clear and alkaline waters (Hammer, 1986). Moreover, as in most Australian lakes, their waters are dominated by Na and Cl ions and these ions show increasing importance at higher salinities (Hart & McKelvie, 1986). The only unusual feature is that of sulphate dominance in some lakes of lower salinity.

Like most other Australian saline lakes, the fauna is dominated by crustaceans, though insects are relatively important in meso- and hyposaline waters. In the Paroo lakes the prominent crustaceans are *Parartemia minuta, Apocyclops dengizicus, Daphniopsis queenslandensis*, and of ostracods *Diacypris*, *Reticypris*, and *Heterocypris*, and to a lesser extent *Trigonocypris globulosa*. Important insects include *Tanytarsus barbitarsis* and *Berosus munitipennis* in hypersaline lakes; these and the beetles *Sternopriscus multimaculatus*, *Necterosoma penicillatum* and *Megaporus howitti*, and the hemipterans *Anisops thienemanni, Micronecta* spp. and *Agraptocorixa* spp. occur in meso- and hyposaline lakes. Other less important taxa in hypo- and subsaline lakes include damsel nymphs (especially *Austrolestes annulosus*), caddis larvae (mainly *Triplectides australis*), moth larvae, and a greater variety of beetles and hemipterans.

The salt lakes of the Paroo exhibit important biogeographical differences from other salt lake areas in Australia. In such comparisons, it should be realised that data on species occurrences and species richness are strongly influenced by sampling effort and sampling procedures, among other factors. These have been very different in the various Australian studies, so while comparisons of lakes within this study has some basis, comparisons between lake areas may be less reliable.

While most species in the Paroo lakes are ubiquitous or shared with saline lakes in southern Australia, there are many which are endemic to the inland or far more important there than elsewhere. These include most of the common crustaceans, viz. *Parartemia minuta*, *Daphniopsis queenslandensis*, *Moina baylyi*, *Reticypris walbu*, *Trigonocypris globulosa*, and a new mytilicyprinind ostracod, all of which also occur in Lake Buchanan or Lake Eyre or both as well as the Paroo and perhaps in other inland areas. A few insects, including *Hydaticus variegatus*, belong to this category as well. Just as significant is the absence of many characteristically southern species, including *Parartemia zietziana*, *Calamoecia salina*, *C. clitellata*, *Haloniscus searli*, *Austrochiltonia* spp., ostracods like *Australocypris* and *Mytilocypris*, and the snails *Coxiella* spp. *Parartemia* and the ostracods have close relatives in the Paroo, but the others do not have equivalents. The absent forms are apparently unable to survive desiccation in unreliable habitats (Williams, 1984), a proposal that seems reasonable under the present climate of the Paroo and certainly for the hypothesized past climatic regimes for inland Australia (e.g. De Deckker, 1986).

As indicated above many similarities are obvious with the fauna of the Lake Buchanan complex in tropical Queensland (Timms, 1987). However it now seems that Buchanan's fauna is best categorized as an inland one, rather than a tropical one. It does have a few (unimportant) insects limited to the tropics, but its common species are those crustaceans (e.g. *Parartemia minuta*, *Trigonocypris globulosa*, *Reticypris walbu*, *Daphniopsis* sp.) now recognised as characteristic of the inland. Thirty-six of Buchanan's 53 species also occur in the Paroo, while 15 of the 22 in Lake Eyre occur in the Paroo, suggesting a inland component to Australia's salt lake fauna.

Overall, species richness in the Paroo lakes is at least as high as it is in most other saline lake districts in southern and western Australia, so that the depauperate fauna of Lake Buchanan (Timms, 1987), and particularly Lake Eyre (Williams, 1990), gives a biased impression of the faunal diversity of inland salt lakes. While these particular episodic lakes may be of little importance as evolutionary loci (Williams, 1984), a special faunal component of salt lakes has evolved in inland waters. Lakes like those of the Paroo, with their wide range of salinities and habitats grading towards reliability, may be important centres.

Many taxa have their highest recorded field salinity tolerances for Australia or even the world in the Paroo. These include *Parartemia minuta*, *Triops australiensis*, conchostracans, *Daphniopsis queenslandensis*, *Trigonocypris globulosa*, *Austrolestes annulosus*, notonectids, corixids, pyralid larvae, and various beetles and water mites. Perhaps this reflects an appropriate response to the harsh environment in the Paroo. The relative importance of insects (for Australia) may be associated with the possible stressful influence on crustaceans of high summer temperatures and low oxygen tensions; the absence of higher forms (e.g. amphipods, isopods) may be due to their lack of aestivating mechanisms.

Dominant, sub-dominant and common taxa in each of the five salinity classes are listed in Table 10. Few species are unique to one salinity class, except for the freshwater end, and even most of these (e.g. *Anisops gratus*, mites, *Cloeon* sp. in the freshwater class, and *Cyzicus* sp. in the subsaline class) extend as less important species in adjacent classes. The greatest overlap in prominent species between classes is in the lists for hyposaline and mesosaline lakes. A contributing reason for this could be the wide salinity fluctuations experienced in these lakes, and the associated presence of euryhaline species. Another anomaly is also explained by wide salinity fluctuation, and this is the appearance in the mesosaline list of species (e.g. *Daphnia carinata*) whose upper tolerance is less than the designated salinity range for mesosaline lakes. The presence of such in the list is due to their dominance when such lakes are less saline.

Acknowledgements

Sincere thanks are due to the Avondale College Foundation for financial support, to numerous field assistants, especially Alec Gaszik, Andrew North, Grant Murray and John Vosper, who endured heat or floods yet helped more than once, to the landholders of the Paroo, bar one, who were very helpful and understanding, and to the following taxonomists for their identifications: M. Brock and M. Cassanova (plants), L. Forro (*Moina*), D. Frey (Chydoridae), M. Geddes (Anostraca, Conchostraca), R. Hamond (Harpactoida), J. Harris (fish), M. Harvey (Hydracarina), G. Ingram (Amphibia), I. Lansbury (Hemiptera), E. Marks (Culicidae), J. Martin (Chironomidae), D. Morton (Cyclopoida), A. Neboiss (Trichoptera), V. Sergeev (*Daphniopsis*), R. Shiel (Rotifera), P. Suter (Ephemeroptera), J. Walker (Gastropoda), J. A. L. Watson (Odonata), and C. H. S. Watts (Coleoptera). I am also grateful to Professor W. D. Williams for his valuable comments on the manuscript.

References

Bayly, I. A. E., 1969. The occurrence of calanoid copepods in athalassic saline waters in relation to salinity and ionic proportions. Verh. int. Ver. Limnol. 17: 449–455.

Bayly, I. A. E., 1974. The plankton of Lake Eyre. Aust. J. Mar. Freshwat. Res. 27: 661–665.

Bayly, I. A. E. & W. D. Williams, 1966. Chemical and biological studies on some saline lakes of south-east Australia. Aust. J. mar. Freshwat. Res. 17: 177–228.

De Deckker, P., 1983. Australian salt lakes: their history, chemistry, and biota – a review. Hydrobiologia 105: 231–244.

De Deckker, P., 1986. What happened to the Australian aquatic biota 18000 years ago? In P. De Deckker & W. D. Williams (eds), Limnology in Australia. CSIRO & Dr W. Junk Publishers, Melbourne & Dordrecht: 487–496.

De Deckker, P. & M. C. Geddes, 1980. Seasonal fauna of ephemeral saline lakes near the Coorong Lagoon, South Australia. Aust. J. mar. Freshwat. Res. 31: 677–699.

Edward, D. H. D., 1964. The biology and taxonomy of the Chironomidae of south western Australia. PH.D. thesis, University of Western Australia.

Ettershank, G., M. Fuller & E. J. Brough, 1966. Hemiptera from saline waters in inland Australia. Aust. J. Sci. 29: 144–145.

Frey, D. G., 1991. A new genus of alonine chydorid cladocerans from athalassic saline waters of New South Wales, Australia. Hydrobiologia 224: 11–48.

Gaffney, D. O., 1975. Rainfall deficiency and evaporation in relation to drought in Australia. Presented to 46th Anzaas Congr., Canberra 1975, Bur. Met., Melbourne.

Geddes, M. C., 1981. Revision of Australian species of *Branchinella* (Crustacea: Anostraca). Aust. J. mar. Freshwat. Res. 32: 253–295.

Geddes, M. C., P. De Deckker, W. D. Williams, D. W. Morton & M. Topping, 1981. On the chemistry and biota of some saline lakes in Western Australia. Hydrobiologia 82: 201–222.

Glover, C. J. M. & T. C. Sim, 1978. A survey of Central Australian ichthyology. Aust. Zool. 19: 245–256.

Hart, B. T. & I. D. McKelvie, 1986. Chemical Limnology in Australia. In P. De Deckker & W. D. Williams (eds), Limnology in Australia, CSIRO, Melbourne/Dr W. Junk Publishers, Dordrecht: 3–31.

Hammer, U. T., 1986. Saline Lake Ecosystems of the World. Dr W. Junk Publishers, Dordrecht, 616 pp.

Johnson, M., 1980. The origin of Australia's salt lakes. Rec. geol. Surv. N.S.W. 19: 221–266.

Kokkinn, M. J., 1986. Osmoregulation, salinity tolerance and the site of ion excretion in the halobiont chironomid, *Tanytarsus barbitarsis* Freeman. Aust. J. mar. Freshwat. Res. 37: 243–250.

Timms, B. V., 1981. Animal communities in three Victorian lakes of differing salinity. Hydrobiologia 81: 181–193.

Timms, B. V., 1983. A study of benthic communities in some shallow saline lakes of western Victoria, Australia. Hydrobiologia 105: 165–177.

Timms, B. V., 1987. Limnology of Lake Buchanan, a tropical saline lake, and associated pools, of North Queensland. Aust. J. mar. Freshwat. Res. 38: 877–884.

Timms, B. V. & C. H. S. Watts, 1987. Water beetles of salt lakes near Colac, Victoria. Bull. Aust. Soc. Limnol. 11: 1–7.

Watts, C. H. S., 1978. A revision of the Australian Dytiscidae (Coleoptera). Aust. J. Zool. Suppl. Ser. No. 57: 1–166.

Williams, W. D., 1981a. The limnology of saline lakes in Western Victoria. Hydrobiologia 82: 233–259.

Williams, W. D., 1981b. The Crustacea of Australian inland waters. In A. Keast (ed.), Ecological Biogeography of Australia. Dr W. Junk Publishers, The Hague: 1103–1138.

Williams, W. D., 1984. Chemical and biological features of salt lakes on the Eyre Peninsula, South Australia, and an explanation of regional differences in the fauna of Australian salt lakes. Verh. int. Ver. Limnol. 22: 1208–1215.

Williams, W. D., 1990. Salt lakes: The limnology of Lake Eyre. In M. J. Tyler, C. R. Twidale, M. Davies & C. B. Wells (eds), Natural History of the North East Deserts. Royal Society of South Australia, Adelaide: 85–99.

Williams, W. D. & M. J. Kokkinn, 1988. The biogeographical affinities of the fauna in episodically filled salt lakes: a study of Lake Eyre South, Australia. Hydrobiologia 158: 227–236.

Williams, W. D. & M. Mellor, 1991. Ecology of *Coxiella*. a prosobranch snail of Australian inland waters. Palaeogeography, Palaeoclimatology, Palaeoecology 84: 339–355.

Williams, W. D., K. Walker & G. W. Brand, 1970. Chemical composition of some inland surface waters and lake deposits of New South Wales, Australia. Aust. J. mar. Freshwat. Res. 21: 103–116.