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WETLANDS OF THE RIVER MURRAY FLOOD PLAIN, SOUTH AUSTRALIA. 1. PRELIMINARY SURVEY OF THE BIOTA AND PHYSICO-CHEMISTRY OF TEN WETLANDS FROM CHOWILLA TO MANNUM.

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Summary

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Qualitative data were collected on the water chemistry and aquatic invertebrate fauna from ten wetlands between Chowilla and Mannum on the River Murray flood plain in South Australia. Sites were separated into two main groups that corresponded to freshwater wetlands connected to the River Murray, and wetlands with TDS concentrations >1000 mgL^{-1} that were isolated from the main channel. Wetlands with TDS concentrations <1000 mgL^{-1} were generally low in nutrients, and characterized by the dipteran *Cladotanytarsus* sp. and the shrimp *Paratya australiensis*. The more saline wetlands were high in nutrients and characterized by the presence of dipterans such as *Procladius* sp., Ephydridae and Culicidae.

Phosphate and nitrogen concentrations from most sites exceeded critical levels for eutrophication. Nutrient enrichment was indicated by the high chlorophyll concentrations recorded from most wetlands. These results indicate that nutrient levels entering the flood plain need to be reduced to minimize the risk of nuisance algal blooms during low flow conditions.

KEY WORDS: Wetlands, Rivery Murray, biota, aquatic invertebrates, physico-chemistry, nutrients, salinity, multivariate analysis, South Australia.

Introduction

Over 1600 wetlands are distributed throughout the River Murray flood plain, lower lakes and Coorong in South Australia (Pressey 1986). Whereas many of these were included in a recent survey of River Murray wetlands (Thompson 1986), little has been published on their biota and physico-chemistry. Thompson (1986) provides some information on the water quality and dominant flora and fauna of the 248 wetlands included in his study. Geddes (1984a & b, 1988) gives a detailed account of the limnology of Lake Alexandrina over several years, whereas O'Malley & Sheldon (1990) describe the results of a survey of the biological communities of the Chowilla flood plain. Birds have been described from some areas (Tubbs 1928; Schodde & Glover 1955; Mack 1961; Cox 1973; Simpson 1973a) and Simpson (1973b) discussed the distribution of the mammals, reptiles and amphibians between Mildura and Renmark. Lloyd & Walker (1986) reported the distribution and conservation status of the small freshwater fish throughout the lower River Murray flood plain.

This paper presents the results of a preliminary survey conducted during May-June 1990 on the aquatic invertebrate assemblages and physico-chemistry of 10 wetlands distributed from Chowilla to Mannum. The aims of the survey were to describe and compare the limnology of flood plain wetlands with different hydrology and geomorphology, including anabranches, swamps and lakes. The emphasis of the work was to study the biota and water chemistry of regulated wetlands, focussing on evaporation basins. This survey is part of a larger study which aims to (1) generate a comprehensive baseline and comparative database on the aquatic biota and physico-chemistry of selected wetlands throughout the River Murray flood plain in South Australia, and (2) investigate the effects of various changes in the hydrological management of regulated wetlands.

Materials and Methods

Selection of study sites

The location of study sites was based on those previously investigated by Thomspon (1986) and Lloyd *et al.* (1984)[1] to enable some comparison with the available data from previous surveys. Additional sites were sampled from some wetlands to examine between-site variation.

Pilby Creek was the only wetland included in this survey not previously studied by the above workers. Sites were located on either side of a causeway which restricted water flow, enabling comparison between two sites in close proximity with different hydrology.

Wetlands surveyed

The wetlands sampled in this study were distributed from the Chowilla flood plain to north of Mannum.

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[1] Lloyd, L., Moller, J. & Balla, S. (1984) "Berri Evaporation Basin Study." (Dept Zoology, Univ. of Adelaide. Unpubl. Report for N.P.W.S.)

TABLE 1. *Location and physical characteristics of the 10 wetlands surveyed along the River Murray flood plain in South Australia during May-June 1990.*

Site No(s)[a]	Wetland	Acronym	Location		Area (ha)	Hydrology and Geomorphology
1,2	Pilby Creek	PILC	33°59′S	140°53′E	5	Permanent flood plain anabranch
3	Clover Lake	CLOL	34°00′S	140°46′E	140	Intermittent flood plain swamp
4	Lake Merreti	LMER	34°01′S	140°45′E	390	Permanent regulated flood plain lake
6, 7	Disher Ck Evap. Basin	DISC	34°14′S	140°42′E	260	Permanent regulated flood plain anabranch
8-10	Katarapko Evap. Basin	KATS, KATN	34°26′S	140°34′E	42,36	Complex of permanent regulated flood plain lakes
11	Berri Evap. Basin	BERB	34°18′S	140°34′E	325	Permanent regulated flood plain swamp
12-15	Ramco Lagoon	RAML	34°10′S	139°55′E	91	Permanent regulated flood plain lake
20, 21	Devon Downs North	DEVD	34°38′S	139°36′E	120	Permanent flood plain lake
19	Wongulla Lagoon	WONL	34°43′S	139°33′E	120	Permanent flood plain swamp
16-18	Lake Carlet	LCAR	34°52′S	139°31′E	330	Permanent flood plain swamp

[a]Site 5 from Lake Woolpolool (34°02′S, 140°43′E) was omitted as samples were not preserved.

Details of the location, area, hydrology and geomorphology are given in Table 1.

The location of sampling sites is shown in Fig. 1. Specific site coordinates and descriptions of the dominant vegetation are given in Appendix 1. Each site was designated with an acronym and number.

Collection and analysis of samples

At each site, the sampling area consisted of a 20 m section of shoreline representative of that part of the wetland. Sites were sampled in May-June 1990 during a rise in the River Murray hydrograph, with a flow of about 30000 ML/D recorded at the S. Aust. border (Unpubl. Murray-Darling Basin Commission records).

Field measurements made at each site were pH (ICI 211 portable pH meter), conductivity (ICI 303 ATC conductivity meter), water temperature, dissolved oxygen (YSI model 58 dissolved oxygen meter), and Secchi disc transparency. Surface water samples were collected and stored in air-free, airtight bottles on ice before laboratory analyses for nutrients (nitrogen, phosphorus and carbon fractions), pesticides, and major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-).

Analyses of NH_3, oxidised nitrogen (NO_3-N), dissolved reactive phosphorus (DRP), SO_4^{2-} and Cl were made using a Skalar automated flow analyser, while HCO_3^-, CO_3^{2-} and alkalinity were determined using titration against a HCL standard solution. Total Kjeldahl nitrogen (TKN) and total phosphorus (TP) analyses were made with a Technicon autoanalyser and spectrophotometer. Cations were analysed using a Labtest model V-25 inductively coupled plasma emission spectrometer fitted with a polychromator. Dissolved and total organic carbon were measured with a flame ionization detector. Pesticides were extracted in hexane and analysed using a Varian 3300 gas chromatograph. All procedures are described in detail in two methods manuals produced by the E. & W.S. Department, South Australia[2,3].

Aquatic invertebrates were sampled from the littoral zone at each site using a 30 s sweep sample with a 200 μm mesh dip net. Samples were preserved in 5% formalin and returned to the laboratory for sorting and identification. Invertebrates were identified to the lowest practical taxonomic level using CSIRO (1970), Smith & Kershaw (1979), Williams (1980a), Matthews (1980, 1982), Smirnov & Timms (1983), Wiederholm (1983), Merritt & Cummins (1984), Hawking (1986), and several unpublished keys prepared by one of us (PS). A voucher collection is maintained for all taxa recorded from the River Murray flood plain in South Australia at the E. & W.S. Dept, State Water Laboratory, Bolivar, S. Aust.

Water samples for analysis of chlorophyll were processed in the field by passing a known volume of water through a 1.2 μm Whatman GF/C filter disk. The GF/C filter was placed in a centrifuge tube containing 95% ethanol, which was then wrapped in alfoil and stored on ice. Samples were centrifuged and then analysed in the laboratory using a Pye SP8-100 ultraviolet spectrophotometer at wavelengths of 750, 665 and 649 nm. Chlorophyll *a* and *b* concentrations

[2]Anon (1989) "Analytical Methods Manual – Inorganic Chemistry." (State Water Laboratory, E. & W.S. Dept, S. Aust. S.W.L. Report No. 30.)
[3]Anon (1990) "Analytical Methods Manual – Organic Chemistry." (State Water Laboratory, E. & W.S. Dept, S. Aust. S.W.L. Report No. 32.)

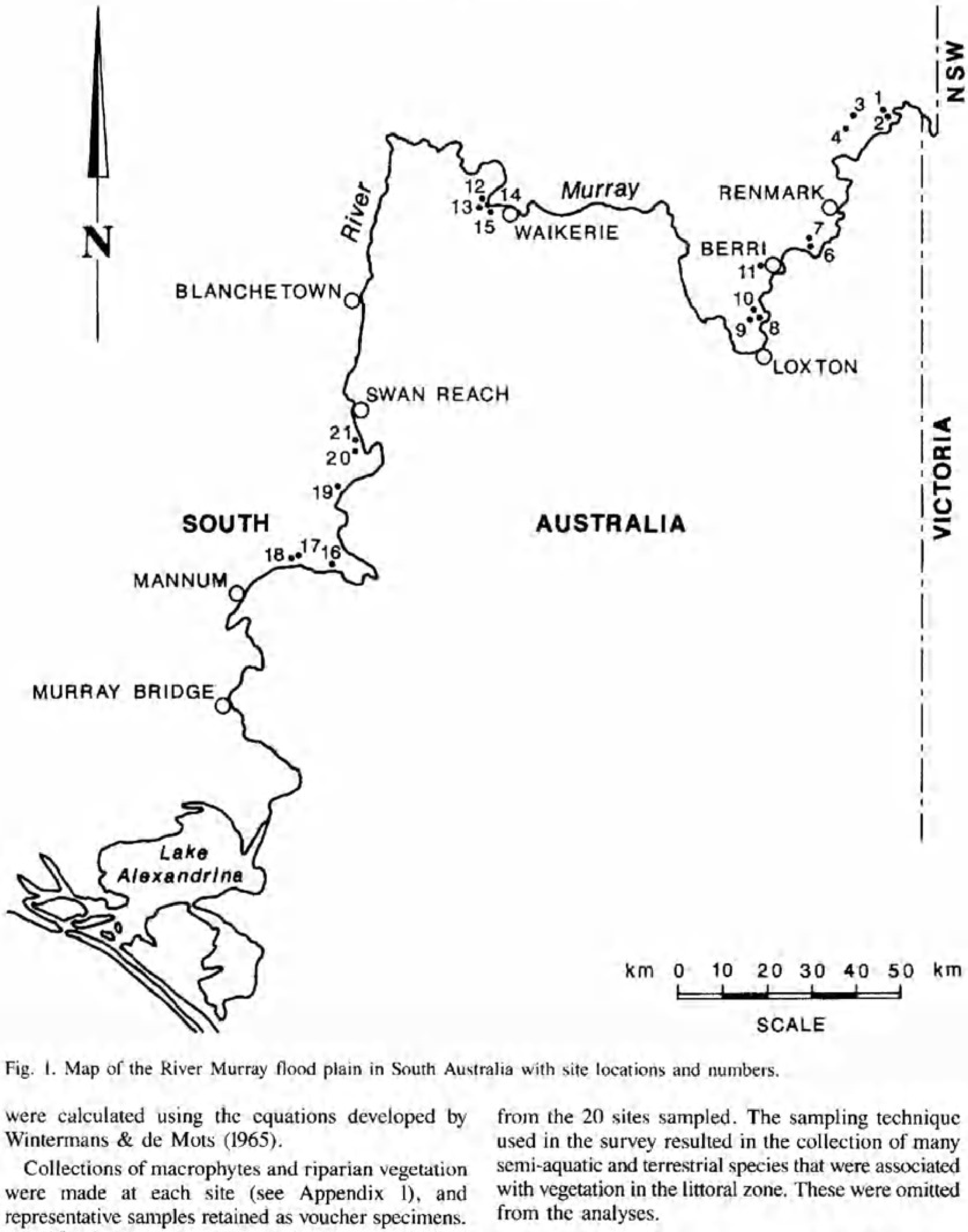

Fig. 1. Map of the River Murray flood plain in South Australia with site locations and numbers.

were calculated using the equations developed by Wintermans & de Mots (1965).

Collections of macrophytes and riparian vegetation were made at each site (see Appendix 1), and representative samples retained as voucher specimens. Identifications were made according to Aston (1973) and Jessop & Toelken (1986).

Data analyses

All biological analyses were based on the presence/absence of the aquatic invertebrates recorded from the 20 sites sampled. The sampling technique used in the survey resulted in the collection of many semi-aquatic and terrestrial species that were associated with vegetation in the littoral zone. These were omitted from the analyses.

Sorensen's index of community similarity (cf. Hellawell 1978) was used to group the sites on the basis of the composition of the fauna at each site. Clustering of sites was summarized in a dendrogram showing the degree of similarity in aquatic invertebrate composition among sites.

TABLE 2. *Physico-chemical features of 18 sites from 10 wetlands surveyed from Chowilla to Mannum in South Australia*
(*water depth too shallow to obtain a measurement. – measurement not recorded or analysed. Units in mgL^{-1} unless otherwise indicated)

Site	Water Depth (m)	pH	Conductivity ($\mu S\ cm^{-1}$)	TDS	Dissolved O_2	Secchi Disc (cm)	Water Temp. (°C)	Ammonia	NO_3-N	TKN	DRP	Total P	Total Hardness	Alkalinity	DOC	TOC
PILC 1	0.45	7.3	7870	4400	11.0	35	14.0	0.85	0.01	3.43	0.09	0.44	1181	112	-	-
PILC 2	>1.00	7.6	501	280	9.8	40	16.0	0.07	<0.01	1.35	0.04	0.18	109	95	-	-
CLOL 3	0.08	8.8	4560	2500	9.7	*	15.5	<0.01	<0.01	6.65	0.06	0.91	420	439	63.0	81
LMER 4	0.65	8.0	421	230	9.8	18	15.0	<0.01	0.01	1.10	0.04	0.30	81	71	5.1	9
DISC 6	0.62	7.9	1200	660	9.6	24	15.5	0.05	0.01	0.89	0.04	0.18	-	-	5.2	8
DISC 7	0.80	8.8	4280	2400	9.8	76	14.5	0.01	<0.01	0.95	0.01	0.09	477	71	5.8	8
KATS 8	0.70	9.0	3430	1900	10.2	22	14.5	<0.01	0.02	3.20	0.03	0.22	366	462	16.0	32
KATS 9	0.95	9.1	3430	1900	9.8	20	15.0	<0.01	<0.01	2.90	0.01	0.20	-	-	14.2	36
KATN 10	0.75	9.2	3980	2200	10.0	26	15.0	<0.01	<0.01	2.07	0.02	0.13	372	525	12.1	29
BERB 11	0.05	8.8	39800	25000	7.6	*	17.0	0.16	0.01	9.68	0.05	0.51	1989	379	91.0	108
RAML 12	0.37	7.7	1250	690	9.2	18	17.5	0.09	0.03	1.33	0.02	0.32	-	-	5.4	9
RAML 13	0.30	8.2	12000	6900	8.4	26	18.0	0.09	0.01	3.93	0.02	0.31	978	299	28.0	29
RAML 14	0.38	8.1	12300	7100	9.7	16	17.5	0.04	0.01	4.69	0.04	0.42	-	-	25.0	31
RAML 15	0.30	9.0	11700	6700	9.5	*	12.5	0.43	0.02	4.48	0.08	0.30	1008	296	19.6	24
LCAR 16[a]	1.10	8.1	504	280	10.0	26	13.0	0.01	0.01	0.80	0.02	0.10	95	71	5.9	8
WONL 19	0.45	9.0	1260	700	9.8	28	9.9	0.01	<0.01	1.21	0.01	0.08	183	123	10.6	12
DEVD 20	0.43	7.7	655	360	-	20	13.2	0.07	0.09	1.07	0.02	0.28	125	90	6.3	10
DEVD 21	0.55	8.0	826	450	-	15	13.5	0.01	0.02	1.83	0.01	0.26	145	98	8.8	14

[a]Physico-chemical features not measured at sites 17 and 18 from Lake Carlet.

TABLE 3. *Ionic composition of water samples from 10 wetlands from Chowilla to Mannum in South Australia* (Units in mgL^{-1}).

Site[a]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-
PILC 1	187	173	1140	11.7	0	137	510	2250
PILC 2	20	14	49	6.0	0	116	20	81
CLOL 3	47	73	792	23.2	36	462	170	1090
LMER 4	15	11	45	4.6	0	86	19	73
DISC 7	61	79	689	12.9	1	85	370	1060
KATS 8	35	68	593	22.9	54	454	200	695
KATN 10	28	74	692	23.6	76	486	290	740
BERB 11	100	423	8760	82.8	1	460	3900	12200
RAML 13	105	174	2130	36.1	0	365	580	3570
RAML 15	110	178	2140	41.5	30	300	630	3480
LCAR 16	16	13	60	4.3	0	87	25	100
WONL 19	26	29	197	7.2	18	114	68	300
DEVD 20	23	16	91	5.7	0	110	32	137
DEVD 21	26	19	116	6.4	0	120	39	180

[a]Analysis of major ions not conducted for DISC6, KATS9, RAML12, RAML14, LCAR17 and LCAR18.

The difference in aquatic invertebrate species composition within and among wetlands was analysed by multivariate procedures. Relationships among sites were examined by the ordination procedure of detrended correspondence analysis (Hill & Gauch 1980; Gauch 1982), using the program DECORANA (Hill 1979a). Salinity measurements were superimposed onto the DECORANA plots to reveal relationships between community composition and salinity (cf. Williams *et al.* 1990). The hierarchical classification procedure of two-way indicator species analysis (Gauch & Whittaker 1981; Gauch 1982), using the program TWINSPAN (Hill 1979b), was carried out to group similar sites together in clusters. Indicator species refer to the preferential taxa used by TWINSPAN to distinguish the clusters. The TWINSPAN program was run using the default options.

The data generated by Thompson (1986) and Lloyd *et al.* (1984)[1] were not included in statistical comparisons with the results from the present survey due to differences in the methods and objectives of each study. Only general trends in the data from these earlier studies are discussed.

Results

Water chemistry

The physico-chemical data are given in Tables 2 and 3. As the preliminary survey consisted of only one sample per site, no data are available concerning fluctuations of the various physico-chemical parameters with season and changes in water level. Consequently, only major trends in the data will be highlighted at this stage.

Ionic concentration

Williams (1967) classified any water with a concentration of total dissolved solids (TDS) greater than 3000 mgL^{-1} as "saline". Based on this definition, Berri Evap. Basin, Ramco Lagoon and Pilby Ck (PILC1) were saline when sampled. Other wetlands to approach this level included Clover Lake, Disher Ck Evap. Basin (DISC7), and Katarapko Evap. Basin. Converting ionic concentrations into ionic equivalents, waters from these wetlands were dominated by sodium and chloride, and had ionic stoichiometries similar to that of seawater (i.e. $Na^+ > Mg^{2+} > Ca^{2+} > K^+$; $Cl^- > SO_4^{2-} > HCO_3^-$). The only deviations in ionic trends among this group of wetlands were Katarapko Evap. Basin and Clover Lake, which had anionic stoichiometries similar to the more freshwater group.

The remaining wetlands had TDS concentrations of less than 1000 mgL^{-1}. Sodium and chloride were also the dominant ions, although they represented smaller fractions of the total cations and anions respectively. Cationic stoichiometry was the same as the more saline wetlands, but the anionic stoichiometry differed in that bicarbonate dominated sulphate ion (i.e. $Cl^- > HCO_3^- > SO_4^{2-} > CO_3^{2-}$).

Ionic composition

An inverse relationship was evident between sodium ion and calcium/magnesium ions, with sodium becoming more dominant with increasing TDS. Potassium ions represented very low fractions of the total cations from all wetlands. The proportion of chloride to total anions increased with increasing TDS, while the proportion of bicarbonate decreased. Sulphate contributed 10-24% of the total anions, with the higher proportions generally being recorded from the more saline wetlands. Carbonate ions were detected from the more alkaline wetlands (pH 8.8-9.4), reflecting the effect of pH on the dissolved CO_2 equilibrium.

Nutrients

Ammonia was present in higher concentrations than NO_3-N at most sites, although at some the concentrations of both forms of dissolved nitrogen were negligible (i.e. <0.01 mgL^{-1}). The highest NH_3 levels were recorded from three of the more saline sites (PILC1, RAML15, BERB11). The highest NO_3-N concentration was recorded at DEVD20, which also had a high NH_3 concentration compared with the other freshwater sites. TKN values were generally higher at the more saline sites, although low concentrations were recorded from Disher Ck Evap. Basin.

DRP levels were relatively low at all wetland sites, but were highest at the more saline sites of PILC1, RAML15, CLOL3 and BERB11. Total phosphorus concentrations showed a similar trend as DRP and TKN levels, with the more saline wetlands generally having higher concentrations of phosphorus than the freshwater wetlands.

Nitrogen was mostly present as organic forms at all wetland sites. It is difficult to comment on phosphorus, however, as only the dissolved fraction of the total reactive phosphorus was measured during this study. Despite this, the DRP results indicate that inorganic phosphorus was a significant contributor to total phosphorus for RAML15, DISC6, and PILC2.

The sites DEVD21, KATS, KATN, DISC7, LCAR and WONL were depleted of both nitrogen and phosphorus in dissolved inorganic forms. The latter three sites also had the lowest TKN and TP concentrations recorded during the survey.

Organic carbon

Concentrations of total organic carbon (TOC) and dissolved organic carbon (DOC) were highest at the

TABLE 4. *Chlorophyll concentrations recorded from 17 sites from Chowilla to Mannum in South Australia.* (Units in $\mu g L^{-1}$)

Site[a]	Chlorophyll a	Chlorophyll b	Site No.	Chlorophyll a	Chlorophyll b
PILC 1	114.8	31.4	BERB 11	60.0	22.8
PILC 2	17.2	5.8	RAML 12	32.3	7.0
CLOL 3	42.1	10.6	RAML 13	9.8	5.9
LMER 4	27.7	7.6	RAML 14	99.6	37.1
DISC 6	17.1	4.1	RAML 15	255.8	83.8
DISC 7	37.2	16.9	LCAR 16	1.2	0.2
KATS 8	39.1	9.6	DEVD 20	10.8	2.5
KATS 9	69.3	15.8	DEVD 21	3.5	0.6
KATN 10	44.1	9.4			

[a]Data not available for LCAR17, LCAR18 and WONL 19.

TABLE 5. *Occurrence of aquatic invertebrate taxa from 20 sites surveyed from Chowilla to Mannum during May-June 1990.*

Taxon	Occurrence (Site No.)	Total No. of Occurrences
TURBELLARIA	2	1
GASTROPODA		
Unidentified snail	6	1
Potomopyrgus niger	16,18	2
Ferrissia petterdi	4,16,19	3
Physa acuta	4,9,10,12,15,16,17,18,19,20	10
Isidorella newcombi	16	1
BIVALVIA		
Sphaerium tasmanicum	16	1
OLIGOCHAETA	1,2,4,8,12,13,14,15,16,17,19,21	12
CRUSTACEA		
OSTRACODA	2,3,4,6,9,10,11,12,13,14,15,16,17,19,20,21	16
COPEPODA : HARPACTICOIDA		
Attheyella australica	1	1
COPEPODA : CYCLOPOIDA	3,6,7,8,11,13,14,17,18,19,20	11
COPEPODA : CALANOIDA	2,3,4,6,7,8,9,10,11,16,17,18,19,20,21	15
AMPHIPODA		
Afrochiltonia australis	9,11,12,13,14,15,16,19,21	9
ISOPODA		
Austroargathona picta	6	1
CLADOCERA		
Leydigia australis	3	1
Ilyocryptus sp.	17,18	2
Daphnia lumholtzi	2,16	2
D. carinata	1	1
Daphniopsis pusilla	11	1
Ceriodaphnia sp.	17,19	2
DECOPODA		
Macrobrachium australiense	20	1
Paratya australiensis	2,4,6,8,9,10,13,14,16,17,18,19,20,21	14
ARACHNIDA		
HYDRACARINA	4,6,13,15,16,17,18	7
INSECTA		
EPHEMEROPTERA		
Cloeon fluviatile	19	1
Tasmanocoenis tillyardi	9,16	2
ODONATA		
Ischnura heterosticta	4,9,10,16,19	5
Austrolestes sp.	21	1
Juvenile Zygoptera	2	1
HEMIPTERA		
Anisops sp.	3	1
Anisops thienemanni	4,8,9,10,14,19,20	7

Taxon	Occurrence (Site No.)	Total No. of Occurrences
Micronecta robusta - M. gracilis	3,4,6,7,10,11,12,13,14,15,16,18,19,20,21	15
M. annae	16,19	2
Agraptocorixa eurynome	1,3,10,12,13,14,19,20	8
Hydrometra sp.	16	1
Mesovelia sp.	16	1
COLEOPTERA: HYDRAENIDAE		
Ochthebius sp.	12,20	2
COLEOPTERA: HYDROPHILIDAE		
Hydrophilid larvae	4	1
Berosus sp. larvae	3	1
Hydrochus sp.	16	1
Helochares australis	16	1
COLEOPTERA: DYTISCIDAE		
Sternopriscus sp.	3	1
LEPIDOPTERA: PYRALIDAE		
Pyralid larvae	6,15,16,20	4
TRICHOPTERA: LEPTOCERIDAE		
Triplectides sp.	2,4,9,16,21	5
Juvenile leptocerid	18	1
TRICHOPTERA: ECNOMIDAE		
Ecnomus pansus	16	1
TRICHOPTERA: HYDROPTILIDAE		
Hydroptila acinacis	16	1
DIPTERA: CHIRONOMIDAE: TANYPODINAE		
Procladius sp.	1,3,4,6,7,11,12,13,14,19,20	11
DIPTERA: CHIRONOMIDAE: CHIRONOMINAE		
Chironomus cloacalis	15,17,18	3
C. duplex	12,13	2
Dicrotendipes sp.	3,8,9	3
Chironomus tepperi	1,2,4,11,14,15	6
Cladopelma sp.	3	1
Kiefferulus intertinctus	4,10,11,14,20	5
Polypedilum sp.	1,2,18,19	4
P. nubifer	3,4,13,14	4
Parachironomus sp.	4,6,8,9,10,14,19,21	8
Cryptochironomus sp.	3,20	2
Cladotanytarsus sp.	4,8,9,10,16,17,19,20,21	9
Tanytarsus. sp.4	19	1
T. barbitarsus	1,2,4,11,21	5
DIPTERA: CHIRONOMIDAE: ORTHOCLADIINAE		
Corynoneura sp.	4	1
Cricotopus sp.	1,3,4,8,9,10,16,19,21	9
C. albitibia	3,4,8,9,10,16,19,20,21	9
Limnophyes sp.	2,4,16,20	4
Parametriocnemus sp.	4	1
DIPTERA: CERATOPOGONIDAE		
SR[a] sp.1	3,10,11,12,13,15	6
SR sp.6	11,13,14,16,19	5
SR sp.8	3	1
SR sp.16	14	1
SR sp.18	7,13	2
DIPTERA: PSYCHODIDAE	11,12,13,14	4
DIPTERA: STRATIOMYIDAE	4,10,11,14,15,20	6
DIPTERA: TABANIDAE	4	1
DIPTERA: SCIOMYZIDAE	8,16,19	3
DIPTERA: EPHYDRIDAE	1,7,11,12,13,15	6
DIPTERA: MUSCIDAE	4,6,7,14	4
DIPTERA: CULICIDAE	3,10,11,13,14,15,20	7
DIPTERA: DOLICHOPODIDAE	1,13	2

[a]SR – refers to voucher specimens in the collection at the State Water Laboratory, Victoria.

more saline wetlands. The fraction of TOC represented by DOC varied from 39-50% at KATS and KATN to 97% at RAML13.

Pesticides

No pesticides were detected in any of the water samples (detection limit of 0.02 μgL^{-1}).

Chlorophyll concentrations

The concentration of chlorophyll was high at most wetland sites (Table 4), indicating that significant phytoplankton production was occurring during the sampling period. Chlorophyll *a* concentrations varied considerably among wetlands, ranging from 1.2 μgL^{-1} at LCAR16 to 255.8 μgL^{-1} at RAML15. Chlorophyll *b* followed a similar trend.

Chlorophyll concentrations also varied markedly within wetlands. The most noted difference occurred at Ramco Lagoon where chlorophyll *a* ranged from 9.8 μgL^{-1} at the more sheltered western site (RAML13) to 255.8 μgL^{-1} at the exposed, downwind site (RAML15). Similar trends occurred at Pilby Ck, Devon Downs Nth, Katarapko Evap. Basin, and Dishers Ck Evap. Basin, where differences in the morphology of the wetland, water flow, and the dominant wind direction may result in large variations in chlorophyll concentrations within wetlands.

Aquatic invertebrate composition

Seventy-eight aquatic invertebrate taxa were recorded from the 20 sites (Table 5). Insect taxa predominated (69%), and the most diverse component of the fauna were dipterans with 32 species, including 19 species of chironomids. Crustacea contributed 18% and Gastropoda 6% of the total taxa recorded.

Ostracod taxa were the most widespread (16 sites), followed by *Micronecta robusta-M. gracilis* (15), calanoids (15), *Paratya australiensis* (14), oligochaetes (12), cyclopoids (11), *Procladius* sp. (11) and *Physa acuta* (10). In contrast, 31 taxa were recorded from only one site.

The taxonomy for many invertebrate groups is incomplete (Williams 1980b; Campbell 1981; Bennison *et al.* 1989), making it difficult to assign some specimens below the generic or family level. Consequently, not all taxa were identified to species, which underestimates the species composition and richness of some sites.

LCAR16 had the highest species richness with 30 taxa and DISC7 the lowest with 7 taxa. Considerable variation occurred within wetlands, particularly Lake Carlet where 11, 11 and 30 taxa were recorded from the three sites sampled. Of the wetlands that were sampled from more than one site, Lake Carlet was the most diverse with a total of 36 taxa, followed by Ramco Lagoon (29), Devon Downs Nth (25), Katarapko Evap. Basin (23), Pilby Ck (18), and Disher Ck Evap. Basin (14).

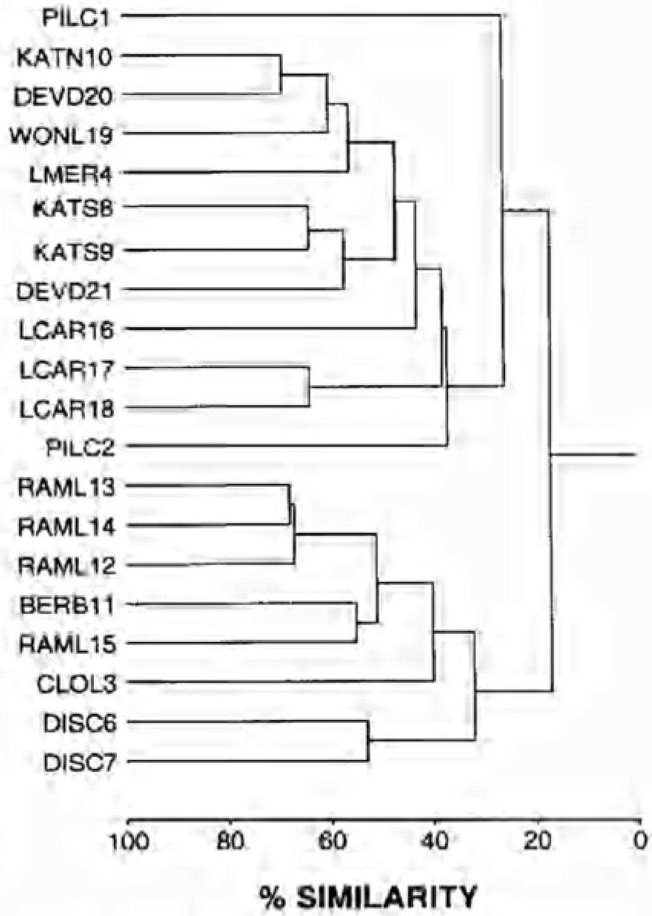

Fig. 2. Dendrogram produced by Sorensen's similarity coefficients of 20 sites based on the aquatic invertebrate data.

Groupings of the sites

Cluster analysis initially separated the sites into two main groups that generally correspond to more saline wetlands with TDS concentrations >1000 mgL^{-1} and less saline wetlands with TDS <1000 mgL^{-1} (Fig. 2). Exceptions included the clustering of the saline anabranch PILC1 and sites from Katarapko Evap. Basin with the freshwater group, and DISC6 and RAML12 with the more saline wetlands.

Within the more saline group, sites from within the same wetland were more similar to each other than sites from different wetlands. In the freshwater group, however, sites from the same wetland did not necessarily cluster together, indicating that some heterogeneity existed within some wetlands (e.g. Devon Downs Nth).

Multivariate analyses

The DECORANA ordinations of the samples are illustrated in Fig. 3, and show the centroids for each

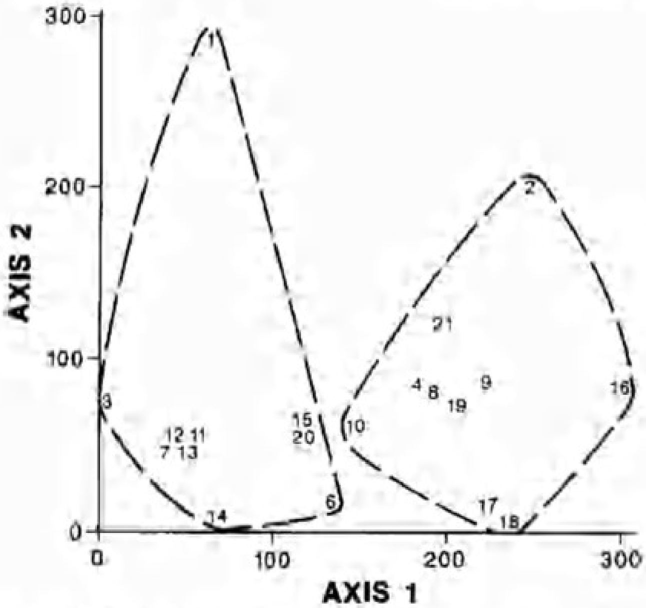

Fig. 3. DECORANA ordination of sites based on the aquatic invertebrate data, with TWINSPAN groups superimposed. (Eigenvalues: Axis 1 = 0.46, Axis 2 = 0.28. Axes in standard deviation units).

of the 20 sites (i.e. the average score for each axis). Superimposing the TWINSPAN groups onto the ordination plots results in two groups that also correspond to more saline wetlands with TDS concentrations >1000 mgL^{-1} and freshwater wetlands with TDS <1000 mgL^{-1}. This trend was confounded by the inclusion of sites from Katarapko Evap. Basin in the freshwater group, and DISC6, RAML12 and DEVD20 in the more saline group.

The two sites from Pilby Ck were outliers on the ordination analysis and tended to "compress" the other sites on the second ordination axis. Deletion of these sites from subsequent analyses did not alter the orientation or spacing of sites appreciably, so the original results based on all sites are presented herein.

The projection of sites onto the first ordination axis is shown with their TDS concentrations in Fig. 4a. Sites to the left were characterized by having freshwater with TDS <1000 mgL^{-1} and were connected to the River Murray (Table 6). These included the permanent flood plain lakes and swamps, and two sites from regulated wetlands. The freshwater site from Pilby Ck also grouped with the other freshwater wetlands despite being isolated from the main channel when sampled. Sites with TDS concentrations between 1000-2999 mgL^{-1} formed intermediate groups. Katarapko Evap. Basin and Disher Ck Evap. Basin (DISC7) were connected to the River Murray through their regulating structures when surveyed, while Clover Lake was isolated due to its location high on the flood plain. Sites to the right were saline with TDS >3000 mgL^{-1} and were isolated from the River Murray. These included the western reach of Pilby Ck (PILC1) and Ramco Lagoon in one group, and the hyper-saline Berri Evap. Basin in the most extreme group.

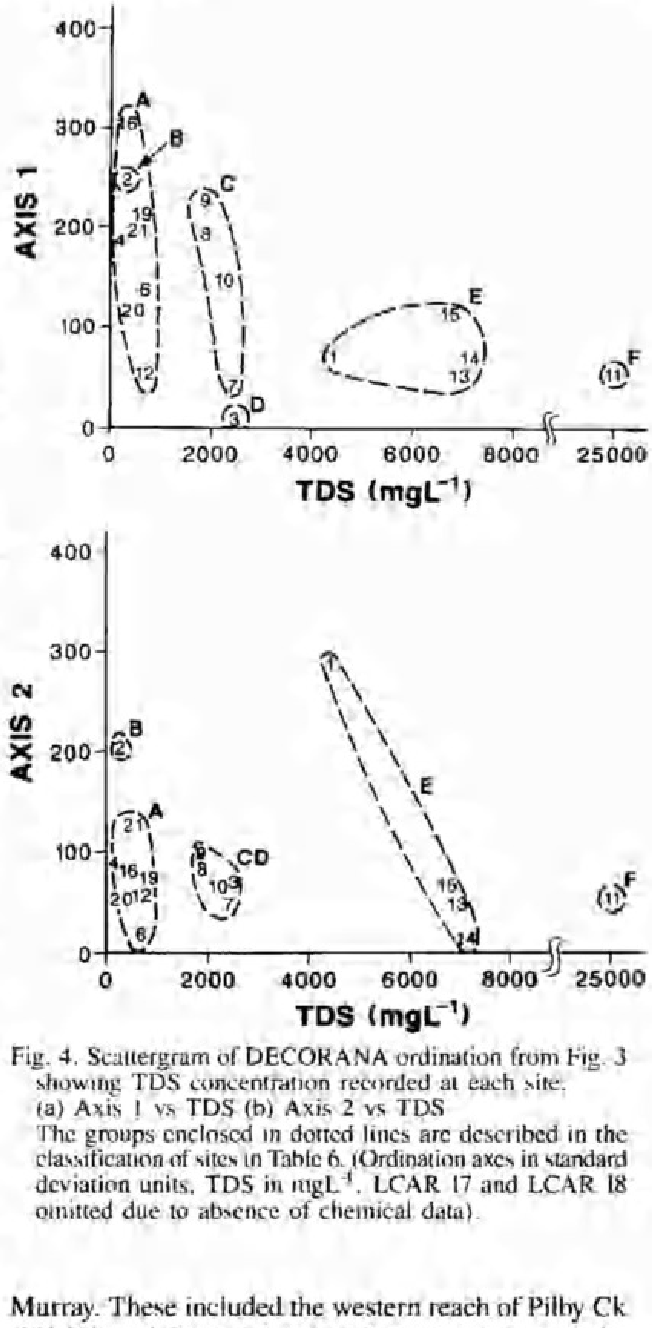

Fig. 4. Scattergram of DECORANA ordination from Fig. 3 showing TDS concentration recorded at each site.
(a) Axis 1 vs TDS (b) Axis 2 vs TDS
The groups enclosed in dotted lines are described in the classification of sites in Table 6. (Ordination axes in standard deviation units, TDS in mgL^{-1}. LCAR 17 and LCAR 18 omitted due to absence of chemical data).

The same general pattern resulted when the points from the second ordination axis were plotted against their TDS concentrations (Fig. 4b), although PILC2 split from the other freshwater wetlands, and the two intermediate groups merged together.

Superimposing the nutrient data onto the ordination plots revealed a similar, though less distinct, gradient between wetlands with/without any connection to the River Murray. TP showed increasing concentration with isolation from the River Murray along the first ordination axis, but no interpretable pattern for the second axis. The remaining physico-chemical variables displayed no obvious pattern along either axes.

TABLE 6. *Classification of wetland sites based on their TDS concentration and connection to the River Murray.*

TDS (mgL^{-1})	0 - 999 Fresh Waters	1000 - 2999	3000 - 9999 Saline	10000 > Highly Saline
Connected to River Murray	4,6,12,16,19,20,21 (GROUP A)	7,8,9,10 (GROUP C)	-	-
Isolated from River Murray	2 (GROUP B)	3 (GROUP D)	1,13,14,15 (GROUP E)	11 (GROUP F)

The TWINSPAN classification (Fig. 5) describes a similar pattern to the ordination results and highlights the indicator taxa that are unique to each grouping. The freshwater group was characterized by the dipteran *Cladotanytarsus* sp. and the shrimp *Paratya australiensis*. The more saline group was distinguished by the presence of the dipterans *Procladius* sp., Ephydridae and Culicidae.

Discussion

Water chemistry

Like most inland waterbodies in Australia, all wetlands included in the present study were dominated by sodium and chloride (Williams & Wan 1972). The differences in ionic concentration and dominance between wetlands were largely the result of dilution and concentration. The freshwater group were permanent waterbodies connected to the mainstream, where water level fluctuations are less extreme than in the more saline group of isolated wetlands. The regulated wetlands, ephemeral swamp, and saline reach of the Pilby Ck anabranch had higher salinities due to the effect of evapoconcentration. Seepage of saline groundwater and the inflow of saline irrigation water also added to the high levels of dissolved salts in the evaporation basins and Ramco Lagoon (Unpubl. E. & W.S. Dept records). Recent and proposed changes in the management of these wetlands by the use of out of the flood plain evaporation basins (e.g. Noora, Stockyard Plains) and groundwater interception schemes, should lead to a reduction in salinity of these wetlands in the long-term. We should note, however, that mean salinity levels would probably need to be reduced to at most 4000 mgL^{-1} before significant changes in the biota of these wetlands would be evident (see Centre for Steam Ecology 1989[4] for references).

Comparison of TP and TKN concentrations recorded in this study (Table 2) with Wetzel's (1975) classification of lake productivity (after Vollenweider 1968), reveal that the 10 wetlands were eutrophic or hyper-eutrophic with respect to TP, and meso-eutrophic or eutrophic with respect to TKN. Levels of DRP and

[4]Centre for Steam Ecology (1989) "Biological Effects of Saline Discharges to Streams and Wetlands." (Chisholm Inst. Tech., Unpubl. Report for Salinity Bureau, Vict.)

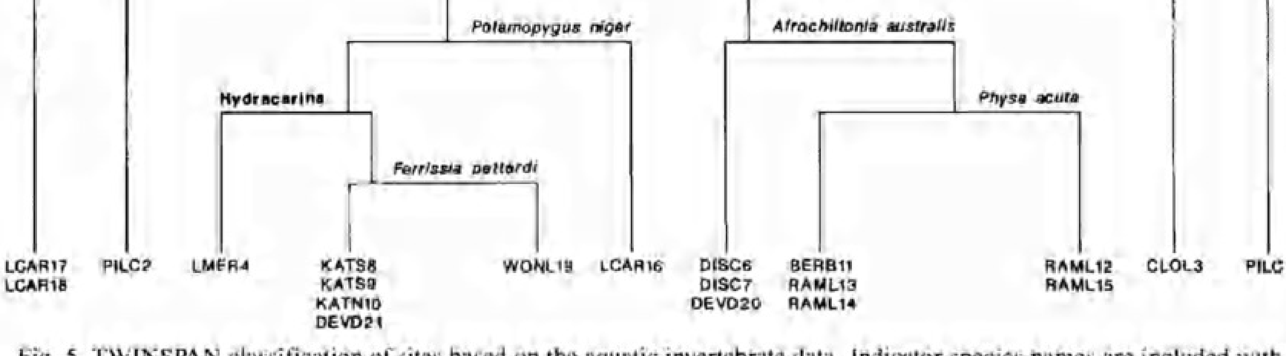

Fig. 5. TWINSPAN classification of sites based on the aquatic invertebrate data. Indicator species names are included with each dichotomy.

NO_3-N, however, were generally low, suggesting that most of the nutrients were in particulate forms that may be unavailable to phytoplankton (Smith 1982; Geddes 1984a).

Nutrient concentrations of the wetlands reflect those in the lower River Murray. Values of TP, DRP, TKN, and NO_3-N were within the ranges reported from Lock 5 to Murray Bridge (MacKay *et al.* 1988) with some exceptions. These included the higher TP concentration from Clover Lake and the higher TKN concentrations from Berri Evap. Basin, Clover Lake, Ramco Lagoon and Katarapko Evap. Basin. These are shallow and/or regulated wetlands subject to considerable evaporation, resulting in high concentrations of nutrients and dissolved salts by evapoconcentration.

Comparison of nutrient levels with other wetlands from the River Murray is difficult as few studies have been published on the chemistry of these waters. Shiel (1980) reported the nutrient concentrations from three billabongs near Wodonga during 1975-77, and found that nitrate varied from 2-685 mg N m^{-3}, and phosphate from 11-624 mg P m^{-3}. Nutrient levels from Lake Alexandrina (Geddes 1984a), Lake Hume and Lake Mulwala (Walker & Hillman 1977; Brymner 1982), Murrumbidgil Swamp and Lake Merrimajeel (Briggs *et al.* 1985) were all within Shiel's ranges. Large fluctuations in nutrient concentrations were recorded from each wetland. In the present study, nitrate and dissolved phosphate concentrations were low compared to Shiel's (1980) values. Low levels of inorganic nitrogen relative to the high TKN concentrations indicate that N was either present in the sediments or had been assimilated by phytoplankton. The high chlorophyll concentrations (Table 4) from most sites support the latter suggestion. Based on Wetzel's (1975) chlorophyll *a* categories, LCARI6, DEVD21, RAML13 and DEVD20 were meso-eutrophic, whereas the other sites were eutrophic. Although meaningful critical concentrations of nutrients have not been defined for Australian waters (Wood 1975; Cullen 1986), the flood plain wetlands included in the present survey were clearly enriched in both N and P. Future work will determine whether the high levels of nutrients and algal biomass are sustained, as this could result in the alteration of phytoplankton communities to favour nuisance species of cyanobacteria (Walker & Hillman 1977).

Aquatic invertebrates

The aquatic invertebrate fauna was diverse (Table 5) considering the small number of samples collected and that sampling occurred during the cool, wet months of May-June. At least 78 taxa were recorded from the 10 wetlands, with insects and crustaceans dominating the invertebrate communities at every site. The majority of insects were dipterans (32 taxa), hemipterans (7) and coleopterans (6). Sites from the permanent freshwater lakes and swamps (LCARI6, LMER4 and WONL19) had the most taxa, while a permanent regulated wetland (DISC7) had the least.

The unpublished database compiled by Thompson (1986) contains remarkably few records of invertebrates and aquatic macrophytes from the wetlands included in his study. This was probably due, in part, to the high flows of very turbid water from the Darling River into the River Murray at the end of 1983 (MacKay *et al.* 1988), resulting in most wetlands being turbid when sampled by Thompson in 1983-4. Apart from noting ostracods from DISC7, no new data could be derived from this database.

Lloyd *et al.* (1984)[1] collected 71 aquatic invertebrate taxa during a 12 month study of the fluctuations in the aquatic invertebrate communities and water chemistry of three wetlands, including Berri and Disher Ck Evap. Basins. Comparison of results from the same time of the year show that the fauna and water chemistry have not changed appreciably at BERBI1, while the artificial manipulation of water levels in DISC6 led to a lower salinity and a more diverse fauna in the present study. A total of 28 taxa were found at BERBI1 by Lloyd *et al.* (1984)[1], with 12 taxa being recorded during May 1984. The same faunal assemblage was present during May 1990, with the addition of *Afrochiltonia australis*, *Daphniopsis pusilla* and *Micronecta robusta-M. gracilis*. Of the 35 taxa recorded from DISC6 in the earlier work, only four were found during May 1984. In May 1990, 11 species were collected, dominated by crustaceans and dipterans. Future work will determine whether the seasonal trends described by the earlier study are maintained. This will provide a useful means of predicting how conservative are the different parameters that were measured in these evaporation basins, and establish a database upon which any changes in the management of these wetlands can be compared.

Lloyd & Boulton (1990) recorded 96 macroinvertebrate taxa during a recent short-term survey of 13 wetlands from the Chowilla flood plain. Wetlands were sampled as river levels fell in October 1988. As in the present study, most taxa were insects, with dipterans (31 taxa) dominating the fauna. Few crustaceans were collected, partly because a larger meshed dip net was used and did not sample the microcrustaceans. The major difference in the fauna between the two studies was the large number of beetles (22 taxa) recorded by Lloyd & Boulton (1990). Dytiscids and hydrophilids are most commonly collected during spring-summer from most inland waterbodies (Matthews 1980, 1982), with shallow temporary wetlands often having a variety of species (Lloyd & Boulton 1990; pers. obsv.). The timing of our survey may account for the fewer species of beetles recorded.

Comparison of the faunal communities at the 20 sites using DECORANA ordination (Fig. 4 and Table 6) illustrated the importance of connection to the River Murray on both the water chemistry and aquatic invertebrate assemblages. Wetlands/sites with direct connection to the River Murray were characterized by low salinities (TDS concentration <1000 mgL^{-1}), generally low nutrient concentrations, and the presence of the dipteran *Cladotanytarsus* sp. and the shrimp *Paratya australiensis*. Wetlands/sites that were isolated from the main channel formed a second group, characterized by higher salinities (TDS concentration >1000 mgL^{-1}), high nutrient concentrations, and the presence of dipteran larvae such as *Procladius* sp., Ephydridae and Culicidae.

The sites misallocated by the analyses deserve special mention. Hydrological manipulations of three regulated wetlands, prior to the survey, confounded the salinity gradient. Katarapko Evap. Basin, Disher Ck Evap. Basin, and the inlet site at Ramco Lagoon were receiving water from the River Murray when sampled, as their regulating structures had been opened two, seven and 10 days respectively, prior to sampling (Unpubl. E. & W.S. Dept records). Salinity readings from these wetlands indicate that some mixing and dilution had occurred in Katarapko Evap. Basin and Disher Ck Evap. Basin (Unpubl. E. & W.S. Dept records), while little to no flushing had occurred beyond the inlet/outlet site at Ramco Lagoon (Table 2). This appears to have altered the fauna of Katarapko Evap. Basin to resemble a more freshwater assemblage of invertebrates. Sites from Disher Ck Evap. Basin and Ramco Lagoon, however, retained invertebrate assemblages typical of the more saline sites/wetlands.

The high nutrient concentrations recorded at DEVD20 may have contributed to an assemblage of invertebrates typical of saline conditions, despite having a TDS concentration of only 360 mgL^{-1}. This site was heavily grazed by sheep, with the stock having direct access to the waterbody. Biological decomposition of the manure in the water could have produced the high NH_3 concentration, which would then oxidise to NO_x-N by bacterial action (Bayly & Williams 1973).

Sites from Pilby Ck tended to form outlier positions in the data analyses, emphasizing a difference in the fauna from this anabranch compared with the other wetlands. Pilby Ck is a small anabranch in the Chowilla region, characterized by narrow banks with River Red Gums extending over the water. As none of the other wetlands resembled this macrohabitat, the distinctiveness of this wetland within the analyses was not remarkable. The causeway across Pilby Ck has clearly reduced the water quality of the western reach to favour organisms adapted to saline, organically enriched conditions. Placement of a culvert with a regulator under the causeway would provide a simple means of manipulating water levels to reduce the salinity and nutrient concentrations of the western reach.

These are the preliminary results of an ongoing study of the water chemistry and biota of flood plain wetlands in South Australia. They provide an initial database and demonstrate the influence of the River Murray on the water chemistry and aquatic invertebrates of the wetlands sampled. Future work will describe the influence of season, flow and regulation on the limnology of some of these wetlands, and provide guidelines for the management of wetlands throughout the Murray-Darling flood plain.

Acknowledgments

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APPENDIX 1. *Map coordinates and descriptions of the dominant vegetation from the 20 sites surveyed from Chowilla to Mannum in South Australia.*

Site No.	Wetland	Map (1:50000 Topographic Series)	Site Coordinates	Dominant Vegetation
1	Pilby Ck (saline western reach)	CHOWILLA 7030-II & PT.7130-III	489550E, 6239200S	*Eucalyptus camaldulensus* (dead), *Muehlenbeckia florulenta*, *Azolla filiculoides* (dead)
2	Pilby Ck (freshwater eastern reach)	CHOWILLA 7030-II & PT.7131-III	489550E, 6239200S	*E. camaldulensis*, *M. florulenta*, *Typha* sp., *Myriophyllum* sp., *A. filiculoides*
3	Clover Lake	PARINGA 7029-I	478600E, 6237550S	*E. largiflorens*, *Acacia stenophylla*, *Cyperus gymnocaulos*.
4	Lake Merreti	PARINGA 7029-I	477800E, 6234400S	*E. camaldulensis*, *E. largiflorens*, *A. stenophylla*, *M. florulenta*, *C. gymnocaulos*.
6	Disher Ck Evaporation Basin (south of basin)	LOXTON 7029-III	472100E, 6209700S	*E. camaldulensis* (dead), *E. largiflorens*, *M. florulenta*, *Phragmites australis*.
7	Disher Ck Evaporation Basin (middle of basin)	RENMARK 7029-IV	471800E, 6211300S	*E. camaldulensis* (dead), *E. largiflorens*, *M. florulenta*.
8	Katarapko Evaporation Basin (south lagoon)	LOXTON 7029-III	460100E, 6189500S	*E. camaldulensis* (living and dead), *M. florulenta*, *P. australis*, *C. gymnocaulos*.
9	Katarapko Evaporation Basin (south lagoon)	LOXTON 7029-III	460100E, 6190300S	*E. camaldulensis* (living and dead), *M. florulenta*, *P. australis*, *C. gymnocaulos*.
10	Katarapko Evaporation Basin (north lagoon)	LOXTON 7029-III	459900E, 6191000S	*E. camaldulensis* (living and dead), *M. florulenta*, *P. australis*, *C. gymnocaulos*, *Typha* sp.
11	Berri Evaporation Basin	LOXTON 7029-III	460100E, 6205700S	*Suaeda australis*, *Pachycornia* sp., *Bolboshoenus caldwellii*, *C. gymnocaulos*.
12	Ramco Lagoon (inlet/outlet)	CADELL 6829-I	399800E, 6219800S	*P. australis*, *Paspalum vaginatus*
13	Ramco Lagoon (western bank)	CADELL 6829-I	399750E, 6219750S	Bare bank.
14	Ramco Lagoon (eastern bank)	CADELL 6829-I	399900E, 6219750S	*C. gymnocaulos*, *P. vaginatus*
15	Ramco Lagoon (southern bank)	CADELL 6829-I	400900E, 6218500S	*P. australis*, *Paspalum* sp.
16	Lake Carlet (inlet)	CAURNAMONT 6828-III	365500E, 6139900S	*P. australis*, *M. florulenta*, *C. gymnocaulos*, *Schoenoplectus validus*, *Ceratophyllum demersum*, *Vallisneria spiralis*, *Azolla* spp.
17	Lake Carlet (willows near outlet)	MANNUM 6728-II	357600E, 6141800S	*Salix babylonica*.
18	Lake Carlet (pool between willows and R.Murray)	MANNUM 6728-II	357600E, 6141800S	*Typha* sp., *M. florulenta*, *C. gymnocaulos*, *S. validus*, *Triglochin procera*, *Azolla* spp., *C. demersum*.
19	Wongulla Lagoon	SWAN REACH 6828-IV	367400E, 6157100S	*E. camaldulensis*, *Myoporum acuminatum*, *M. florulenta*, *C. gymnocaulos*, *S. validus*, *B. caldwellii*, *Azolla* spp. *V. spiralis*.
20	Devon Downs North Lagoon (southern reach)	SWAN REACH 6828-IV	372150E, 6166100S	*E. camaldulensis*, *M. acuminatum*, *E. largiflorens*, *C. gymnocaulos*.
21	Devon Downs North Lagoon (northern reach)	SWAN REACH 6828-IV	372400E, 6167750S	*M. florulenta*, *E. camaldulensis* (dead), *C. gymnocaulos*, *Eragrostis* sp., *Paspalum* sp.