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# A Study of the Saline Lakes of the Esperance Hinterland, Western Australia, with Special Reference to the Roles of Acidity and Episodicity

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## ABSTRACT

Most saline lakes are alkaline, but acid groundwaters in some southern areas in Western Australia cause some to have pHs as low as 3. Their fauna is severely restricted to an endemic brine shrimp (*Parartemia* sp.), a copepod *Calamoecia trilobata*, and two species of ostracods, including *Australocypris bennetti.* Nearby alkaline salt lakes show an attenuating fauna with increasing salinity with dominance by various crustaceans particularly *Parartemia* spp., various ostracods, copepods, *Daphnia* (*Daphniopsis*) *truncata*, *Haloniscus searlei* and snails including *Coxiella glauerti*, as is typical in salinas in southern Australia. When both types of lakes fill with episodic rain, their salinity is vastly reduced and pH approaches neutrality. Such lakes are colonized by insects and by large branchiopods. Many of the latter are new to science and occur only in these brief hyposaline stages. Such a unique assemblage is in danger of extinction due to hypersaline mining waste waters being dumped in saline lakes and to secondary salinization.

## INTRODUCTION

The essential characteristics of Australia's numerous saline lakes are now relatively well-known (e.g. Williams 1984, 1998), including those in southwestern Australia (Pinder et al. 2002, 2004, 2005). This has been achieved by many broad scale studies (e.g. Geddes et al. 1981 on southwestern Australia) and by some more detailed studies of salt lake districts (e.g. Halse 1981 on the Marchagee lakes in Western Australia (WA)). While these studies have concentrated on the predictably seasonal lakes in southern Australia, some information is also available on typically episodic lakes of the inland (e.g. Timms et al. 2006 on the Carey system in the northern goldfields of WA). However there are few data showing the effect of unusual episodic events in the south, or on those saline lakes subject to rising acid groundwater due to anthropogenic influences.

There are thousands of small saline lakes inland of the town of Esperance in south-western Australia. Knowledge on them is restricted to one lake included in the Geddes et al. (1981) study, plus three in the Brock & Shiel (1983) study and three in the Pinder et al. (2004) study. These reveal typical alkaline lakes, seasonally filled and of low biotic diversity with dominance by crustaceans, including *Parartemia* spp., and ostracods. However, within the Esperance hinterland there are numerous natural acid salinas (T. Massenbauer, pers. comm.) and long-term rainfall records reveal there are episodic summer periods of filling in addition to fillings during the normal winter-spring rainfall (A. Longbottom, pers. comm). In view of salinization in wheatbelt lakes which often involve acidification of saline lakes (Halse et al. 2003) and the unpredictable nature of episodic fills (Timms 2005), this study aims to elucidate the characteristics of naturally acid saline lakes and the effect of an episodic summer fill. This was done in a background of normal seasonal filling and the dominant alkaline lakes of the area.

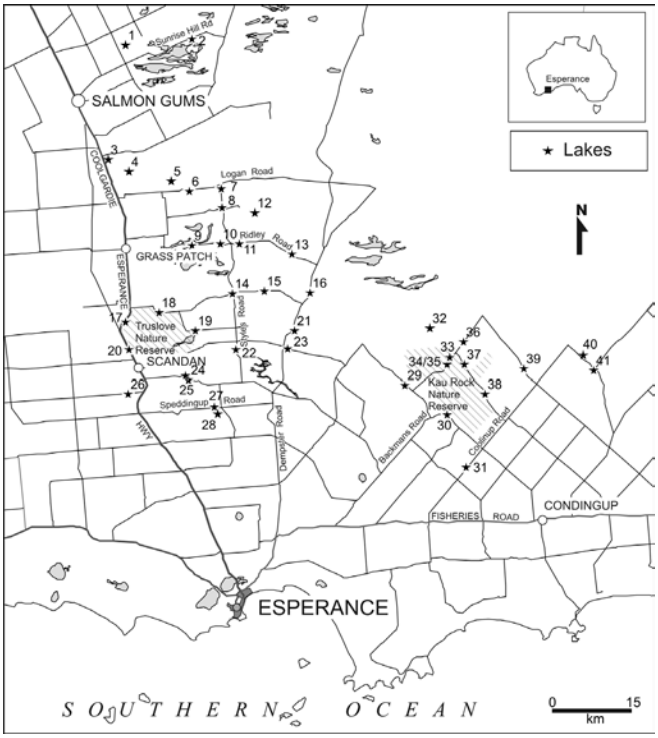

**Figure 1**–Map of the Esperance area showing towns and major roads and the position of the 41 lakes studied.

### The Lakes

Thousands of small lakes lie on the Esperance sandplain within ca 100 km north and northeast of Esperance (Figure 1; Morgan & Peers 1973). Most are roundish to elongated, very shallow and saline and all lie in swales of old dunes most of which are aligned in a general east-west direction. They tend to fill in winter-spring and dry in summer-autumn, less reliably in the north where rainfall is less, and also tending to be of higher salinity in the north. The greater majority lie in carbonate rich sands, but mainly in the north these deposits are very thin or absent so that granitic rocks or sandstones/siltstones lie near the surface (Morgan & Peers 1973). This fundamental difference in geology means that the latter group of lakes tends to be acidic from emerging acidic groundwaters while those on calcareous substrates are alkaline. Fifteen of the 41 lakes chosen were acidic, a much greater proportion than in nature. Even more were targeted, but they were so saline and/or so acidic that no macroscopic life was present; they are represented by Lake No. 1 in this study. The majority of lakes chosen were 1 to 10 ha in size and were < 30 cm deep (Appendix 1); this group likely over-represents the smaller lakes in the region. Many lakes are moving slowly westwards so that westward shores are steeper and eastern shores have spits and lunettes and may even be segmented (Timms 1992). The latter may mean the two parts can be different hydrologically and in salinity and hence have a somewhat different fauna. This was explored only in one basin (Lakes 34 & 35).

## METHODS

The 41 chosen lakes were visited four times: August and September 2005 and January and March 2007. In addition some data are available on a few of the lakes (Nos. 5, 9, 18, 20, 22, 27, 28) from August 2006 to January 2008. The study was interrupted by drought during the normal wet season in 2006 and recommenced when episodic summer rain fell in early January 2007. Some sites were not sampled in September 2005 and March 2007 because they had already dried. Of the 41 sites studied (Table 1, Appendix 1), 8 were sampled twice, 24 three times and 9 four times. Surprisingly, cumulative species richness was not affected by sample number (r = -0.0462, not significant at 0.05%).

At each site a surface water sample was taken about 10 m from the shore and conductivity determined with a Hanna HI 8663 m. Conductivities were converted to TDS in $g\ l^{-1}$ using the formula of Williams (1966). The word salinity is used in the general sense; it is roughly equivalent to TDS, but the later includes dissolved organic matter as well as salts. Water clarity was measured with a Secchi tube calibrated in NTUs. The pH was determined with a Hanna HI 8924 m.

All biological sampling was done by wading, as most sites were shallow enough. Zooplankton was collected with a plankton net of mesh size 159 µm mounted on a pole and with an aperture 30 x 15 cm. It was trawled for 1 minute (sometimes longer when zooplankton was sparse) and the sample preserved in formalin. Species present were identified in the laboratory and their relative abundance was determined by counting the first 200 organisms seen in a representative subsample and then by scanning the whole collection looking for rare species. Phytoplankton samples were collected in September 2005 and January 2007, using a 35 µm mesh net, also on a handle. Samples were preserved immediately in Lugol iodine.

**Table 1**–Summary of the physicochemical data in the study lakes.

| no. | Site name* | mean pH | mean TDS $g\ l^{-1}$ | mean turbidity (NTU) |
|---|---|---|---|---|
| 1 | McRea | 2.7 | 171 | 110 |
| 2 | Salmon Gums NE | 5.2 | 146 | 217 |
| 3 | Highway Circle Valley | 8.3 | 99 | 117 |
| 4 | Guest (West) | 4.5 | 54 | 74 |
| 5 | Guest (Southeast) | 4.8 | 42 | 44 |
| 6 | Logans | 9.3 | 41 | 12 |
| 7 | Styles & Logan | 5.0 | 98 | 26 |
| 8 | Styles & Kent | 7.2 | 112 | 90 |
| 9 | Big Ridley | 5.8 | 122 | 8 |
| 10 | Ridley W Little | 5.2 | 131 | 42 |
| 11 | Ridley Near E | 3.4 | 194 | 60 |
| 12 | Ridley Mid E | 4.3 | 110 | 77 |
| 13 | Ridley Far E | 5.8 | 70 | 160 |
| 14 | Styles & Lignite | 8.1 | 116 | 127 |
| 15 | Lignite East | 8.0 | 86 | 170 |
| 16 | Demspter Nth | 3.2 | 122 | 41 |
| 17 | West Truslove | 5.0 | 60 | 20 |
| 18 | Truslove Nat. Res. | 4.5 | 136 | 173 |
| 19 | Coxs Rd | 4.5 | 110 | 135 |
| 20 | Highway Scaddan | 8.9 | 51 | 7 |
| 21 | Dempster Mid | 9.2 | 31 | 7 |
| 22 | Styles South | 7.8 | 79 | 325 |
| 23 | Norwood Rd | 7.8 | 54 | 42 |
| 24 | unnamed Rd Scaddan | 8.8 | 74 | 6 |
| 25 | unnamed Rd Scaddan | 8.7 | 66 | 40 |
| 26 | Griffith | 8.2 | 63 | 12 |
| 27 | Speddingup Nth | 7.4 | 170 | 42 |
| 28 | Speddingup Sth | 9.0 | 66 | 10 |
| 29 | Burdett | 7.1 | 103 | 22 |
| 30 | Eld Rd | 7.7 | 145 | 4 |
| 31 | Coolingup | 8.9 | 53 | 8 |
| 32 | Kau Rock | 8.5 | 70 | 46 |
| 33 | Kau Nat Reserve | 8.2 | 60 | 10 |
| 34 | Kau Nat Res main | 7.4 | 123 | 37 |
| 35 | Kau Nat Res cutoff | 7.2 | 68 | 32 |
| 36 | Mt Nev | 3.9 | 60 | 70 |
| 37 | Avondale | 8.3 | 37 | 15 |
| 38 | Kau Rd | 8.8 | 76 | 15 |
| 39 | Howick | 7.7 | 58 | 40 |
| 40 | Heywood | 8.9 | 59 | 7 |
| 41 | Berg | 8.2 | 106 | 30 |

* not one of the sites has an official name, these names refer to a nearby road or Nature Reserve.

**Table 2**–Crustaceans found in the inland Esperance lakes.

| Species | Salinity Range g $l^{-1}$ | pH Range | Number of Records | Lakes From Which Recorded |
|---|---|---|---|---|
| **Anostraca** | | | | |
| *Artemia parthenogenetica* Bowen & Stirling | 97-102 | 7.4-7.6 | 2 | 39 |
| *Parartemia cylindrifera* Linder | 12-140 | 7.6-8.2 | 16 | 6,20,21-23,31-33,37,40 |
| *Parartemia longicaudata* Linder | 87-240 | 7.3-8.0 | 10 | 14,27,34 |
| *Parartemia serventyi* Linder | 119-258 | 7.5-8.2 | 4 | 3 |
| *Parartemia* sp. A | 20-235 | 7.4-9.2 | 41 | 15,22,24,25,26,28-32,34,38,41 |
| *Parartemia* sp. F | 35-210 | 3.4-7.4 | 42 | 2,4,5,7-13,16-19,36 |
| *Branchinella affinis* Linder | 2.8-9 | 7.8-8.2 | 2 | 5,23 |
| **Notostraca** | | | | |
| *Triops* sp. near *australiensis* (Spencer & Hall) | 27-31 | 9.3-9.9 | 2 | 6 |
| **Spinicaudata** | | | | |
| *Limnadia* sp. near *cygnorum* (Dakin) | 2.8-15 | 5.8-9.8 | 4 | 4,5,26 |
| *Caenestheriella packardi* (Brady) | 2.8-9 | 7.8-8.2 | 2 | 5,23 |
| **Cladocera** | | | | |
| *Alona* spp | 31-37 | 5.4-5.8 | 2 | 4,5 |
| *Daphnia carinata* s.l.King | 2.8 | 7.8 | 1 | 5 |
| *Daphnia* (*Daphniopsis*) *truncata* (Hebert & Wilson) | 15-84 | 6.9-9.5 | 14 | 20,23,24,26,31,33,40 |
| *Moina ?australiensis* Sars | 2.8-11 | 5.8-8.2 | 4 | 4,5,21,23 |
| **Copepoda** | | | | |
| *Boeckella triarticulata* Thomson | 2.8 | 7.8 | 1 | 5 |
| *Calamoecia ampulla* (Searle) | 2.8 | 7.8 | 1 | 5 |
| *Calamoecia clitellata* Bayly | 45-102 | 8.2-9.4 | 9 | 20,31,33,39,40 |
| *Calamoecia salina* (Nicholls) | 46-110 | 7.4-9.2 | 15 | 15,22,24-26,28,38 |
| *Calamoecia trilobata* Halse & McRae | 54-63 | 3.8-3.9 | 1 | 36 |
| *Apocyclops dengizicus* (Lepeschkin) | 15-56 | 5.1-9.8 | 4 | 6,26,27,29 |
| *Metacyclops laurentiisae* Karanovic | 3-123 | 3.8-9.2 | 22 | 4,5,13,18,20,22,23,32,33,36,37,38 |
| *Metacyclops* sp. | 24-118 | 7.4-9.5 | 13 | 3,15,21,27,28,31,34,35,39,40 |
| **Ostracoda** | | | | |
| *Australocypris beaumontii* Halse & McRae | 45-81 | 8.2-9.4 | 12 | 20,24,26,31,32,38 |
| *Australocypris bennetti* Halse & McRae acid form | 63-164 | 3.4-6.1 | 24 | 4,5,7,9-13,16-19,36 |
| *Australocypris bennetti* Halse & McRae alkaline form | 62-124 | 7.4-9.2 | 14 | 8,14,15,22,23,25,28,32,34,35,41 |
| *Australocypris insularis* (Chapman) | 52-102 | 7.6-8.3 | 5 | 3,21,33,37,39 |
| *Mytilocypris splendida* (Chapman) | 15-85 | 6.9-9.8 | 5 | 26,37,39 |
| *Cyprinotus edwardi* McKenzie | 15-35 | 7.8-8.4 | 3 | 23,33,40 |
| *Diacypris* spp.[1] | 15-164 | 3.4-9.8 | 77 | all except 1,21,27,29 and 39 |
| *Platycypris baueri* Herbst | 24-128 | 3.8-9.5 | 48 | 3,4,7,10-15,18-26,28,32-35,37,40,41 |
| *Reticypris* spp. | 23-120 | 7.4-9.5 | 15 | 23,24,28,31,34,40 |
| **Isopoda** | | | | |
| *Haloniscus searlei* Chilton | 15-102 | 6.4-9.8 | 26 | 15,20-22,24-26,31,33,35,37,38,40 |

[1] at least five species present: *D. dictyota* De Deckker, *D. spinosa* De Deckker, *D. compacta* (Herbst), *D. whitei* (Herbst) and *Diacypris* sp.

Littoral invertebrates were collected with a 30 x 20 cm D-shaped net with 1 mm mesh. At each site, 15 minutes was spent collecting invertebrates on each trip, ample time for the species accumulation curve to plateau. Littoral samples contained animals from a variety of microhabitats, including nektonic, epiphytic, and epibenthic, but some eubenthic species such as polychaetes, chironomids and ceratopogonids were probably incompletely sampled. All collections were sorted on site and preliminary identifications made. For each species an estimate was made of abundance using a coarse logarithmic scale (0.1, 0.5, 1, 1.5, 2, 2.5, 3, 4 for 1, 3, 10, 30, 100, 300, 1000, 10000 individuals per 15 min collection).

Some taxa could not be identified to the species level, either because of inadequate taxonomic knowledge (e.g. *Coxiella* spp., many dipteran larvae) or because unknown variability meant it was too time consuming a task (e.g. *Diacypris*

–De Deckker 1981). Fortunately, work by Halse & McRae (2004) allowed acid-alkaline forms of *Australocypris bennetti* to be separated and hence distinctions made between the fauna of acid and alkaline lakes. Possible similar distinctions in *Diacypris* have been missed, probably dulling the difference between lakes.

Relationships between the 40 sites (site 1 had no animals) were investigated using PRIMER (v5) software (Clarke and Gorley 2001). Littoral and planktonic invertebrates were analysed together. The abundance data of the invertebrates was log (N+1) transformed prior to multivariate analysis. To elucidate the influence of the episodic filling, data for the most affected sites (numbers 4, 5, 23, 26 and 39) were separated into seasonal filling collections and episodic collections and a few acid (numbers 7, 9, 13, 18, 36) and alkaline sites (numbers 22, 31, 37, 38) of similar salinity added for comparisons. Non-metric multidimensional scaling, based on the Bray-Curtis similarity matrix, was used to represent assemblage composition or physical-chemical conditions in two-dimensional space. Relative distances apart in ordinations represent relative dissimilarity. In the ordination on physicochemical features, only pH, salinity and turbidity were used, as there was no relationship with size or depth.

## RESULTS

The 41 lakes ranged in conductivity from 5–250 mS/cm, i.e. from 3.5–198 g $l^{-1}$ salinity, and from pH 2.1 to 9.8 (Table 1, Appendix 1). Even higher salinities and lower pHs were encountered in exploration of lakes, mainly to the northeast of Grass Patch and Salmon Gums (author's unpublished data and K. Benison, pers. comm.). The highest pH values were recorded on warm summer afternoons, suggesting photosynthesis had increased apparent alkalinities. Turbidities ranged from 2–450 NTU (Appendix 1) and in alkaline lakes were haphazardly influenced by resuspension of the fine calcareous deposits if wind had occurred shortly before or during the sampling.

Only two species of aquatic plants were found in the lakes and then only in alkaline waters: *Lepilaena preissii* (Lehm.) F. Muell in lower salinities (to 54 g $l^{-1}$) and *Ruppia tuberosa* Davis & Tomlinson at higher salinities (to 95 g $l^{-1}$). Both are species typical of seasonal ephemeral systems (Brock & Lane 1983).

From limited collections, approximately 33 taxa of phytoplankton were identified in the lakes over the two sampling periods, 27 taxa in 2005 and 31 taxa in 2007 (Joan Powling, Melbourne University, pers. comm.). The list comprises 15 diatoms, the most common of which were halophile species of *Nitzschia* and *Chaetoceros*, two unidentified dinoflagellates, 10 green algae including the halophile flagellate *Dunaliella salina*, and six filamentous cyanobacteria including *Nodularia spumigena*. Diatoms were more diverse in the winter collection of 2005 but were rare in the low pH sites in both years. *Dunaliella* was very common in three sites in 2007 with high conductivity and very low pH. A filamentous green alga, cf. *Oedogonium* sp. was common in three sites in 2005 and two sites in 2007, which had a low pH and moderately low conductivity. *Nodularia* was found only in the summer sampling of 2007 in sites of moderate conductivity.

Seventy taxa of invertebrates, representing about 75 species, were encountered in the 41 lakes (Tables 2 and 3). Widespread dominant species included crustaceans *Parartemia* sp. a and sp. f (see Timms 2004 for explanation of notation), *Australocypris bennettii*, *Diacypris* spp., *Platycypris baueri* and the snail *Coxiella glauerti*. A further nine crustacean taxa (*Parartemia cylindrifera*, *P. longicaudata*, *Daphnia* (*Daphniopsis*) *truncata*, *Calamoecia clitellata*, *C. salina*, *Metacyclops laurentiisae*, *Australocypris beaumonti*, *Reticypris* spp., and *Haloniscus searlei*) were common, together with just three beetles (*Antiporus gilberti*, *Berosus* spp. and *Necterosoma penicillatum*) and a rotifer (*Hexarthra* nr *fennica*) (Table 2 & 3). Although similar numbers of insects and crustacean taxa were recorded, insects were far less common and moreover, restricted to much lower salinities (Tables 2 & 3). The dominant crustaceans together with the two common *Parartemia* species were by far the most salt tolerant (Table 2).

A seasonal study of seven of the lakes from August 2006 to December 2007 added an average of 1.4 species to each lake's list, resulting mainly from the unusual summer filling (Timms et al. 2008).

Tadpoles of the frog *Littoria cyclorhynchus* (Boulenger) grew in Lake 4 during January to March, 2007, after it had been markedly reduced in salinity and increased in pH by the episodic rainfall. It occurred over a salinity range of 3-11 g $l^{-1}$ and a pH range of 4.1-7.8. No fish were found in any of the lakes.

Cumulative species richness per lake ranged from 2 to 32. This parameter was influenced positively by increasing pH ($r = 0.3676$, significant at $P < 0.05$) and negatively by salinity ($r = -0.7869$, significant at $P < 0.001$). When the lakes (Nos. 4, 5, 23, 26, 39) which changed greatly by episodic in-fills were removed from the series, the correlation with pH increased ($r = 0.6022$, significant at $p < 0.001$) while that with salinity decreased a little ($r = -0.6895$, significant at $p < 0.001$). Within both alkaline and acid lakes series, correlations with species richness were not significant ($p > 0.05$; $r = 0.2581$ and $r = 0.4611$ respectively).

**Table 3**–Insects and miscellaneous animals of the inland Esperance lakes.

| Species | Salinity Range g $l^{-1}$ | pH Range | Number of Records | Lakes from which Recorded |
|---|---|---|---|---|
| **Odonata** | | | | |
| *Hemianax papuensis* (Burmeister) | 10 | 4.1 | 1 | 5 |
| *Hemicordulia tau* (Selys) | 9-49 | 3.7-8.2 | 5 | 4,5,23,26,39 |
| *Austrolestes annulosus* (Selys) | 9-49 | 3.7-8.5 | 7 | 4,5,23,26,37,39 |
| *Xanthoagrion erythroneurum* Selys | 24 | 7.6 | 1 | 39 |
| **Hemiptera** | | | | |
| *Agraptocorixa* spp. | 3-36 | 3.7-8.2 | 6 | 4,5,23,26,29,39 |
| Micronecta sp. | 3-67 | 3.7-8.5 | 7 | 4,5,27,39 |
| *Anisops* spp. | 3-56 | 4.1-8.2 | 8 | 5,23,26,29,37,39 |
| **Coleoptera** | | | | |
| *Allodesses bistrigatus* (Clark) | 3-10 | 5.1-7.8 | 4 | 4,5,29 |
| *Antiporus gilberti* Clark | 7-94 | 3.7-9.8 | 11 | 4,5,7,26-28,32,39 |
| *Berosus* spp.[1] | 3-94 | 3.7-9.8 | 13 | 4,5,7,15,20,21,23,29,37,38 |
| *Cybister tripunctatus* Olivier | 9 | 8.2 | 1 | 23 |
| *Enochrus elongatus* (W. MacLeay) | 10-25 | 4.1-8.2 | 2 | 5,39 |
| *Eretes australis* (Erichson) | 2.5-70 | 4.1-9.9 | 7 | 4-6, 24,26,32, |
| *Limnoxenus zealandicus* (Broun) | 9-24 | 4.1-8.2 | 4 | 4,5,23,39 |
| *Megaporus howitti* Clark | 10 | 4.1 | 1 | 5 |
| *Necterosoma penicillatum* (Clark) | 9-85 | 4.1-9.8 | 11 | 5,6,21,23,26,29,31,32,37,38 |
| *Rhantus suturalis* MacLeay | 9-10 | 8.2 | 2 | 23,29 |
| unidentified Curculionidae | 9-6 | 3.7-4.1 | 2 | 3,4 |
| **Diptera** | | | | |
| *Chironomus cloacalis* Atchley & Martin | 22-54 | 8-9.8 | 3 | 20,28,29 |
| *Cryptochironomus* sp. | 10-49 | 4.1-9.8 | 4 | 5,26,31,37 |
| *Polypedilum nubifer* (Skuse) | 10-32 | 4.1-9.8 | 4 | 5,26,39 |
| *Procladius paludicola* Skuse | 9-40 | 6.7-9.8 | 3 | 23,26,29 |
| *Tanytarsus barbitarsus* Freeman | 24-96 | 5.1-9.1 | 5 | 3,29,35,39 |
| *Tanytarsus semibarbitarsus* Glover | 9-50 | 3.7-9.8 | 7 | 4,5,17,23,29,32,38 |
| *Aedes camptorhynchus* (Thomson) | 10-54 | 8.2-9.2 | 2 | 20,39 |
| unidentified ceratopogonid larva | 24 | 7.4 | 1 | 39 |
| unidentified dolichopodid larva | 24 | 7.4 | 1 | 39 |
| unidentified stratiomyid larva | 10-75 | 3.9-5.7 | 3 | 5,9 |
| unidentified tabanid larva | 25-126 | 5.2-9.5 | 4 | 13,14,32,39 |
| **Lepidoptera** | | | | |
| unidentified pyralid larva | 15-31 | 9.5-9.8 | 2 | 6, 21, 26 |
| **Platyhelminthes** | | | | |
| unidentified rhabdocoel | 63 | 8.4 | 1 | 35 |
| **Rotifera** | | | | |
| *Brachionus plicatilis* s.l. (Müller) | 9-50 | 6.7-9.9 | 9 | 6,7,21,23,26,29,32,37 |
| *Brachionus rotundiformis* Tschugunoff | 40 | 6.7 | 1 | 29 |
| *Hexarthra cf brandorffii* Koste | 36 | 3.7 | 1 | 4 |
| *Hexarthra cf fennica* (Levander) | 9-68 | 3.7-9.9 | 14 | 4-6,13,23-26,32,38 |
| *Hexarthra* sp. | 54-62 | 3.8-3.9 | 1 | 36 |
| **Mollusca** | | | | |
| *Coxiella glauerti* Macpherson | 15-118 | 7.4-9.8 | 32 | 3,15,20-24,26-28,32-34,37 |
| *Coxiella* spp. | 9-92 | 7.7-9.5 | 5 | 23,32,40 |

[1] *B. nutans* (W. MacLeay), *B. reardoni* Watts

In many lakes spits have grown across the original dune hollow to segment it into two or more sub-basins (Timms 1992). Despite being less than 2 m apart at their closest point and in the same greater basin, such twin lakes can be very different. In the only example studied, the two sub-basins had different physicochemical features, with the main circular central basin (Lake 33) more saline and of higher pH than the cut-off bay (Lake 34) (Appendix 1). The central basin had a lower species richness (6 species) compared to that of the cut off bay (9 species). Of the differences in species composition, the most obvious were the presence of *Parartemia* n.sp. and *Reticypris* sp. in Lake 33 and the presence of *P. cylindrifera*, *Daphnia truncata* and *Haloniscus searlei* in Lake 34. Of the shared species, some were much more common in one or the other lake (e.g. *Diacypris* spp. in Lake 33, *Coxiella glauerti* in Lake 34). Reconnaissance of other lakes with subbasins suggested differences between such divided lakes were common.

Multivariate analysis using just the physiochemical features of the lakes showed a clear distinction between acid and alkaline lakes, with many alkaline lakes variously turbid (haphazardly due to wind — see earlier) and both sets of lakes traversing a wide salinity range. In the ordination plot (Figure 2), the most acid lakes (1, 11, and 16) are on the far left and the least acid lakes (9, 13) nearest the least alkaline lakes (8, 29). This acid-alkaline division is reflected in the ordination plot of invertebrate communities in the lakes (Figure 3), in which the acid lakes cluster together, with the alkaline lakes scattered in an gentle arc away from the acid lakes. Among the acid lakes, 4 and 5 are somewhat separate from the main group which is explained by their episodic filling (see later). One alkaline lake, No. 8, grouped with the acid lakes, which is not surprising given its fluctuation between pH 6.5 to 7.7. Among the alkaline lakes, numbers 29, 30, 6, 21, 35 39 and 27 are separated from the main group on different axes (Figure 3) for different apparent reasons. Lake 27 is highly saline and more persistent than most (T. Massenbauer of WA Department of Environment and Conservation, pers. comm.), lakes 6 and 21 are of persistent relatively low salinity and lakes 35 and 39 are of seasonally low salinity.

Acid lakes have low diversity and are dominated by *Parartemia* sp. f and have the acid form of *Australocypris bennetti* (Table 4). On the other hand, alkaline lakes are less dominated by one species and have *Diacypris* spp. and *Parartemia* sp. a common and an array of other species, all crustaceans, differentiating them (Table 4).

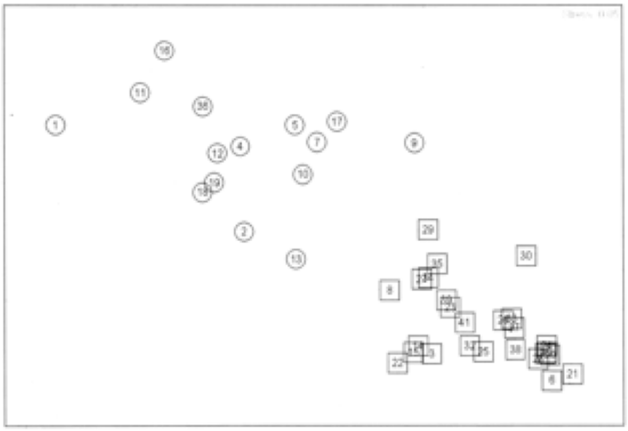

**Figure 2**–Ordination of the lakes based on their physicochemical features. Acid lakes are circled and alkaline lakes are in squares. Numbers in symbols refer to lakes described in Table 4. A stress factor of 0.05 was used in the analysis.

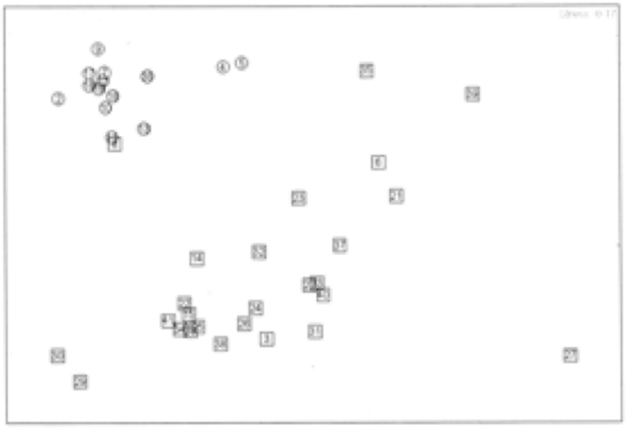

**Figure 3**–Ordination of the lakes based on their invertebrates. Acid lakes are circled and alkaline lakes are in squares. Numbers in symbols refer to lakes described in Table 4. Stress 0.17.

The unusual ±200 mm of rain that fell on January 4, 2007 put water in most lakes, but generally at depths not much different from a normal winter-spring filling. Some lakes, however, received much water from overland flow and filled to far greater depths than normal. Two of these were from the acid series (Nos. 4 and 5) and three from the alkaline series (Nos. 23, 26 and 39). All five became almost fresh and near neutral in pH. Species normally found in them were replaced by many insects, a few species of branchiopods and a few others. These episodic changes in biota are plotted in an ordination diagram (Figure 4) in which data for each were divided into normal winter-spring features ('a' notation) and episodic conditions ('b' notation) and then compared with a few other lakes from each group of similar salinity. Clearly this approach recognized three types of lakes (see Figure 4): acid to the lower left, alkaline to upper middle and a new group of low salinity lakes to the lower right. Four lakes (Nos. 4, 5, 23, 39) changed markedly as a result of their episodic fill and one changed position in the alkaline group (No. 26).

Characteristic species in the acid and alkaline groups were similar between the 'a' sites and their respective groups, but a new low salinity episodic group ('b' sites) had a new array of characteristic species, dominated by an array of insects (Table 4).

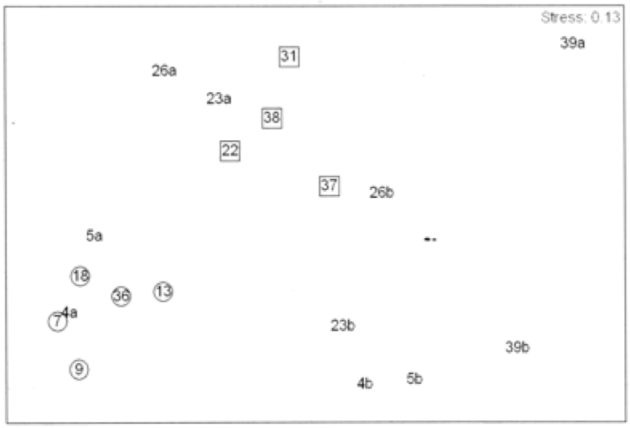

**Figure 4**–Ordination of episodic lakes based on their invertebrates. Lakes remaining acid are circled and lakes always alkaline are in squares. Numbers in symbols refer to lakes described in Table 4. The episodic lakes in normal condition are labelled 'a' and after the episodic rain are labelled 'b.' Stress 0.13.

## DISCUSSION

Differing characteristics among these lakes are due largely to their position with reference to surface rocks and their derived soils. Although some lakes are subject to occasional large overland flows, most are groundwater "windows". As such, acidity/alkalinity of groundwater influences their pH. Throughout much of the southwest on the Yilgarn Block groundwaters tend to be acid, often very much so (pH < 2.8) (Mann 1983; McArthur et al. 1991). The reason for this is contentious, but David Gray of CSIRO, Perth (pers. comm.) thinks the acidity is generated through soil pedological processes, resulting in the accumulation of carbonates in the soil profile and recharge of iron-rich, sometimes acidic waters, to shallow aquifers. On the other hand, Kathy Benison of Central Michigan University (pers. comm.) hypothesises that sulfide oxidation in host rocks results in acid groundwaters, which may be further acidified by ferrolysis, microbial action and/or evaporative concentration in lakes without carbonates to buffer the acidity. Where carbonates are scarce or isolated from lakes, as in most lakes north of Ridley Rd (east of Grass Patch) and a few others mainly in the Truslove Nature Reserve area (Morgan & Peers 1973), lakes are acid. Elsewhere in deep carbonates (particularly Lakes 14, 15, 20-35, 37-41), lakes are alkaline. At least for one lake in shallow carbonates (No. 3), groundwaters are acid (pH 3.5) though lake waters are alkaline (pH 8-8.5) (K. Benison, pers. comm.). This may be at least a partial explanation for differing pHs in main and cut-off parts of a basin (as in Lakes 33 & 34), the later being more active hydrologically. The cut-off part may also be more influenced by overland flows which would not be as acid as the groundwater and certainly would be less saline. The lakes subject to large overland flows (Nos 4, 5, 23, 26, 39) all had low salinities and neutral pHs following episodic rainfall events.

**Table 4**–Characteristic species of each group of lakes.

| Higher category | Genus and species | %* |
|---|---|---|
| **Acid lakes** | | |
| Anostraca | *Parartemia* n.sp. f | 51.6 |
| Ostracoda | *Australocypris bennetti* acid | 28.0 |
| Ostracoda | *Diacypris* spp. | 13.6 |
| **Alkaline lakes** | | |
| Ostracoda | *Diacypris* spp. | 37.7 |
| Anostraca | *Parartemia* n.sp. a | 24.8 |
| Ostracoda | *Platycypris baueri* | 6.8 |
| Ostracoda | *Australocypris bennetti* alkaline | 6.0 |
| Anostraca | *Parartemia cylindrifera* | 4.7 |
| Isopoda | *Haloniscus searlei* | 4.3 |
| Ostracoda | *Australocypris beaumonti* | 4.0 |
| **Episodic change –standard acid lakes** | | |
| Anostraca | *Parartemia* n.sp. f | 54.9 |
| Ostracoda | *Australocypris bennetti* acid | 31.5 |
| Ostracoda | *Diacypris* spp. | 9.8 |
| **Episodic change – standard alkaline lakes** | | |
| Ostracoda | *Diacypris* spp. | 37.1 |
| Ostracoda | *Australocypris bennetti* alkaline | 10.5 |
| Isopoda | *Haloniscus searlei* | 9.2 |
| Anostraca | *Parartemia* n.sp. a | 8.8 |
| Ostracoda | *Platycypris baueri* | 8.2 |
| Copepoda | *Metacyclops laurentiisae* | 5.8 |
| Ostracoda | *Mytilocypris splendida* | 4.8 |
| **Episodic change – new low salinity lakes** | | |
| Insecta | *Anisops* spp. | 13.8 |
| Insecta | *Agraptocorixa* spp. | 13.7 |
| Anostraca | *Branchinella affinis* | 10.2 |
| Copopoda | *Metacyclops laurentiisae* | 9.5 |
| Rotifera | *Hexarthra* nr *fennica* | 9.1 |
| Insecta | *Austrolestes annulosus* | 8.3 |
| Insecta | *Micronecta* sp. | 8.2 |
| Insecta | *Hemicordulia tau* | 7.0 |
| Insecta | *Limnoxenus zealandicus* | 6.9 |
| Spinicaudata | *Caenestheriella packardi* | 6.6 |

* The percentages in the table refer to the % of the total difference between the groups that is contributed by the different species.

Groundwater-controlled lake pHs are known for lakes north of the study area (Lakes Swann, Gilmore, Lefroy) (McArthur et al. 1991; Clarke 1994) but with unknown implications for lake invertebrates. However, in the Lake Hope area, 150 km to the northwest of Grass Parch, saline lakes adjacent to laterite are acid and have a different fauna from that of alkaline lakes on the sand plain (Timms 2006). Conte & Geddes (1988) first noted the restrictive role of pH in Western Australian salt lakes, noting the presence of just *Parartemia contracta* in acid lakes. These Esperance acid lakes provide a more intensive example of the role of low pH in restricting fauna. Secondarily salinized waters are often acidic as well and Halse et al. (2003) have noted the absence of most halophilic/halobiont species in them.

In addition to the influence of pH, salinity, not surprisingly exerts a strong control over species composition and species richness as it does in most inland saline waters, including those in Western Australia (Pinder et al. 2002). On the other hand, the apparent effects of seasonality on community composition were more easily explained by differences in pH and/or salinity (Timms et al. 2008). Two exceptions were many insects which were more abundant in summer and *Daphnia* (*Daphniopsis*) *truncata* which was most abundant in winter-spring.

The alkaline saline lakes of the Esperance inland support a fauna that is broadly similar throughout southern Australia (Geddes 1976; De Deckker & Geddes 1980; Pinder et al. 2002, 2004, 2005; Timms 2009), though species differ regionally (Williams 1984). The Esperance hinterland lakes have a species of *Parartemia*, many species of ostracods, including a mytilicyprinid species, *Diacypris*, *Platycypris* and *Reticypris*, and perhaps a species or two of rotifers and copepods, a halophilic *Daphnia* (*Daphniopsis*), the isopod *Haloniscus searlei*, and a *Coxiella* snail. Of these, *Parartemia* n.sp. a and *Australocypris beaumonti* are apparently endemic to the Esperance area, and *Parartemia cylindrifera*, *P. longicaudata*, *P. serventyi*, *Australocypris bennetti* and *Coxiella glauerti* are shared with a few others. Previous studies have found fewer species in the area (Geddes et al. 1981; Brock & Shiel 1983) or a few more, mainly a polychaete and some chironomids (Pinder et al. 2002).

The fauna of the acid salinas is more restricted with just *Parartemia* n.sp. f, *Australocypris bennetti* (acid form), *Diacypris* spp. and the copepod *Calamoecia trilobata*, with the first two apparently restricted to the area. This restricted fauna is less diverse than that in acid lakes in the wheatbelt further west in Western Australia which have these species, except *Parartemia* sp. f., and also perhaps a variety of dipterans, a few beetles, more ostracods and *Parartemia contracta* (Adrian Pinder, pers. comm.). This fauna is more restricted than occurs in alkaline lakes in the wheatbelt (Pinder et al. 2004, 2005). At least for *Parartemia* spp this is probably due to the necessity for a different method of osmoregulation in acid conditions where there are no bicarbonate/carbonate ions (Conte & Geddes 1988).

Many saline lakes of the Australian inland are dominated by episodic events so that they fill and dry over years, vary widely in salinity and have a corresponding array of characteristic species as salinity changes widely (Timms 2008). Most lakes in the south fill and dry regularly each year and, though varying widely in salinity, lack a fresh/hyposaline stage and so have a more limited fauna that changes little during the wet phase (e.g. Geddes 1976; De Deckker & Geddes 1980). This is explained by a rapid change in a richer array of species as salinity slowly increases in the hypsosaline range but wide tolerances of the limited array of species in the much wider mesosaline-hypersaline range, or in other words a 'question of scale' (Williams et al. 1990). The Esperance hinterland lakes are of the second type based on their latitude and some seasonal evidence. However, they are subject to occasional episodic filling, and in some lakes where the hydrology is favourable, there can be vast changes in their characteristics (Figure 4). Their fauna, when fresh or hyposaline, is uncharacteristic of their normal composition and more akin to widespread faunal elements in hyposaline filling stages of lakes further inland. Particularly noticeable in both these unusual Esperance lakes and the episodic inland lakes is the abundance of insects tolerant to lower salinities and the absence of brine shrimp and ostracods tolerant to high salinities.

Of even more interest is the presence in these episodic fillings of animals not seen in typical saline lakes. These are large branchiopods either of tolerant freshwater forms or of specialist hyposaline forms. The Esperance hinterland lakes subject to the episodic filling of January 2007 had the slightly tolerant *Branchinella affinis* and *Caenestheria packardi* (Timms in press) and two nearby lakes had a new species of *Branchinella*, and the clam shrimps *Limnadia* near *cygnorum* and *Eocyzicus parooensis* (Timms 2009). Their presence in appreciable numbers shows these lakes have sufficiently frequent episodic fillings to have an egg bank capable of responding to the unusual conditions of being fresh or hyposaline and around neutral pH. Should episodic fills be too spaced temporally or averted due to increased salt loads in a basin due to mining inputs or salinization, then this specialized fauna will be lost (Timms 2005). It is not known how much of this fauna is catalogued, but in Western Australia it includes the fairy shrimps *Branchinella compacta*, *B. nichollsi*, *B. nana*, and *Branchinella papillata*, the clam shrimps, *Caenestheria dictyon*, *Caenestheriella packardi*, *Eocyzicus parooensis* and *Limnadia* near *cygnorum* and a form of the shield shrimp *Triops* near *australiensis* (Timms 2009).

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## REFERENCES

Brock, M.A. & J.A.K. Lane. 1983. The aquatic macrophytes of saline wetlands in Western Australia in relation to salinity and permanence. Hydrobiologia 105: 63–76.

Brock, M.A. & R.J. Shiel. 1983. The composition of aquatic communities in saline wetlands in Western Australia. Hydrobiologia 105: 77–84.

Clarke, J.D.A. 1994. Lake Lefroy, a palaeodrainage playa in Western Australia. Australian Journal of Earth Sciences 41: 417–427.

Clarke, K.R. & R.N. Gorley. 2001. PRIMER v5: user manual/tutorial. PRIMER-E, Plymouth.

Conte, F.P. & M.C. Geddes. 1988. Acid brine shrimp: metabolic strategies in osmotic and ionic adaptation. Hydrobiologia 158: 191–200.

De Deckker, P. 1981. Taxonomic notes on some Australian ostracods with description of new species. Zoologica Scripta 10: 37–55.

De Deckker, P. & M.C. Geddes. 1980. Seasonal fauna of ephemeral saline lakes near the Coorong lagoon, South Australia. Australian Journal Marine Freshwater Research 31: 677–699.

Geddes, M.C. 1976. Seasonal fauna of some ephemeral saline waters in western Victoria with particular reference to *Parartemia zietziana* Sayce (Crustacea: Anostraca). Australian Journal Marine Freshwater Research 27: 1–22.

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.

Halse, S.A. 1981. Faunal assemblages in some saline lakes near Marchagee, Western Australia. Australian Journal Marine Freshwater Research 32: 133–142.

Halse, S.A. & J.M. McRae. 2004. New genera and species of 'giant' ostracods (Crustacea: Cyprinidae) from Australia. Hydrobiologia 524: 1–52.

Halse, S.A., J.K. Ruprecht & A.M. Pinder. 2003. Salinisation and prospects for biodiversity in rivers and wetlands of south-west Western Australia. Australian Journal of Botany 51: 673–688.

Mann, A.W. 1983. Hydrogeochemistry and weathering on the Yilgarn Block, Western Australia - ferrolysis and heavy metals in continental brines. Geochimica et Cosmochimica Acta 47: 181–190.

McArthur, J.M., J.V. Turner, W.B. Lyons, A.O. Osborn & M.F. Thirlwall. 1991. Hydrogeochemistry on the Yilgarn Block, Western Australia: Ferrolysis and mineralisation in acidic brines. Geochimica et Cosmochimica Acta 55: 1273–1288.

Morgan, K.H. & R. Peers. 1973. 1:250000 Geological Series Explanatory Notes. Esperance-Mondrain Island WA Sheet SI/51-6. Australian Government Publishing Service, Canberra.

Pinder, A.M., S.A. Halse, R.J. Shiel, D.J. Cale & J. McRae. 2002. Halophile aquatic invertebrates in the wheatbelt region of south-western Australia. Verhandlungen der Internationale Vereiningung für Theoretische und Angewandte Limnologie 28: 1687–1694.

Pinder, A.M., S.A. Halse, J.M. McRae & R.J. Shiel. 2004. Aquatic invertebrate assemblages of wetlands and rivers in the wheatbelt region of Western Australia. Records of the Western Australian Museum Supplement No. 67: 7–37.

Pinder, A.M., S.A. Halse, J.M. McRae & R.J. Shiel. 2005. Occurrences of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity. Hydrobiologia 543: 1–24.

Timms, B.V. 1992. Lake geomorphology. Gleneagles Press, Adelaide, 180 pp.

Timms, B.V. 2004. An identification guide to the fairy shrimps (Crustacea: Anostraca) of Australia. CRCFC Identification and Ecology Guide No 47, Thurgoona, New South Wales, 76 pp.

Timms, B.V. 2005. Salt lakes in Australia: present problems and prognosis for the future. Hydrobiologia 552: 1–15.

Timms, B.V. 2006. Report on invertebrate sampling of saline lakes in the Lake Hope Mining Area in 2005 for LionOre Australia Limited Lake Johnson Operations. Unpublished report to LionOre Australia, Perth.

Timms, B.V. 2008. The ecology of episodic saline lakes of inland eastern Australia, as exemplified by a ten year study of the Rockwell-Wombah Lakes of the Paroo. Proceedings of the Linnean Society of New South Wales 129: 1–16.

Timms, B.V. 2009. Biodiversity of large branchiopods in Australian saline waters. Current Science 96: 74-80.

Timms, B.V., B. Datson & M. Coleman. 2006. The wetlands of the Lake Carey catchment, northeast goldfields of Western Australia, with special reference to large branchiopods. Journal of the Royal Society of Western Australia 89: 175–183.

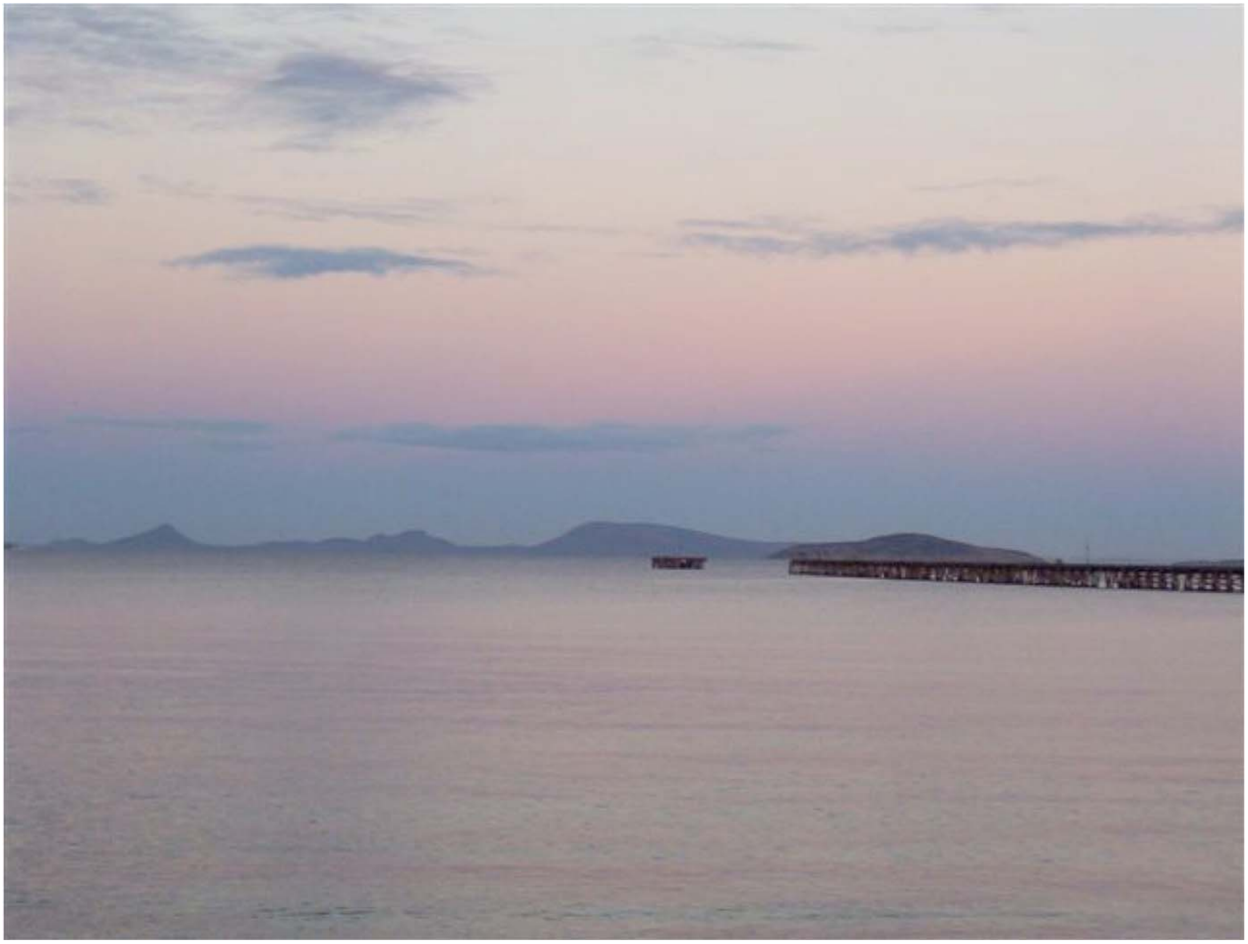
Timms, B.V., T. Massenbauer, D. Winton & O. Massenbauer. 2008. Monitoring of selected saline lakes inland of Esperance, 2005 to 2007. Unpublished report to the Department of Environment and Conservation, Esperance.

Williams, W.D. 1966. Conductivity and the concentration of total dissolved solids in Australian lakes. Australian Journal Marine Freshwater Research 17: 169–176.

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. Verhandlungen der Internationale Vereiningung für Theoretische und Angewandte Limnologie 22: 1208–1215.

Williams, W.D. 1998. Salinity as a determinant of the structure of biological communities in salt lakes. Hydrobiologia 381: 181–201.

Williams, W.D., A.J. Boulton & R.G. Taaffe. 1990. Salinity as a determinant of salt lake fauna: a question of scale. Hydrobiologia 197: 257–266.



Esperance Bay featuring the Tanker Jetty. December 2005. Wikimedia Commons at en.wikipedia.org. Accessed February 2009.

**Appendix 1**–Geomorphic and physicochemical data on the lakes.

| No | Name | Latitude | Longitude | Area when full (ha) | Lake depths (cm) | | Number of visits | pH range | Salinity Range g $l^{-1}$ | Turbidity (NTU) range |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | mean | Max. | | | | |
| 1 | McRea | 32° 53' | 121° 45' | 4.0 | 6 | 10 | 3 | 2.1-3.0 | 148-195 | 60-160 |
| 2 | Salmon Gums NE | 32° 53' | 121° 53' | 33.5 | 7 | 15 | 3 | 4.9-5.5 | 88-187 | 200-250 |
| 3 | Highway Circle Valley | 33° 05' | 121° 42' | 8.2 | 13 | 30 | 3 | 7.5-9.1 | 92-109 | 45-240 |
| 4 | Guest (West) | 33° 06' | 121° 44' | 3.2 | 22 | ca 50 | 4 | 3.7-5.8 | 11-95 | 10-250 |
| 5 | Guest (Southeast) | 33° 08' | 121° 49' | 2.6 | 49 | ca 150 | 4 | 3.7-7.8 | 4-182 | 10-130 |
| 6 | Logans | 33° 09' | 121° 51' | 1.4 | 30 | 35 | 2 | 8.8-9.9 | 31-51 | 10-15 |
| 7 | Styles & Logan | 33° 09' | 121° 55' | 2.8 | 16 | 40 | 4 | 3.7-7.7 | 27-144 | 5-50 |
| 8 | Styles & Kent | 33° 11' | 121° 55' | 13.4 | 5 | 10 | 3 | 6.5-7.7 | 87-133 | 10-200 |
| 9 | Big Ridley | 33° 14' | 121° 51' | 365 | 7 | 12 | 3 | 5.1-6.3 | 117-132 | 5-10 |
| 10 | Ridley W Little | 33° 14' | 121° 54' | 4.1 | 40 | ca 70 | 3 | 4.5-6.3 | 129-131 | 10-70 |
| 11 | Ridley Near E | 33° 15' | 121° 57' | 3.7 | 23 | 25 | 3 | 2.5-4.4 | 111-148 | 5-150 |
| 12 | Ridley Mid E | 33° 15' | 121° 59' | 23.7 | 12 | 15 | 3 | 4.1-4.7 | 101-124 | 10-160 |
| 13 | Ridley Far E | 33° 16' | 122° 03' | 27.5 | 7 | 10 | 3 | 5.2-6.2 | 46-88 | 60-330 |
| 14 | Styles & Lignite | 33° 19' | 121° 55' | 38.4 | 5 | 10 | 3 | 7.9-8.5 | 99-126 | 40-250 |
| 15 | Lignite East | 33° 19' | 121° 59' | 6.6 | 4 | 5 | 3 | 7.4-8.7 | 44-116 | 30-300 |
| 16 | Demspter Nth | 33° 20' | 122° 05' | 5.5 | 13 | 20 | 3 | 2.7-3.6 | 110-149 | 18-60 |
| 17 | West Truslove | 33° 22' | 121° 42' | 5.4 | 7 | 10 | 3 | 4.3-5.5 | 40-84 | 10-40 |
| 18 | Truslove Nat. Reserve | 33° 20' | 121° 46' | 7.3 | 11 | 12 | 3 | 4.3-4.7 | 123-159 | 50-320 |
| 19 | Coxs | 33° 23' | 121° 51' | 7.6 | 7 | 7 | 3 | 4.4-4.6 | 104-128 | 35-320 |
| 20 | Highway Scaddan | 33° 24' | 121° 42' | 6.0 | 26 | 30 | 3 | 8.4-9.2 | 45-55 | 5-10 |
| 21 | Dempster Mid | 33° 24' | 122° 03' | 1.5 | 33 | 45 | 2 | 8.9-9.5 | 24-38 | 5-10 |
| 22 | Styles South | 33° 25' | 121° 55' | 1.8 | 4 | 10 | 2 | 7.7-7.9 | 56-101 | 200-450 |
| 23 | Norwood | 33° 25' | 122° 02' | 13.2 | 18 | ca 50 | 4 | 7.4-8.2 | 9-92 | 5-180 |
| 24 | unnamed Rd Scaddan | 33° 28' | 121° 49' | 3.7 | 15 | 25 | 3 | 8.5-9.2 | 66-88 | 2-10 |
| 25 | unnamed Rd Scaddan | 33° 28' | 121° 49' | 3.1 | 15 | 20 | 3 | 8.3-9.0 | 61-70 | 5-80 |
| 26 | Griffiths | 33° 29' | 121° 42' | 2.2 | 27 | 40 | 4 | 6.9-9.8 | 15-84 | 5-25 |
| 27 | Speddingup Nth | 33° 31' | 121° 52' | 1.8 | 37 | ca 50 | 4 | 7.0-8.0 | 118-195 | 15-95 |
| 28 | Speddingup Sth | 33° 32' | 121° 53' | 2.0 | 22 | 30 | 3 | 8.4-9.3 | 62-67 | 5-20 |
| 29 | Burdett | 33° 30' | 122° 16' | 2.2 | 55 | ca 100 | 4 | 6.1-7.8 | 40-56 | 20-30 |
| 30 | Eld | 33° 33' | 122° 21' | 2.4 | 28 | 30 | 2 | 7.6-7.9 | 121-169 | 2-5 |
| 31 | Coolingup | 33° 39' | 122° 23' | 5.3 | 28 | 35 | 3 | 8.5-9.4 | 44-68 | 5-10 |
| 32 | Kau Rock | 33° 25' | 122° 20' | 10.9 | 9 | 12 | 3 | 7.8-9.5 | 28-105 | 8-120 |
| 33 | Kau Nat Reserve | 33° 28' | 122° 21' | 6.1 | 12 | 15 | 3 | 8.0-8.4 | 52-68 | 8-12 |
| 34 | Kau Nat Res main | 33° 28' | 122° 22' | 4.2 | 20 | 25 | 2 | 7.3-7.5 | 120-128 | 20-55 |
| 35 | Kau Nat Re cutoff | 33° 28' | 122° 22' | 0.5 | 8 | 12 | 2 | 6.4-8.0 | 63-74 | 20-45 |
| 36 | Mt Nev | 33° 26' | 122° 23' | 6.1 | 15 | 20 | 3 | 3.8-3.9 | 56-62 | 50-80 |
| 37 | Kau Rd south | 33° 29' | 122° 23' | 0.6 | 8 | 12 | 2 | 8.1-8.5 | 24-49 | 10-20 |
| 38 | Kau Rd north | 33° 32' | 122° 26' | 3.3 | 35 | 40 | 4 | 7.8-9.2 | 46-147 | 5-30 |
| 39 | Howick | 33° 29' | 122° 31' | 6.0 | 63 | ca 100 | 4 | 7.4-8.2 | 10-102 | 10-60 |
| 40 | Heywood | 33° 29' | 122° 37' | 6.9 | 11 | 15 | 3 | 8.5-9.2 | 52-66 | 5-10 |
| 41 | Berg | 33° 30' | 122° 39' | 1.1 | 32 | 40 | 2 | 8.0-8.4 | 95-116 | 20-40 |