Conservation Science W. Aust. 5 (1) : 20–135 (2004)

Wetland monitoring in the Wheatbelt of south-west Western Australia: site descriptions, waterbird, aquatic invertebrate and groundwater data

D.J. CALE[1], S.A. HALSE[1] AND C.D. WALKER[2]

[1]Science Division, Department of Conservation and Land Management,
PO Box 51 Wanneroo Western Australia 6956 Email: davidca@calm.wa.gov.au, stuarth@calm.wa.gov.au
[2]GEO & HYDRO Environmental Management, Suite 1, 9 Wygonda Road
Roleystone Western Australia 6111 Email: walker@essunl.murdoch.educ.au

ABSTRACT

The Wheatbelt of south-west Western Australia contains a range of wetland types with varying salinity, including many naturally saline lakes and playas. The increase in salinity of most wetlands during the last 50 years as a result of land-clearing is a major threat to wetland biodiversity. As part of the State Salinity Strategy, a wetland monitoring program began in 1997 at 25 wetlands from locations throughout the wheatbelt. The aim of the monitoring program was to document trends in biodiversity at the 25 wetlands and relate these trends to physical conditons in the wetlands and patterns of surrounding landuse.

This report summarizes existing information on the wetlands and provides, as baseline conditions, results of initial waterbird, aquatic invertebrate and groundwater monitoring. It documents the monitoring methods used and highlights the need for a long-term program.

There was a strong negative relationship between aquatic invertebrate species richness and salinity. A negative relationship also existed for waterbird richness, although other factors determined numbers of species in many wetlands with salinity being a constraint on maximum potential waterbird richness rather than a determinant of the actual number of species. Further salinization is likely to change detrimentally both invertebrate and waterbird communities. Such changes are apparent in historical waterbird data from some wetlands.

The ultimate cause of increased salinity in wetlands is rising groundwater, although sometimes wetlands are more directly affected by the increased surface run-off that results from high watertables in the catchment than by groundwater beneath the wetland.

INTRODUCTION

The Wheatbelt region of south-west Western Australia contains many different types of wetlands with a range of water salinities (Lane and McComb 1988). Land-clearing, grazing and rising watertables have altered the characteristics of many wetlands over the last 150 years but the physiognomic and chemical diversity of Wheatbelt wetlands remains considerable and they contain a corresponding diversity of plants and animals. The most comprehensive summary of waterbird use of Wheatbelt wetlands is that of Jaensch *et al.* (1988). Information on wetland plants is more scattered but Halse *et al.* (1993b) provide an overview of vegetation structure and the main species. Aquatic invertebrates were largely overlooked until recent years and there is little published information available about their occurrence in most lake types. However, Pinder (2000; 2003) review what is known about species in granite rock pools and hypersaline lakes, Halse *et al.* (2000a) provide information about Toolibin and Walbyring Lakes, Geddes *et al.* (1981) provide a list of crustaceans for many wetlands in the eastern Wheatbelt, and Brock and Shiel (1983) provide a list of rotifers and other invertebrates.

Over the next few years, considerably more information on the biodiversity of wetlands should become available as the results of the recent State Salinity Strategy biological survey of the Wheatbelt are published (Lyons *et al.* 2002; Blinn *et al.* 2003; Halse *et al.* 2003). The biological survey began in 1997 and 232 wetlands were surveyed for aquatic invertebrates, waterbirds and wetland plants. A range of physico-chemical parameters were also measured. The State Salinity Strategy is intended to combat the detrimental effects of increasing secondary salinization on biodiversity, agricultural production and rural infrastructure (Government of Western Australia 1996).

Secondary salinization is a global phenomenon but is particularly acute in the Wheatbelt of south-west Western Australia, where > 70 % of Australia's secondary salinization occurs (Williams 1987; Williams 1999). In the Wheatbelt, increased salinity is the result of 'dryland salinization', which results from the clearing of deep-rooted perennial vegetation and its replacement by annual crops that evapo-transpire much less soil water (George *et al.* 1995). As a result of reduced evapo-transpiration, watertables rise and salt stored in soil above the previous watertable is dissolved to create more saline groundwater that will cause scalding and death of vegetation as the watertable approaches the land surface. Secondary salinization can also be caused by irrigation, though this rarely happens in Western Australia.

Not all saline landscapes are the result of anthropogenic activity and concomitant secondary salinization. Many inland lakes and river systems in Western Australia are naturally (or primarily) saline and one of the features of the Western Australian environment is the high proportion of brackish or saline water in inland water bodies (see Schofield *et al.* 1988 for a summary of nineteenth century observations). The cause of primary salinity is similar to secondary salinization in the sense that it is the result of discharge of saline surface or groundwater into a lake, but the time periods involved are orders of magnitude greater (Johnson 1979). Naturally saline groundwater is produced by the accumulation of marine aerosols over hundreds of thousands of years (Commander *et al.* 1994; Herczeg *et al.* 2001). Climate, rather than land clearing, determines the distribution of primary salinity in inland areas and in Western Australia most naturally saline systems occur in palaeo-valleys. As a result of the prevalence of this natural salinity, much of the Western Australian biota is salt-tolerant by comparison with the remainder of Australia (Halse 1981; Kay *et al.* 2001; Pinder *et al.* 2003). There are also a few naturally saline lakes in coastal areas that reflect previously higher ocean levels, rather than groundwater conditions (eg. Moore 1987; Hodgkin and Hesp 1998). Their biota usually contains a significant marine component.

Information about the detrimental effect of secondary salinization on biodiversity in wetlands of the Wheatbelt is partly anecdotal (Sanders 1991) because there is little quantified baseline information on biodiversity prior to salinization. However, a survey of Wheatbelt wetlands by Halse *et al.* (1993b) suggested significant reduction in plant species richness had occurred in secondarily saline sites. Large-scale death of vegetation as a result of increased water level and salinity has been observed at Coomalbidgup Swamp (Froend and van der Moezel 1994), Toolibin Lake and surrounding wetlands (Froend *et al.* 1987) and Lake Towerrining (Froend and McComb 1991). The likely effect of salinization on waterbirds has been discussed by Halse *et al.*(1993c) and data on changes at Toolibin Lake over the past 30 years have been presented by (Halse *et al.* 2000a). Published information about the effect of salinization on aquatic invertebrates in rivers is somewhat contradictory (see Kay *et al.* 2001 for a review). Work by Pinder *et al.* (2000 and unpublished data) suggests only a small proportion of the species in Wheatbelt wetlands, often occurring in granite rock pools and other specialised habitats, are restricted to very fresh water. Most freshwater species in Wheatbelt wetlands tolerate brackish or moderately saline conditions (Halse *et al.* 2000a). It should be noted that some species occur only in naturally saline lakes and they may be as much threatened by salinization as freshwater species because of the changed patterns of inundation, salinity and ionic composition that accompany salinization (Pinder *et al.* 2003).

In this report, we describe the wetlands being monitored as part of the State Salinity Strategy and present results from the first four years of monitoring. Data for lake chemistry, groundwater, waterbirds and aquatic invertebrates are presented as an estimate of baseline conditions and discussed in the context of the methodology, historical data and future monitoring. The overall aim of the monitoring program is to measure changes over time in wetland conditions and biodiversity to provide information that will lead to better land management decisions (Wallace 2001). More specific objectives for the part of the program covered in this report are:

- to monitor trends in water chemistry, groundwater levels and salinity, waterbirds and aquatic invertebrates at 25 Wheatbelt wetlands representative of a range of wetland types
- to relate trends to patterns of surrounding land-use, management actions and historical data on wetland conditions

The monitoring program includes two other components. Vegetation health and plant species diversity are monitored at the 25 wetlands (Ogden and Froend 1998; Gurner *et al.* 1999; Gurner *et al.* 2000). Bi-annual measurement (in September and November) of depth, salinity and other parameters occurs at 100 wetlands in the south-west, including the 25 wetlands where biological monitoring is occurring (see Lane and Munro 1983 for historical information on this part of the program).

METHODS

Locations of the 25 wetlands where biological monitoring is occurring are shown in Figure 1. Seven criteria were used to guide the selection of these wetlands and are listed below (see also Table 1):

1 *Wetland listed in Government of Western Australia (1996)*; Toolibin Lake, Noobijup Swamp and Lake Wheatfield occur in the 3 original Recovery Catchments (Toolibin, Muir, Warden); and Lake Bryde was used as an example of a threatened catchment in the State Salinity Strategy (Government of Western Australia 1996) and is now in a listed Recovery Catchment.

2 *Adherence to overall monitoring design*, aimed to select five wetlands in each of five water quality categories (primary saline, secondarily saline, fresh, declining, improving).

3 *Wetlands have high conservation value* required that conservation value was high for at least one of the following biological attributes - vegetation, waterbirds, aquatic invertebrates.

4 *Geographic representativeness*; as far as possible, the resulting group of wetlands represented a mix of wheatbelt regions and drainage systems.

5 *Long record of data*; generally, wetlands with existing data on salinity or wetland conditions were preferred.

6 *Landcare activities in local catchment*; the extent to which this criterion was important varied with wetland category - it was extremely important when selecting Improving wetlands but perhaps less important when selecting Declining wetlands.

7 *Size*; although not an over-riding consideration, very large wetlands were usually avoided except when meeting the requirements of representativeness.

Faunal and physico-chemical monitoring began in spring 1997, although work is yet to commence at Toolibin and Dumbleyung because neither lake has contained sufficient quantities of water during the last five years to enable sampling. Groundwater monitoring began in 1999.

Timing of monitoring

In most cases, groundwater is monitored each year and fauna and physico-chemical parameters are monitored on a biennial cycle, with half the lakes sampled one year and the remainder the second year. For the purposes of monitoring, three sampling seasons are recognised: late winter (Aug-Sep), spring (Oct-Nov) and autumn (Feb-

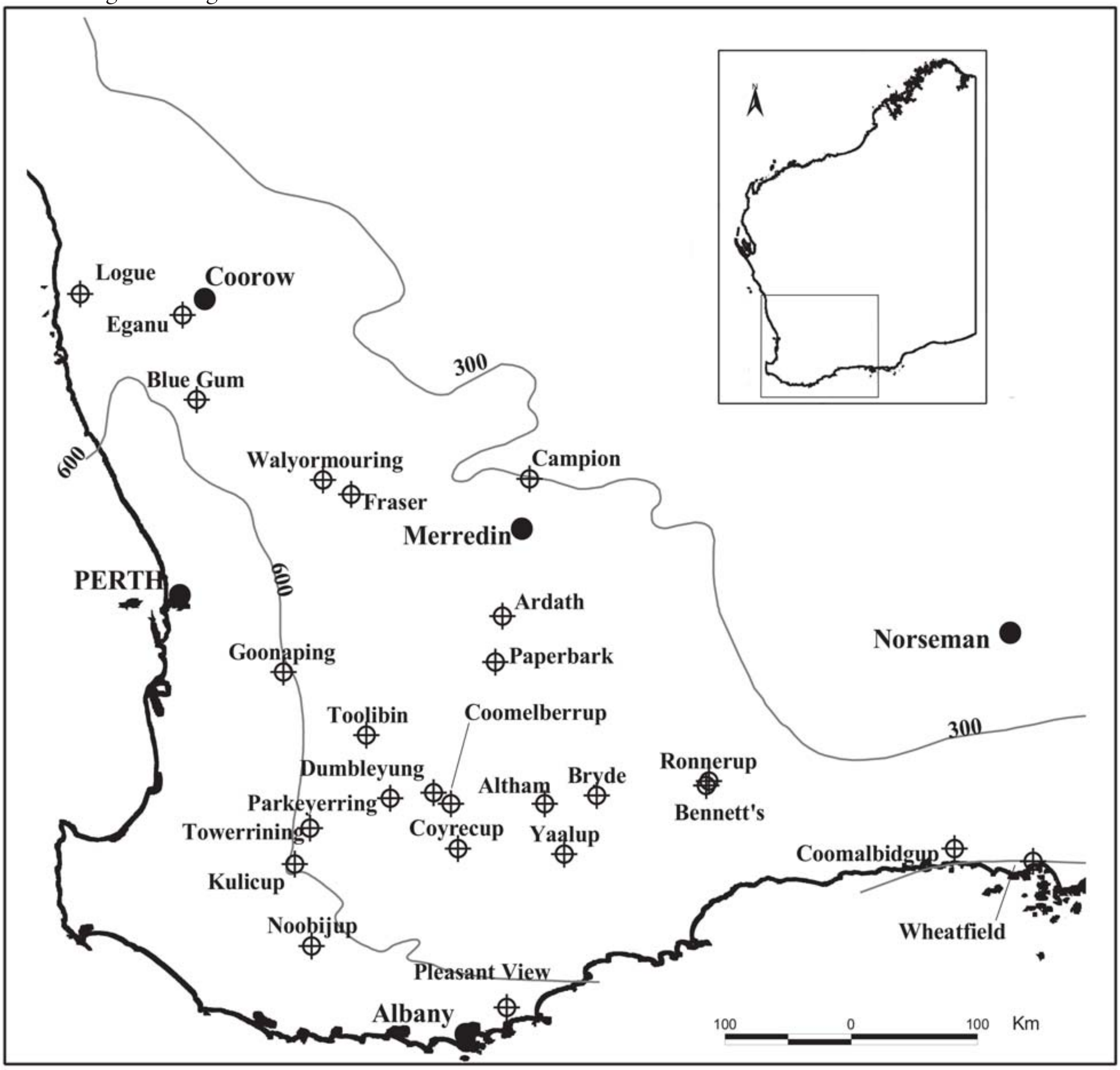

Figure 1. The location of the 25 wetlands included in the monitoring program. The 600 mm and 300 mm average annual isohyets approximately define the boundaries of the Wheatbelt.

TABLE 1
The 25 wetlands included in the monitoring program and factors influencing their selection. See the text for a description of selection criteria.

SITE	CRITERIA 2 CATEGORY	COMMENTS	CRITERIA MET
Altham	Primary saline	Regularly filled naturally saline lake, intact vegetation, waterbird data, long history of gauging	2,3,4,5,7
Ardath	Declining	Naturally saline lake with secondarily increased salinity, but with intact fauna, sampled by State Salinity Strategy Wheatbelt Survey	2,3,4,7
Bennetts	Primary saline	Good vegetation, previous invertebrate and waterbird study, some salinity data	2,3,4,5,7
Kulicup	Fresh	Good vegetation and invert fauna, excellent data record, fresh and will not change in near future	2,3,4,5,7
Bryde	Improving	Recovery Catchment, good vegetation and invert, moderate waterbird fauna, long record, management activity in catchment	1,2,3,4,5,6,7
Campion	Primary saline	Large naturally saline system in Eastern wheatbelt, inflow comparatively often, long history of gauging	2,3,4,5,
Coomalbidgup	Declining	Good vegetation, moderate record, catchment hydrology changing as result of clearing	2,3,4,5,7
Coomelberrup	Declining	In Datatine drainage scheme, moderate salinity which may increase, long data record	2,4,5,6,7
Coyrecup	Secondarily saline	Good waterbird fauna, long data record, moderately saline but this may increase, lot of catchment management activity	2,3,4,5,6
Dumbleyung	Secondarily saline	Major waterbird wetland and largest wheatbelt lake, long history of gauging	2,3,4,5
Eganu	Secondarily saline	Major waterbird wetland, long history of gauging/study, has declined since early 1970s	2,3,4,5,7
Goonaping	Fresh	Fresh dark-water swamp. Most of lake and catchment in forest, sampled by State Salinity Strategy Wheatbelt Survey	2,3,5,7
Blue Gum	Declining	Moderate waterbird fauna, history of gauging in one lake in system (Streets), located in a sizeable remnant	2,4,5,7
Logue	Fresh	Good vegetation and fauna, long data record, focus of management interest	2,3,4,5,6,7
Fraser's	Fresh	Fresh swamp, a threatened community with consequent high conservation values	2,3,7
Noobijup	Improving	Recovery catchment (Muir), good vegetation and invert fauna, detailed recent studies	1,2,3,4,5,6,7
Paperbark	Fresh	Excellent fresh swamp in Nature Reserve. Sampled by State Salinity Strategy Wheatbelt Survey. History of gauging	2,3,4,5,7
Parkeyerring	Secondarily saline	Salt-affected vegetation, good waterbird fauna, long history of gauging	2,3,4,5,
Pleasant View	Fresh	Good vegetation, rare waterbirds (bittern), long history of gauging	2,3,4,5,7
Ronnerup	Primary saline	Good vegetation, nearest clearing 4-5 km away	2,3,4,7
Toolibin	Improving	Recovery catchment, good fauna and vegetation, local remedial works, long record	1,2,3,5,6,7
Towerinning	Improving	Good waterbird, local remedial works, long data record	2,3,5,6
Walyormouring	Secondarily saline	Good waterbird fauna, long history of gauging, reasonable amount of vegetation	2,3,4,5
Wheatfield	Primary saline	Recovery catchment (Warden), good fauna and vegetation, brackish but susceptible to change, lot of catchment activity (incl replanting)	1,2,3,4,6
Yaalup	Declining	Good vegetation (northern *E. occidentalis* swamp) though clearing close on east side, waterbird data, long history of gauging	2,3,4,5,7

Apr). Because the sampling regime is based on a hydrological cycle (i.e. inflows occur in late winter and low water levels occur in autumn), it spans two calendar years but for recording purposes the year in which the spring sample was collected was used as the year of sampling.

In a year when aquatic fauna and physico-chemical parameters are being monitored at a wetland, waterbirds are surveyed in late winter, spring and autumn, while invertebrates are sampled only in spring. Some physico-chemical parameters are measured in all three seasons, others are measured only in spring. Table 2 shows the years in which sampling has occurred at each wetland.

All groundwater, faunal and chemical data collected during the wetland monitoring program are on the Salinity Action Plan Wetlands Database in the Department of Conservation and Land Management's Science Division.

Waterbirds

Censuses of waterbirds were conducted in late winter, spring and autumn by one or two observers. The aim of the censuses was to record all species and all individual birds present. At large wetlands, e.g. Towerrining, Campion and Logue, a small powerboat was used to circumnavigate the lake. At smaller wetlands, or where vegetation impeded the passage of a boat, the waterbird survey was conducted on foot. Observations were made using binoculars and spotting scopes. All waterbirds seen were identified and counted and the numbers of nests and broods of each species were recorded. Up to five hours were spent surveying individual wetlands.

Waterbird data analysis

Two of the most difficult aspects of monitoring are detection of trends and presentation of monitoring data in a meaningful way. Froend *et al.* (1997) suggested ordination was a useful method of presenting data and Halse *et al.* (2002) showed it could be used to detect trends. While the monitoring data collected since 1997 provide too short a time series for reliable trends to emerge, we have displayed the results for waterbird surveys from each wetland in an ordination that includes five 'marker' wetlands. The marker wetlands were chosen because they are characteristic of particular types of wetlands and thus, comparison of their communities with that of monitored wetlands enables the monitored wetland to be placed in a conservation context.

Reasons for selection of the marker wetlands, and sources of waterbird survey data for them, were varied. At least until recently, the waterbird fauna of Toolibin Lake exemplified that of fresh to brackish inland wetlands providing high quality waterbird habitat. Data collected during a Department of Conservation and Land Management / Birds Australia project (Jaensch *et al.* 1988) and comprising late winter, spring and autumn surveys for 1983 was used as representative of Toolibin prior to salinization. In 1983, the waterbird fauna of Lake Pinjarrega reflected a recent history of increased salinity but remained diverse and typical of deeper brackish wetlands used as moulting habitat and drought refuge by large numbers of waterbirds, especially ducks. We used three Jaensch *et al.* (1988) surveys from 1983 to represent Pinjarrega. Lake Goorly has a waterbird fauna typical of

TABLE 2
Sampling occasions for each of the wetlands in the study.

SITE CODE	AUG-97	OCT-97	MAR-98	AUG-98	OCT-98	APR-99	AUG-99	OCT-99	APR-00	AUG-00	OCT-00	APR-01	TIMES SAMPLED	YEARS SAMPLED
Bryde	1	1	1				1	1	1				6	2
Logue	1	1					1	1	1	1	1	1	8	3
Towerrining	1	1	1				1	1	1				6	2
Coyrecup	1	1	1				1	1	1				6	2
Wheatfield	1	1	1				1	1	1				6	2
Altham				1	1	1				1	1	DRY	5	2
Noobijup				1	1	1				1	1	1	6	2
Bennett's				1	1	1				1	1	1	6	2
Ardath				1	1	1				1	1	1	6	2
Blue Gum				1	1	1				1	1	DRY	5	2
Kulicp				DRY	1	1				1	1	DRY	4	2
Campion				1	1	1				1	1	1	6	2
Goonaping				1	1	DRY			1	1	1	DRY	5	2
Coomelberrup				1	1	1				1	1	DRY	5	2
Walyormouring				1	1	1				1	1	DRY	5	2
Eganu				1	1	1				1	1	1	6	2
Fraser				1	1	DRY	1	1	1	1	1	1	8	3
Toolibin				DRY	DRY	DRY				DRY	DRY	DRY	0	0
Paperbark							1	1	1				3	1
Dumbleyung							DRY	DRY	DRY				0	0
Comalbidgup							1	1	1				3	1
Yaalup							1	1	1				3	1
Parkeyerring							1	1	1				3	1
Pleasant View							1	1	1				3	1
Ronnerup							1	1	1				3	1

naturally saline playa lakes with a comparatively rich assemblage of salt tolerant species. We used a single survey from October 1999 to represent the lake (SA Halse and AM Pinder unpublished data). Despite the low sampling effort, this survey probably recorded most of the species likely to occur at Lake Goorly. We used monitoring program data from Lake Altham in 1998 and Lake Pleasant View in 1999 to characterise the waterbird faunas of species-poor shallow saline wetlands and freshwater sedge swamps respectively.

Ordination was performed on a presence/absence data matrix containing an annual species list for each monitoring wetland from each year sampled and the five marker wetlands. The initial data matrix included 45 site/ year combinations and 61 bird species. Semi-strong hybrid multidimensional scaling (SSH) in the PATN data analysis package was used (Belbin 1993) and disimilarity matrices were calculated using the Bray-Curtis association measure. When a high proportion of Bray-Curtis values were close to 1.0, they were re-estimated using the shortest path option. To enable easy interpretation of printed output from the ordination, sites other than the wetland of interest and the five marker wetlands are suppressed.

When suitable data were available, an alternative ordination was performed to relate monitoring data for a wetland with historical information. Historical data from the early 1980s were provided by Jaensch *et al.* (1988). Data from each sampling year between 1981 and 1984 were included, if three suitable surveys had occurred each year. The ordination was based on annual species lists for all monitoring wetlands, the five marker wetlands, and the annual lists derived from the historical surveys of the wetland in question. An additional marker wetland was provided by including Jaensch *et al.* (1988) data from Lake Coyrecup in 1983. Following ordination, an equimax principal components rotation was performed using the PCR module of PATN (Belbin 1993).

Aquatic invertebrates

Invertebrates were collected in spring. The aim of the invertebrate sampling protocol was to maximize the number of species collected (see Halse *et al.* 2002). Two sites (A and B) were sampled at each wetland and were placed to include a range of habitats and conditions (e.g. temperature and wind) within the main waterbody at the time of sampling. This generally resulted in placing the first site at the depth guage and the second on an opposite shoreline (see Fig. 2). Two sub-samples were collected from each site. The first, referred to as a benthic sub-sample, was collected using a D-framed pondnet with 250 μm-size mesh. The net was used to gather a series of sweeps totalling 50 m in length from all identifiable habitats over a path of 200 m, including the benthos, submerged macrophytes, the base of emergent vegetation and fallen logs. Lake substrates were vigorously disturbed. The benthic sub-sample was preserved in 70-80% ethanol. The second, plankton sub-sample was collected using a 50 μm-size mesh on the same pondnet frame. The same habitats were sampled, except for benthic sediment, which fouled the fine mesh. The plankton sample was preserved in 5% borax-buffered formalin.

In the laboratory, sub-samples were separated into three size fractions using 2 μm, 500 μm and 250 μm sieves for the benthic sub-sample and 250 μm, 90 μm and 53 μm sieves for the plankton sub-sample. Representatives of each species (or morphospecies) were picked out using a dissecting microscope with 10–50x magnification and the species were scored for abundance on a log scale (1–10 animals = 1, 11–100 = 2 etc.). All species were identified to the lowest taxonomic level possible, with many of the identifications being confirmed by taxonomic specialists using voucher specimens.

Results from all sub-samples and sites were combined for analysis. The analytical approach was the same as for waterbirds and is documented in Halse *et al.* (2002). Four monitoring wetlands were chosen as markers in the absence of existing invertebrate datasets that were based on equal sampling effort to that used in the monitoring program. They were Noobijup Swamp and Lake Campion, based on 1998 sampling, and Yaalup Lagoon and Lake Parkeyerring, based on 1999 sampling.

Water chemistry and physico-chemical parameters

The parameters measured each sampling season at Site A were: (1) water depth using surveyed depth gauges (Lane and Munro 1983), (2) electrical conductivity, pH and dissolved oxygen using a WTW multi-line meter to take *in situ* measurements, (3) chlorophyll measured by absorbance in the laboratory (APHA 1989) and (4) total soluble persulphate nitrogen and phosphorus filtered through 0.45 mm Millipore filters. Site A was generally located near the depth gauge in each wetland.

In conjunction with invertebrate sampling in spring, additional unfiltered water samples were collected from Site A for laboratory measurement of ionic composition, total dissolved solids, colour, turbidity, alkalinity and hardness. Also in spring, a second set of conductivity, pH, dissolved oxygen, chlorophyll and nutrient measurements were taken from Site B, which was in a different sector of the wetland (see Fig. 2), to provide information on spatial variability of water parameters.

Measurement units and conversions

Salinity is defined as the mass of ionic compounds per unit volume of water. In practise salinity is rarely measured but estimated from electrical conductivity (EC) or total dissolved solids (TDS). Common units of conductivity are mS/m, mS/cm and μS/cm. Over the conductivity range 5-100 mS/cm, salinity can be estimated (as g/L) from electrical conductivity (in mS/cm) according to:

$S(g/L) = 0.4665EC^{1.0878}$ (Williams 1986)

Approximate conversions to the standard unit of salinity (mg/L) are:

1 mS/m = 0.01mS/cm = 10 μS/cm = 6 mg/L or 1 μS/cm = 0.6 mg/L

At salinities above 100 000 µS/cm, the relationship between conductivity and salinity approaches 1 µS/cm = 1 mg/L but is rather variable.

Total dissolved solids (TDS) is measured gravimetrically by drying a known volume of water. Such TDS measurements include the retained water of crystallization and can be converted to an estimate of salinity using the formula;

salinity (mg/L) = 0.91x TDS (mg/L).

Dissolved oxygen can be measured directly as mg O_2/L. However, the solubility of oxygen is strongly influenced by temperature and salinity of water. Therefore, the amount of oxygen present in water is often expressed as a percentage of the amount that would be dissolved if the water were saturated with oxygen and at equilibrium. Percentage saturation has been used as a measure of dissolved oxygen in this report.

The ratio of different ions in water can affect the ability of animals to osmoregulate and carry out other physiological functions. Ratios can be most easily compared if cations (Na, Ca, Mg and K) and anions (Cl, SO_4, CO_3/HCO_3) are converted to % milliequivalents. This adjusts each anion or cation according to its molecular weight and number of electrons (Wetzel and Likens 1991).

The concentration of photosynthetic pigments (i.e. chlorophyll and its breakdown product phaeophytin) are

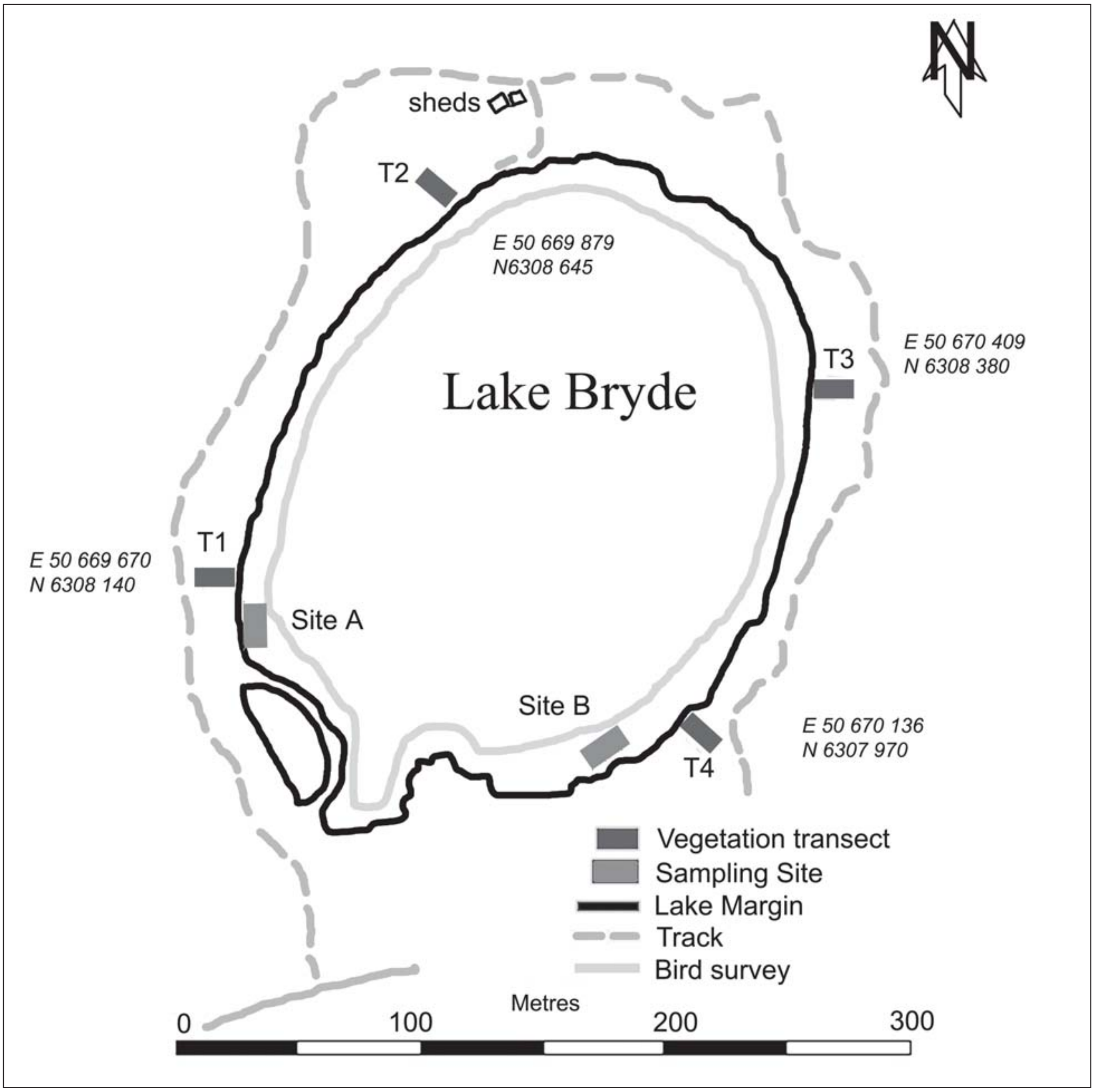

Figure 2. The arrangement of invertebrate and physico-chemical sample sites, vegetation transects and the route taken for bird surveys at Lake Bryde.

useful indices of primary production within a wetland (e.g. algal photosynthesis). In this study four chlorophyll fractions, differing in the wavelength of light they capture, were measured. Often only chlorophyll a, which is usually most abundant, is measured. The concentration of phaeophytin can be used to infer the status of primary production at the time of sampling. Low phaeophytin and high chlorophyll suggest current activity while high phaeophytin and low chlorophyll suggest production is declining. High levels of both imply a sustained period of production.

Groundwater

Groundwater monitoring bores were installed at each wetland in association with the vegetation monitoring transects (Ogden and Froend 1998; Gurner *et al.* 1999; Gurner *et al.* 2000). Bores were sited about one-third of the way from the lowest end and one-third from the upper end of each transect. They were constructed from 40 mm PVC pipe with the lower portion slotted and the top capped; the hole around the pipe was back-filled with blue-metal and sealed near the surface with bentonite. Location, construction and depth details for each bore are recorded in the Salinity Action Plan Wetlands Database. Bores were sampled opportunistically as construction was completed, then usually in late winter, spring and autumn of the post-construction year, before sampling was scaled back to spring and autumn in 2002. Parameters measured in the bores were depth to groundwater, measured with an electrical continuity dipper tape, and electrical conductivity and pH measured with a TPS WP-81 meter from the second sample withdrawn using a 0.5 L stainless steel bailer.

WETLAND DESCRIPTIONS AND MONITORING RESULTS

Lake Bryde

Lake Bryde (33° 21'S 118° 49'E) (Fig. 3) is an intermittently flooded wetland, approximately 50 ha in size, situated in the Lake Bryde Nature Reserve (No. 29021), south of Newdegate. Lake salinity varies as water levels cycle between full and dry over many years. Single flood events may fill the lake for two or three years. Such flood events occurred in three of the four years between 1967 and 1985 when annual rainfall at nearby Pingrup exceeded 348 mm (Watkins and McNee 1987). The catchment of Lake Bryde is extensively (65%) cleared for agriculture and this has resulted in higher catchment run-off than occurred pre-clearing. An analysis of the flow pathways of surface run-off into Lake Bryde described the Lake Bryde catchment as internally draining and comprised of 6 sub catchments.

Vegetation surrounding the lake is described by Ogden and Froend (1998). The upland woodland includes *Eucalyptus flocktoniae* and *E. occidentalis* over *Melaleuca* spp., while the lowland is dominated by *E. occidentalis* and stands of *Melaleuca strobophylla* and *M. cuticularis*. The lake-bed is dominated by *Muehlenbeckia horrida* subsp. *abdita*, which is endemic to the lake and grows as an emergent, and *Tecticornia verrucosa*.

Lake Bryde was cited as an example of a threatened catchment in the first Salinity Action Plan (Government of Western Australia 1996) and is now a Biodiversity Recovery Catchment. Considerable management action is occurring to stabilise the condition of the wetland. It has a long history of depth and water quality data (Lane and Munro 1983).

Figure 3. Lake Bryde is an episodically filled wetland. When the lake is near dry Muehlenbeckia horrida dominates the lake bed, however, this plant population senesces during the flooded phase.

Water chemistry and physico-chemical parameters

During the monitoring period, Lake Bryde fluctuated from a maximum depth of 1.74 m to being dry (Fig. 4). Initial water sampling in August and October 1997 was during a period of high water level and contrasted with the almost dry condition of the lake when sampled in August and October 1999. Heavy summer rains in early 2000 caused the lake to re-flood and took lake depth above the high levels of October 1997.

Water chemistry parameters were strongly influenced by lake depth and evapo-concentration. For example, conductivity ranged from 1197 µS/cm to 56 450 µS/cm, largely according to depth (Fig. 4). However, total nitrogen and phosphorus concentrations measured in March 2000, after summer flooding, were higher than levels recorded in spring 1997 at a similar water depth, suggesting that a large quantity of nutrients was washed into the lake during summer flooding. Chlorophyll concentrations were relatively high in spring 1999, indicating the presence of higher algal activity at a time when total nitrogen concentration peaked because of low water levels.

A maximum conductivity of 16 000 µS/cm was recorded by JAK Lane (see Jaensch *et al.* 1988) between 1982-1985, suggesting salinity has increased at least at low water levels since this time.

Throughout the study period, cation concentrations followed the common Wheatbelt pattern Na> Mg> Ca> K while Cl was the dominant anion.

Groundwater

Paired monitoring bores were installed on all four vegetation transects at Lake Bryde. Monitoring of these bores began in early 2000 and showed groundwater was present at depths between 1.5 m and 3.5 m below local ground level, depending on location (Fig. 5). Groundwater distribution beneath Lake Bryde was complex with bores on the lakes north-western side (T2) generally dry and evidence, from deep bores maintained by the Bryde Recovery Catchment, that a body of acidic groundwater exists at depths greater than those sampled in the monitoring program. Groundwater (41 300–73 900 µS/cm) was more saline than lake water, except perhaps in the final stages of evapo-concentration, indicating considerable potential for salinisation of Lake Bryde.

Waterbirds

A total of 24 species of waterbird were recorded during monitoring at Lake Bryde (Table 3), compared with 16 seen in 10 surveys by Jaensch *et al.* (1988) between 1981 and 1985, when the lake experienced both high and low water levels. Most of the species recorded during monitoring are common and widely distributed, except for the Australasian Bittern and Freckled Duck. Waterbird species richness and total abundance increased through the 1997 sampling year with peak abundance of 1099 birds of 17 species in autumn 1998 (Fig. 6). By contrast, three or fewer species were recorded when lake levels were low in late winter and spring 1999. However, after re-flooding in summer 10 species were seen in autumn, so that the overall waterbird lists in 1997 and 1999 became more similar.

The increase in waterbirds recorded at Lake Bryde during monitoring, compared with Jaensch *et al.*'s (1988) earlier data, probably reflects greater use of the lake in recent years, although improved species detection during monitoring cannot be discounted as a cause of the changes. Counts of ducks, coots and swans in October 1997 and March 1998 were higher than corresponding November and March counts made between 1988 and 1992 (Halse *et al.* 1995 and references therein).

Ordination of the waterbird assemblages in both years of survey at Lake Bryde indicated that waterbird communities showed strong similarities to communities in other wetlands with inundated trees or recently dead trees (Fig. 7). Reflecting the lower waterbird use of Bryde in the early 1980s, the 1983 community occupied a substantially different place in the ordination from the 1997 and 1999 communities, although water depth in 1983 and 1997 were similar.

Invertebrates

Invertebrates were monitored in October 1997 and 1999 at Lake Bryde with each sampling occasion clearly representing a different community, with salinity the major factor structuring them. A total of 91 invertebrate taxa were collected, of which 80 species were unique to one of the sampling dates (Table 4). In 1997, the year of greater water depth, 77 invertebrate taxa were collected from two sites (we did not use some of the data collected in 1997, when four sites were sampled at Bryde to refine sampling methods, because we wanted equal sampling effort through time - see Halse *et al.* 2002). Invertebrate diversity in 1997 was evenly divided between crustaceans (46% of species) and insects (42%). The most diverse taxonomic groups were cladocerans with 17 species, ostracods (11 species) and chironomids (15 species).

Low water levels and saline conditions in October 1999 resulted in a less diverse invertebrate assemblage, with only 25 species being collected. Somewhat surprisingly, insects dominated the fauna (62% of species). Half the insects were dipterans typical of ephemeral waters, including culicids, stratiomyids, chironomids, ephydrids and muscids.

Ordination of the invertebrate assemblages from Lake Bryde together with the marker sites showed the assemblage at Bryde to have affinities with Yaalup in 1997 (Fig. 8). There were considerable differences between the assemblages in 1997 and 1999, compared with the smaller variation seen at sites with more constant sampling conditions (e.g. Lake Coyrecup – Fig. 25).

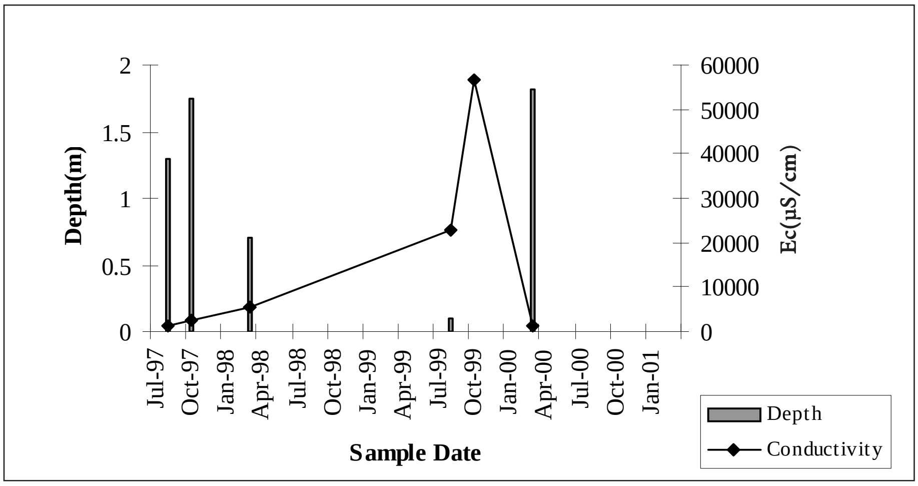

Figure 4. Gauged depth and electrical conductivity at Lake Bryde for 1997 and 1999 sampling years.

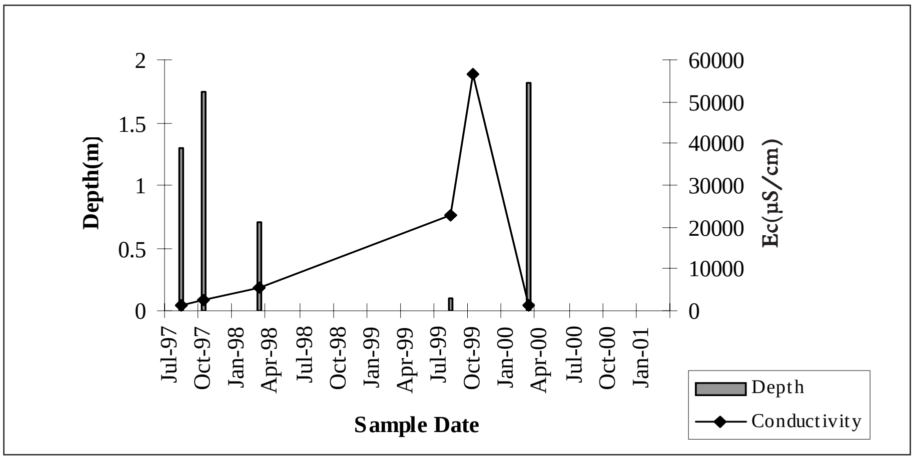

Figure 5. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Bryde. Open symbols represent dry bores. Legend values in parenthesis are depth of the bore in metres.

TABLE 3
Waterbird species and their abundance on six sampling occasions at Lake Bryde.

			DATE			
	AUG-97	OCT-97	MAR-98	AUG-99	OCT-99	MAR-00
Australasian Bittern	0	2	0	0	0	0
Australasian Grebe	2	0	2	0	0	0
Australasian Shoveler	3	0	1	0	0	0
Australian Shelduck	5	6	195	6	0	16
Australian Wood Duck	2	8	6	0	0	4
Black Swan	3	7	0	0	0	0
Black-fronted Dotterel	0	0	2	0	0	0
Black-tailed Native-hen	0	0	13	0	0	0
Black-winged Stilt	0	0	5	0	0	0
Blue-billed Duck	0	0	0	0	0	6
Common Greenshank	0	0	0	0	1	0
Darter	0	0	0	0	0	1
Eurasian Coot	7	27	87	0	0	14
Freckled Duck	0	0	2	0	0	0
Grey Teal	66	12	675	0	0	36
Hardhead	0	0	12	0	0	0
Hoary-headed Grebe	45	276	57	0	0	0
Little Pied Cormorant	0	4	6	0	0	0
Musk Duck	3	16	5	0	0	4
Pacific Black Duck	2	9	15	0	0	9
Pink-eared Duck	12	13	0	0	0	2
Sharp-tailed Sandpiper	0	0	0	0	2	0
White-faced Heron	0	1	5	0	3	3
Yellow-billed Spoonbill	0	0	2	0	0	0

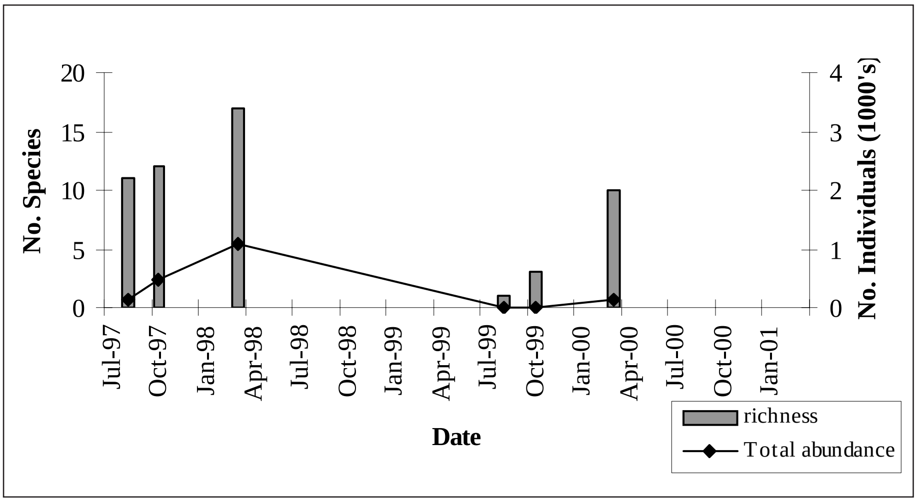

Figure 6. Species richness and abundance of waterbirds at Lake Bryde in 1997 and 1999 sampling years.

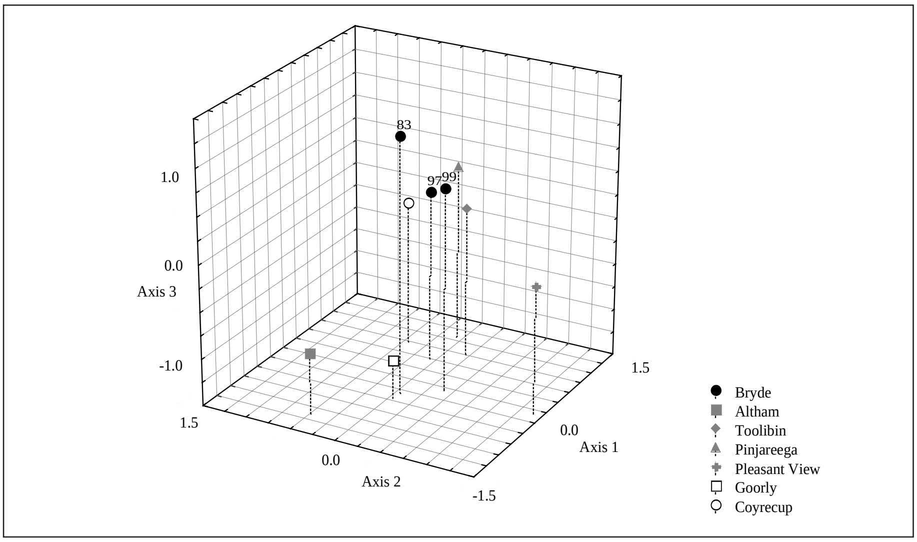

Figure 7. Ordination (PCR) of waterbird species data from Lake Bryde, showing historical and monitoring data for Lake Bryde and data for six marker wetlands.

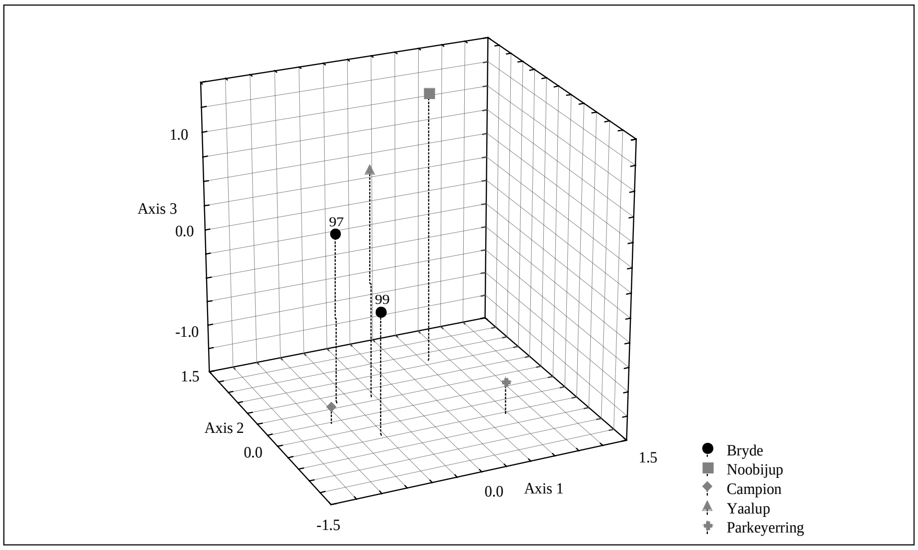

Figure 8. Ordination (SSH) of invertebrate data, showing Lake Bryde in 1997 and 1999 and four marker wetlands.

TABLE 4
Invertebrate species collected from Lake Bryde in the 1997 and 1999 sampling years.

TAXA	1997	1999
Turbellaria	✓	
Nematoda	✓	✓
ROTIFERA		
Hexarthra mira	✓	
Brachionus quadridentatus	✓	
Trichocerca rattus carinata	✓	
OLIGOCHAETA		
Ainudrilus nharna	✓	
Dero digitata	✓	
Enchytraeidae	✓	
CONCHOSTRACA		
Caenestheria sp. nov. A (nr *lutraria*)	✓	
Caenestheriella sp.	✓	
CLADOCERA		
Alona diaphana	✓	
Alona diaphana vermiculata	✓	
Alona rigidicaudis s.l.	✓	
Alona longinqua	✓	
Alona sp. nov. A (Bryde)	✓	
Leydigia cf. *ciliata*	✓	
Monospilus diporus	✓	
Monospilus elongatus	✓	
Plurispina cf. *chauliodis*	✓	
Pleuroxus cf. *foveatus*	✓	
Daphnia carinata	✓	
Daphnia cephalata	✓	
Daphniopsis queenslandensis	✓	
Daphniopsis sp.		✓
Simocephalus exspinosus	✓	
Simocephalus victoriensis	✓	
Macrothrix breviseta	✓	
Neothrix cf. armata	✓	
OSTRACODA		
Limnocythere mowbrayensis	✓	✓
Ilyocypris australiensis	✓	
Bennelongia australis	✓	
Candonocypris novaezelandiae	✓	
Cypretta baylyi	✓	
Heterocypris vatia	✓	
Mytilocypris ambiguosa	✓	✓
Mytilocypris tasmanica chapmani		✓
Reticypris clava	✓	
Ilyodromus ellipticus	✓	
Cypericercus sp. 442	✓	
Sarscypridopsis aculeata	✓	✓
COPEPODA		
Boeckella triarticulata	✓	
Calamoecia ampulla	✓	
Metacyclops sp. 462	✓	
Australocyclops australis	✓	
Eucyclops australiensis	✓	
Apocyclops dengizicus		✓
Mesochra nr *flava*		✓
AMPHIPODA		
Austrochiltonia subtenuis	✓	✓
COLEOPTERA		
Allodessus bistrigatus	✓	
Antiporus gilberti	✓	
Sternopriscus sp.	✓	
Necterosoma penicillatus		✓
Berosus discolor	✓	✓
Berosus munitipennis		✓
Berosus sp.	✓	
Enochrus eyrensis		✓
Hydrophilidae		✓
Heteroceridae	✓	
Curculionidae	✓	
DIPTERA		
Tipulidae group C	✓	
Aedes camptorhynchus		✓
Culicoides sp.	✓	
Stratiomyidae	✓	✓
Ephydridae		✓
Muscidae		✓
Procladius paludicola	✓	✓
Procladius villosimanus	✓	
Ablabesmyia notabilis	✓	
Paramerina levidensis	✓	
Paralimnophyes sp. 1 (*pullulus*)	✓	
Cricotopus albitarsus	✓	
Orthocladiinae sp. A	✓	
Tanytarsus sp. A (nr. K10)	✓	✓
Chironomus occidentalis	✓	
Chironomus tepperi	✓	
Chironomus sp.		✓
Chironomus aff. *alternans*	✓	
Dicrotendipes pseudoconjunctus	✓	
Cryptochironomus griseidorsum	✓	
Cladopelma curtivalva	✓	✓
Parachironomus sp. 1	✓	
HEMIPTERA		
Agraptocorixa parvipunctata	✓	
Micronecta gracilis	✓	
Anisops occipitalis	✓	
Anisops sp.		✓
ODONATA		
Austrolestes annulosus	✓	✓
Hemianax papuensis	✓	
Hemicordulia tau	✓	
TRICHOPTERA		
Oecetis sp.	✓	
Leptoceridae	✓	

Lake Logue

Lake Logue (Fig. 9) is a large, seasonal wetland (29° 51'S 115° 8'E) located in the Lake Logue Nature Reserve (Reserve No. 29073) on the coastal sandplain west of Eneabba. The lake is fresh to brackish, with an area of approximately 425 ha (Halse *et al.* 1993b) and is linked to nearby Lake Indoon by groundwater. Together, the lakes form an important feeding and refuge area for waterbirds (Lane *et al.* 1996).

Vegetation of the surrounding dunes consists of open woodland of *Banksia prionotes* over myrtaceous shrubs. *Casuarina obesa* is dominant at the margin of the lake, with an extensive outer zone of *Melaleuca strobophylla* and *M. rhaphiophylla* in some areas (Gurner *et al.* 1999). Lake Logue has a long record of depth and salinity readings and waterbird counts (Lane and Munro 1983; Jaensch *et al.* 1988), and its faunal communities and vegetation are essentially intact. Consequently, for the purpose of the monitoring program, Lake Logue was designated a freshwater wetland without obvious threats. However, the lake is the focus of management interest because of the death of vegetation in the south-eastern corner.

Water chemistry and physico-chemical parameters

Water levels were low in 1997, when the lake was first surveyed, but the lake filled well beyond its normal flood-line in May 1999 after extensive autumn rains (Fig. 10). Cations conformed to a pattern Na>Mg>Ca>K and Cl was the dominant anion. Water tended to be turbid, particularly at low water levels (max. 210 NTU). Immediately after filling, lake-water was highly coloured (280 TCU), probably as a result of leaching from terrestrial vegetation and debris, and iron concentrations were higher, reflecting leaching from previously dried sediments. Total nitrogen and phosphorus concentrations were moderate to high (maxima of 2500 µg L^{-1} and 140 µg L^{-1}, respectively) in all surveys despite increased water levels in 1999, suggesting high levels of input from floodwaters or flooded sediments. Chlorophyll levels were highest in October 1997 with individual samples containing chlorophyll *a* at concentrations as high as 88 µg L^{-1} and a lake average of 38 µg L^{-1}.

Groundwater

Monitoring bores were not installed until March 2001 because high water levels prevented access to the vegetation transects. Preliminary data from December 2001 suggested the lake is interacting with groundwater (as would be expected of a lake in a swale amongst sand dunes) and that lake-water is fresher than underlying groundwater, which is either brackish or moderately saline.

Waterbirds

A total of 44 waterbird species were recorded at Lake Logue between August 1997 and March 2001 (Table 5). The number of species recorded on any one sampling occasion remained relatively constant for 1997 and 1999 sampling years (Fig. 11), however, abundance declined after the lake filled in 1999 and richness was also lower in 2000.

Species composition showed marked changes between 1997 when water levels were low and 1999 and 2000, after the lake had filled. In 1997, the lake supported large areas of shallows on which 14 wading species fed, including Red Necked Avocet (1300 individuals) and Black winged Stilt (379 individuals). At higher water levels, the number of wading species declined to four, all in low abundance. This change was concomitant with an increase in the number of duck species from five to ten.

Figure 9. Lake Logue is a seasonal brackish wetland. When flooded, large areas of fringing vegetation are inundated.

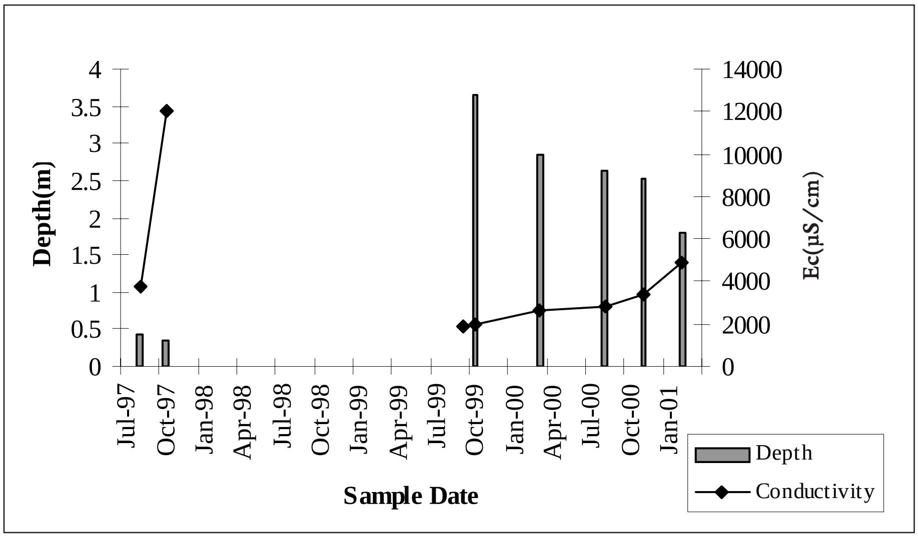

Figure 10. Gauged depth and electrical conductivity for Lake Logue for the 1997, 1999 and 2000 sampling years (no depth recorded in September 1999).

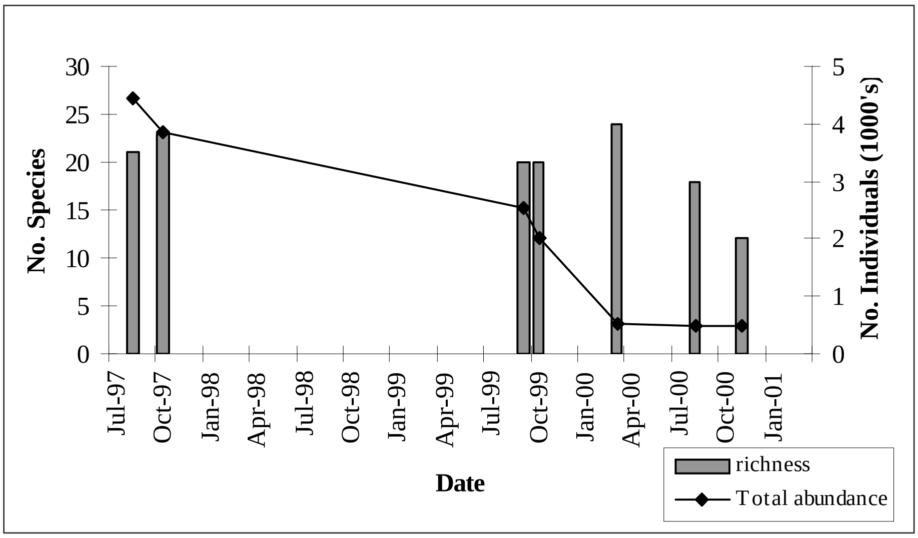

Figure 11. Species richness and abundance of waterbirds at Lake Logue for the 1997, 1999 and 2000 sampling years.

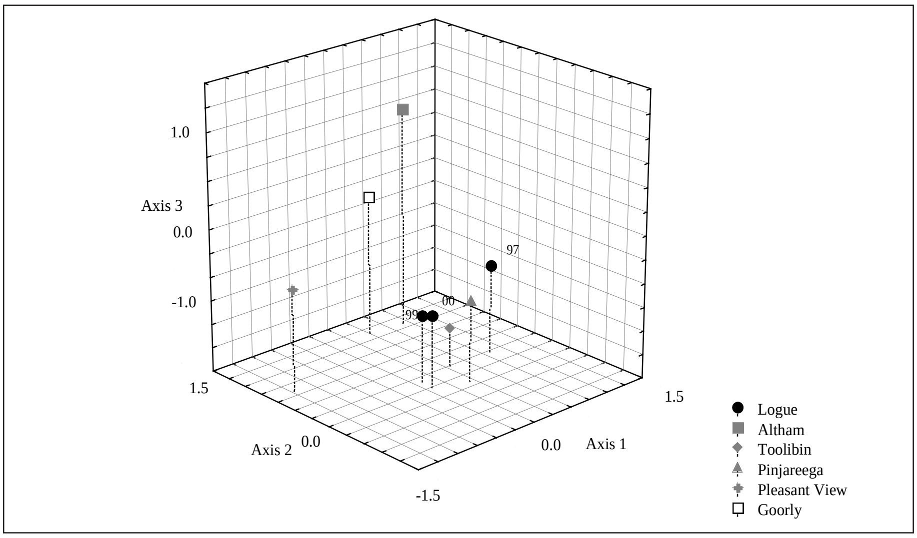

Figure 12. Ordination (SSH) of waterbird species data, showing Lake Logue from 1997, before the lake filled and from 1999 and 2000, after the lake had filled and the five marker wetlands.

TABLE 5
Waterbird species and their abundance on eight sampling occasions at Lake Logue.

				DATE				
	AUG-97	OCT-97	SEP-99	OCT-99	MAR-00	AUG-00	NOV-00	FEB-01
Australasian Grebe	1	0	0	1	2	0	0	0
Australasian Shoveler	64	7	2	8	2	4	0	0
Australian Pelican	0	0	0	0	3	0	0	1
Australian Shelduck	87	517	6	1300	30	1	338	42
Australian White Ibis	0	0	0	0	8	1	0	11
Australian Wood Duck	0	0	12	1	6	29	0	7
Banded Stilt	22	50	0	0	0	0	0	0
Black Swan	1	0	0	40	47	1	0	0
Black-fronted Dotterel	2	18	0	0	0	2	0	0
Black-tailed Native-hen	0	0	5	0	0	0	0	0
Black-winged Stilt	662	379	0	0	11	0	0	0
Blue-billed Duck	0	0	7	1	1	0	0	16
Chestnut Teal	8	0	0	0	0	1	0	0
Common Greenshank	4	26	0	0	0	0	0	0
Curlew Sandpiper	0	1	0	0	0	0	0	0
Darter	0	0	0	0	1	0	2	0
Eurasian Coot	0	0	152	147	52	31	5	31
Freckled Duck	0	0	0	2	0	0	0	0
Glossy Ibis	2	0	0	0	0	2	0	0
Great Crested Grebe	0	0	4	5	1	0	0	0
Great Egret	0	0	1	0	19	0	0	1
Grey Teal	2045	762	2169	218	115	196	14	302
Hardhead	4	0	36	15	4	7	0	0
Hoary-headed Grebe	39	218	12	25	15	29	27	91
Little Black Cormorant	0	0	2	1	1	3	4	3
Little Pied Cormorant	0	0	1	10	1	6	30	89
Musk Duck	0	0	8	8	50	18	1	13
Nankeen Night Heron	0	0	30	0	0	0	2	0
Pacific Black Duck	582	284	30	129	0	130	65	58
Pink-eared Duck	18	11	36	33	33	32	3	0
Red-capped Plover	61	155	0	0	0	0	0	0
Red-kneed Dotterel	0	3	0	0	0	0	0	0
Red-necked Avocet	600	1300	0	0	0	0	0	0
Red-necked Stint	150	35	0	0	0	0	0	0
Sharp-tailed Sandpiper	0	40	0	0	0	0	0	0
Silver Gull	24	0	0	1	0	0	0	0
Spotless Crake	0	1	0	0	0	0	0	0
Straw-necked Ibis	0	22	1	65	55	0	0	0
Swamp Harrier	0	1	0	0	1	0	0	1
Terek Sandpiper	0	1	0	0	0	0	0	0
Whiskered Tern	33	20	0	0	0	0	0	0
White-faced Heron	27	0	6	7	40	2	3	31
Wood Sandpiper	0	3	0	0	0	0	0	0
Yellow-billed Spoonbill	0	1	3	0	40	0	0	2

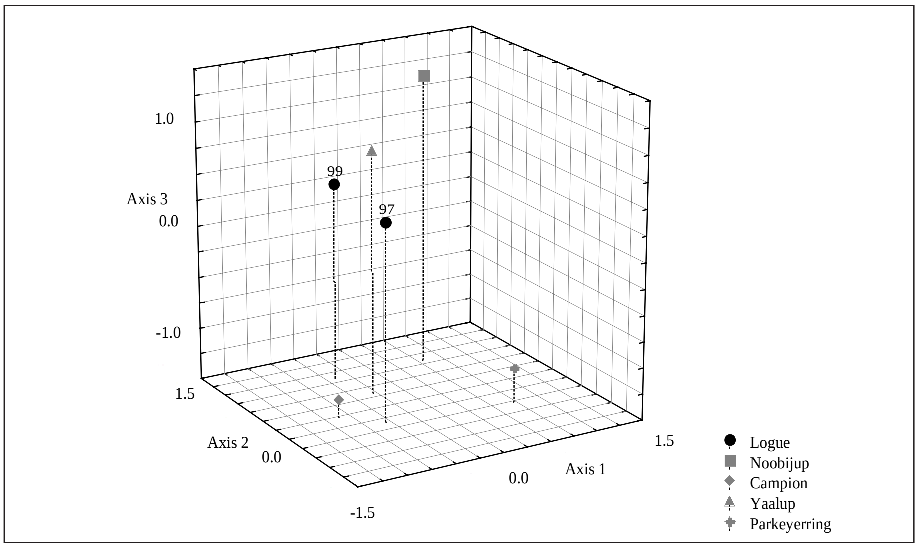

Figure 13. Ordination (SSH) of invertebrate data, showing Lake Logue in 1997 and 1999 and four marker wetlands.

The most obvious trend in the data was the sharp decline in waterbird abundance during the period of high water levels (compare Figs. 10 and 11). Reasons for the decline are unclear but it is not an uncommon phenomenon. Sometimes a temporary drop in numbers is associated with migration to extensive surface water elsewhere (which was present in the north-west in 1999 and 2000 – SA Halse and GB Pearson unpublished data) but the cause is probably often local. Crome (1986) showed that productivity and breeding effort were much greater in the first few months after flooding in a New South Wales wetland.

Despite the decline in abundance, species composition remained very similar during the two years of high water levels (1999 and 2000). This was reflected in ordination (Fig. 12) where the 1997 waterbird assemblage occupied a different position in ordination space.

Invertebrates

A total of 84 invertebrate species were collected from Lake Logue during monitoring (Table 6). Most notable was the discovery of a new species of oligochaete; *Ainudrilus angustivasa* (Pinder and Halse 2002) In 1997, there were

TABLE 6

Invertebrate species collected from Lake Logue in the 1997 and 1999 sampling years.

TAXA	1997	1999
Turbellaria	✓	✓
Nematoda	✓	
ROTIFERA		
Asplanchna sp.		✓
Brachionus sp.		✓
Keratella australis		✓
Dicranophorus		✓
Lecane bulla		✓
Lecane sp.		✓
OLIGOCHAETA		
Aphanoneura		✓
Ainudrilus angustivasa		✓
Tubificidae	✓	
Chaetogaster diastrophus		✓
ACARINA		
Eylais sp.		✓
Acercella sp.		✓
Arrenurus balladoniensis		✓
CLADOCERA		
Alona rigidicaudis s.l.		✓
Alona setigera		✓
Alona sp.		✓
Chydorus sp.		✓
Leydigia sp.		✓
Pleuroxus sp.		✓
Daphnia carinata	✓	
Daphnia cf. *cephalata*		✓
Moina sp.		✓
OSTRACODA		
Ilyocypris spiculata	✓	✓
Alboa worooa	✓	
Bennelongia australis	✓	
Bennelongia barangaroo		✓
Candonocypris novaezelandiae	✓	✓
Cypericercus sp. *658 (* nr. *salinus)*		✓
Cabonocypris nunkeri	✓	
Sarscypridopsis aculeata	✓	✓
COPEPODA		
Boeckella triarticulata	✓	✓
Calamoecia ampulla	✓	
Calamoecia sp. 342 (*ampulla* variant)		✓
Microcyclops varicans		✓
Metacyclops sp. 462	✓	
Australocyclops australis		✓
Mesocyclops brooksi		✓
AMPHIPODA		
Austrochiltonia subtenuis	✓	✓
COLEOPTERA		
Allodessus bistrigatus	✓	✓
Liodessus inornatus		✓
Antiporus gilberti	✓	✓
Sternopriscus multimaculatus		✓
Platynectes sp.		✓
Berosus munitipennis	✓	
Berosus sp.		✓
DIPTERA		
Anopheles annulipes	✓	✓
Culicoides sp.	✓	
Nilobezzia sp. 1	✓	
Atrichopogon sp.		✓
Stratiomyidae		✓
Dolichopodidae	✓	
Syrphidae		✓
Ephydridae	✓	
Procladius paludicola	✓	✓
Ablabesmyia notabilis		✓
Paramerina levidensis		✓
Cricotopus albitarsus		✓
Tanytarsus sp. A (nr. K10)	✓	
Paratanytarsus sp. A		✓
Chironomus occidentalis	✓	
Dicrotendipes conjunctus		✓
Dicrotendipes jobetus		✓
Dicrotendipes 'CA1' (was lindae)		✓
Polypedilum nubifer		✓
Cryptochironomus griseidorsum		✓
Cladopelma curtivalva	✓	
HEMIPTERA		
Saldidae	✓	
Agraptocorixa eurynome		✓
Agraptocorixa hirtifrons	✓	✓
Micronecta robusta		✓
Micronecta gracilis		✓
Anisops thienemanni		✓
Anisops hyperion	✓	✓
Anisops gratus	✓	
ODONATA		
Ischnura aurora aurora		✓
Austrolestes annulosus	✓	
Hemianax papuensis		✓
Hemicordulia tau		✓
TRICHOPTERA		
Oecetis sp.		✓
Triplectides australis		✓

31 species, of which 17 (54%) were insects and 11 species (35%) were crustaceans. After flooding in 1999, 63 species were collected with 31 (49%) insect species and 19 (30%) crustaceans. Invertebrate samples from 1997 and 1999 were quite widely separated on ordination axes (Fig. 13). This was because few species were common to both sampling occasions, with only four of 25 crustaceans and four of 44 insects occurring twice. The fauna of 1999 had a greater number of planktonic species (eight cladocerans and six rotifers compared with one cladoceran species in 1997), suggesting an increased primary productivity of the lake waters following filling. In contrast, the 1997 fauna had a greater proportion of species typical of drying or ephemeral wetlands, such as the dipteran families Stratiomyidae and Syrphridae.

Lake Towerrining

Lake Towerrining (33° 34'S 116° 46'E) (Fig. 14) lies 32 km south of Darkan in the Towerrining Nature Reserve (Reserve No. 24917). The lake is permanent and brackish with an area of approximately 180 ha . Its catchment was extensively cleared by the 1960s and the historical decline in water quality and remnant vegetation is described by Froend (1991). Lake Towerrining was considered fresh until 1966 and at this time supported large fringing stands of *Baumea articulata*, however, between 1964 and 1973 water quality deteriorated dramatically and fringing sedges almost totally disappeared (Froend and McComb 1991). The lake dried for a period between 1979 and 1981 and the submergent benthic macrophytes present below mean lake depth up until that time also disappeared subsequently. These macrophytes did not re-colonise, despite water levels consistently about 2 m and turbidity was implicated as a limiting factor (Froend and McComb 1991). High water levels in recent decades have reduced salinity and modifications to the outlet of the lake by the Department of Agriculture have further improved water quality by increasing lake volume and the potential for flushing. The macrophyte *Ruppia* sp. has recolonised parts of the lakebed. Currently the majority of remnant vegetation occurs as a thin band in the vicinity of the inlet on the western shore. It consists principally of *Melaleuca rhaphiophylla* and *Eucalyptus rudis* (Gurner *et al.* 1999). The lake was selected for monitoring because local remedial work had been undertaken and it was anticipated that lake condition would stabilise or improve. The lake has a long record of waterbird and depth data (Lane and Munro 1983; Jaensch *et al.* 1988).

Water chemistry and physico-chemical parameters

Depth remained relatively constant in Lake Towerrining during monitoring, varying from 2.49 m to 3.34 m (Fig. 15), and conductivity remained between 8000 and 10 000 µS/cm. Cations conformed to the pattern Na>Mg>Ca>K and Cl was the dominant anion. The lake was mesotrophic with respect to total nitrogen and phosphorus (maxima of 3000 µg/L and 10 µg/L, respectively) but high concentrations of chlorophyll were measured (maximum 245 µg/L) in March 2000.

Figure 14. Lake Towerrining is a large permanent and brackish wetland, which lies partly in the Towerrining Nature Reserve.

Groundwater

Monitoring bores were installed on three vegetation transects at Lake Towerrining and sampling commenced in January 2000. Depth to groundwater was 1.08–1.66 m in April 2000 and 0.2–0.66 m in August 2000 (Fig. 16). Groundwater was more saline in bores on transect 1 (up to 30 000 µS/cm) than the other two transects and more saline in bores than in the lake, although the more elevated bore on transect 2 was returning water equivalent to lake water.

Waterbirds

A total of 33 species of waterbird were recorded at Lake Towerrining during monitoring (Table 7), compared with 35 recorded in 24 surveys by Jaensch *et al.* (1988). Of these, 70% were frequent users of the lake and seen on two or more occasions. Species recorded only once included the comparatively rare Freckled Duck. Number of species remained constant at 28 for both sampling years and 82% of the fauna was common to both sampling years. The waterbird fauna was numerically dominated by ducks, with large numbers of Hardhead (*ca.* 800 individuals) in August and October 1997 and Blue-billed Ducks (269 individuals) in August 1997 being noteworthy. Counts of more than 250 Blue-billed Ducks are rare in the south-west (see Halse *et al.* 1995 and earlier duck count reports) and supports the view that Lake Towerrining is an important lake for waterbirds.

During the 1997 monitoring year, abundance of waterbirds remained constant (range 2006–2372); in 1999, numbers were low (*ca.* 500 individuals) in late winter and spring but increased to 1500 individuals in autumn (Fig. 17).

The considerable similarity of species composition across years meant that assemblages in 1997 and 1999 were close in ordination space (Fig. 18). However, they were slightly removed from assemblages in 1982-1984

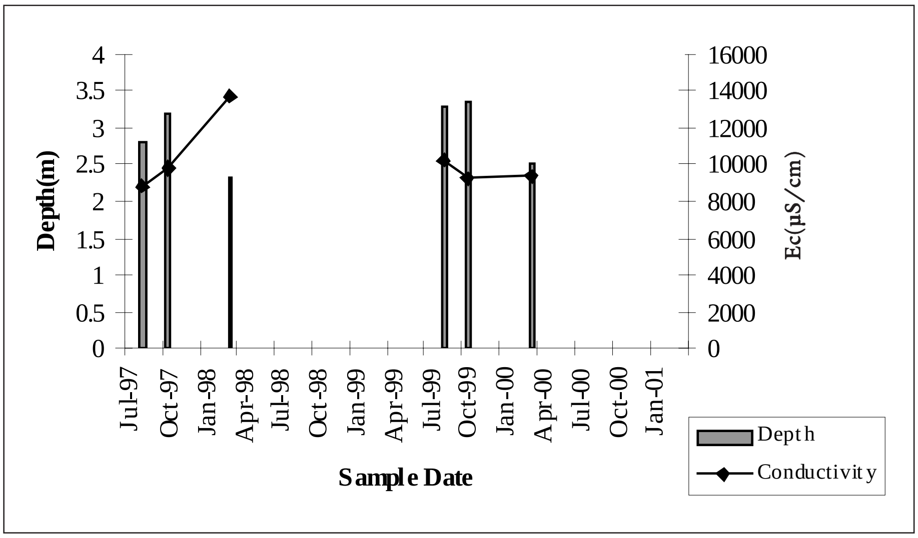

Figure 15. Gauged depth and electrical conductivity at Lake Towerrining for the 1997 and 1999 sampling years.

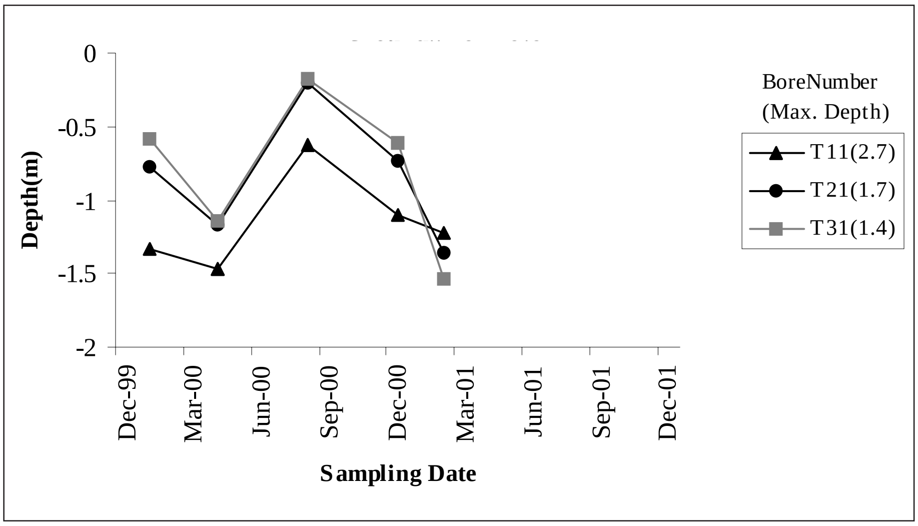

Figure 16. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Towerrining. Legend values in parenthesis are depth of the bore in metres.

TABLE 7
Waterbird species and their abundance on six sampling occasions at Lake Towerrining.

	DATE					
	AUG-97	OCT-97	MAR-98	AUG-99	OCT-99	MAR-00
Australasian Grebe	0	0	5	1	0	7
Australasian Shoveler	14	4	39	4	2	0
Australian Pelican	0	0	0	1	0	0
Australian Shelduck	9	105	484	15	174	402
Australian White Ibis	0	0	3	2	0	1
Banded Stilt	0	0	24	0	0	0
Black Swan	5	30	2	5	16	12
Black-fronted Dotterel	1	2	0	2	0	25
Black-winged Stilt	5	0	54	0	1	3
Blue-billed Duck	269	39	0	127	17	18
Common Sandpiper	0	3	3	3	2	4
Darter	0	0	0	0	0	2
Eurasian Coot	131	483	103	44	6	17
Freckled Duck	0	0	2	0	0	0
Great Crested Grebe	6	5	0	0	0	2
Great Egret	3	1	3	0	0	4
Grey Teal	78	160	265	101	104	339
Hardhead	849	796	46	64	2	0
Hoary-headed Grebe	308	470	500	41	105	7
Little Black Cormorant	121	25	81	65	57	42
Little Pied Cormorant	36	0	25	3	7	14
Musk Duck	173	5	53	14	1	77
Pacific Black Duck	0	5	121	14	19	524
Pink-eared Duck	350	22	131	8	14	4
Red-capped Plover	0	0	0	0	0	21
Red-kneed Dotterel	0	3	0	0	0	0
Red-necked Avocet	0	0	6	0	0	0
Silver Gull	13	12	32	23	35	17
Straw-necked Ibis	0	0	3	0	0	0
Swamp Harrier	0	0	0	2	0	0
Whiskered Tern	0	0	0	0	6	0
White-faced Heron	1	0	4	1	9	10
Yellow-billed Spoonbill	0	0	17	3	0	19

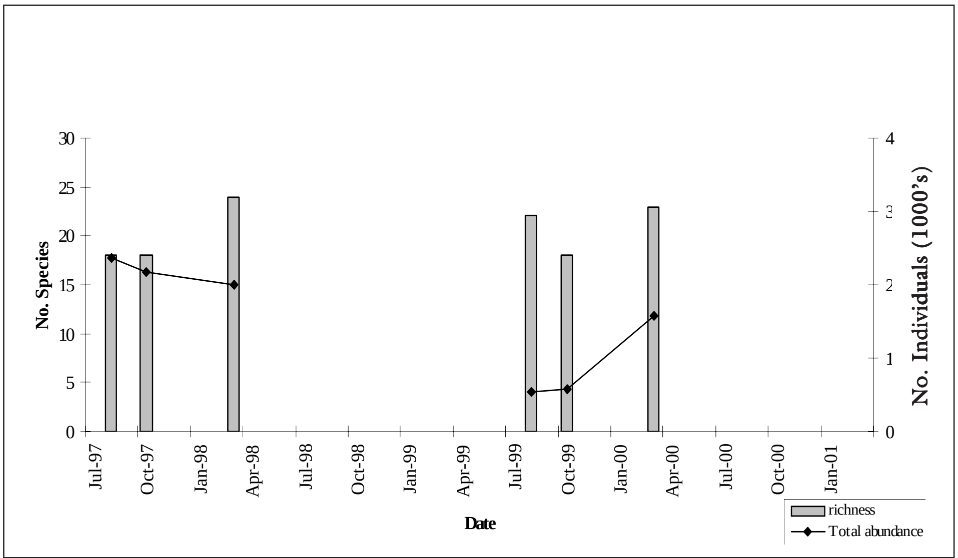

Figure 17. Species richness and abundance of waterbirds at Lake Towerrining during the 1997 and 1999 sampling years.

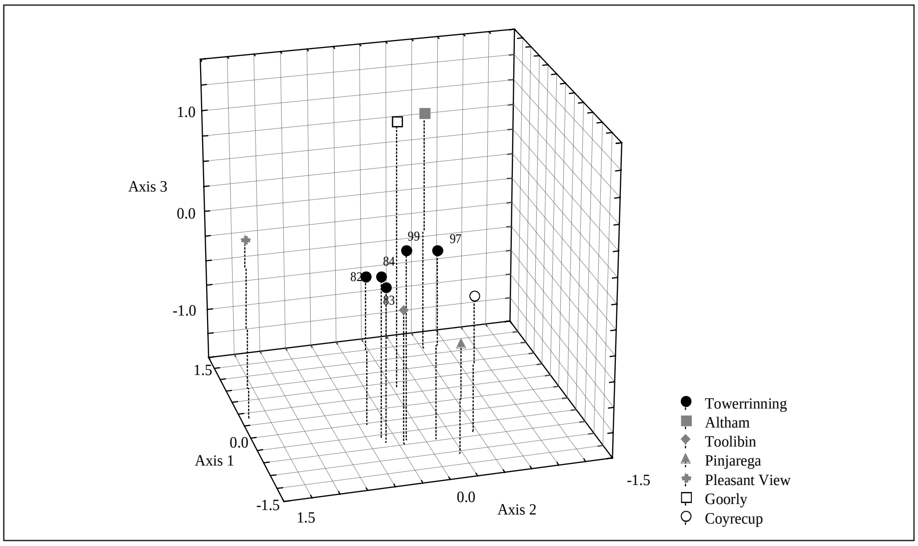

Figure 18. Ordination (PCR) of waterbird species data from Lake Towerrining, showing historical and monitoring data for Lake Towerrining and data for six marker wetlands.

(Jaensch *et al.* 1988). However, Jaensch *et. al.* surveys did not include Moodiarrup Swamp (the bay on Lake Towerrining's western shoreline) and while water levels were similar, salinity was higher (approximately 17 000 µS/cm) than during the monitoring period. The occurrence of more species typical of shallow bare shorelines, which occurred predominantly in the swamp in the 1997 and 1999 surveys (e.g. Red-capped Plover, Red-kneed Dotterel, Red-necked Avocet, Banded and Black-winged Stilt), accounted for most of the differences apparent within the ordination.

Invertebrates

A total of 74 taxa of invertebrates were recorded during monitoring. In 1997, 42 species were collected of which 22 (52%) were insects and 15 (36%) were crustaceans. The proportion of insects in 1999 was similar with 28 species comprising 48% of the fauna compared with 18 crustaceans (31%) (Table 8) In 1999, 58 taxa were collected, reflecting an increase in the richness of several invertebrate groups: eg., rotifers (+5 spp), chironomids (+2 spp) and ostracods (+2 spp). Nevertheless, the invertebrate assemblages of Lake Towerrining remained close in ordination space and were clearly distinguishable from wetlands with different ecological characters (Fig. 19).

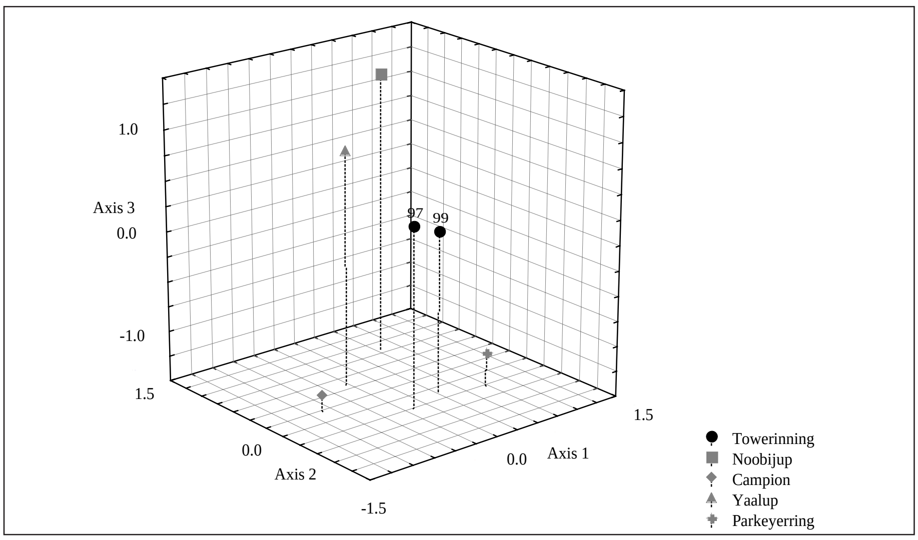

Figure 19. Ordination (SSH) of invertebrate data, showing Lake Towerrining in 1997 and 1999 and four marker wetlands.

TABLE 8

Invertebrate species collected from Lake Towerrining in the 1997 and 1999 sampling years.

TAXA	1997	1999
Turbellaria	✓	
Nematoda	✓	✓
ROTIFERA		
Brachionus rotundiformis		✓
Brachionus sp.		✓
Keratella australis		✓
Lecane sp.		✓
Lecanidae		✓
GASTROPODA		
Coxiella sp.		✓
OLIGOCHAETA		
Tubificidae WA10		✓
Dero digitata	✓	
Paranais litoralis	✓	✓
Enchytraeidae	✓	✓
ACARINA		
Limnesia sp.		✓
Pezidae		✓
CLACOCERA		
Alona sp.		✓
Ceriodaphnia laticaudata s.l.	✓	
Daphnia carinata	✓	
Macrothrix breviseta	✓	✓
OSTRACODA		
Limnocythere porphretica		✓
Ilyocypris australiensis		✓
Cyprinotus edwardi	✓	✓
Diacypris spinosa	✓	✓
Mytilocypris ambiguosa	✓	✓
Mytilocypris tasmanica chapmani	✓	✓
Sarscypridopsis aculeata	✓	✓
COPEPODA		
Boeckella triarticulata	✓	
Calamoecia clitellata		✓
Sulcanus conflictus		✓
Metacyclops sp. 462	✓	
Metacyclops sp. 434 (*arnaudi* sensu Sars)	✓	
Halicyclops sp. 1 (nr *ambiguus*)		✓
Mesocyclops brooksi	✓	✓
Apocyclops dengizicus		✓
Cletocamptus aff *deitersi*		✓
Onychocamptus bengalensis	✓	✓
Nitocra reducta	✓	✓
AMPHIPODA		
Austrochiltonia subtenuis	✓	✓
COLEOPTERA		
Antiporus gilberti	✓	
Antiporus sp.		✓
Necterosoma penicillatus	✓	✓
Berosus discolor	✓	✓
Berosus munitipennis	✓	✓
DIPTERA		
Culicoides sp.	✓	✓
Monohelea sp.		✓
Monohelea sp. 1	✓	
Nilobezzia sp.		✓
Nilobezzia sp. 1	✓	
Psychodinae sp. 2	✓	
Tabanidae		✓
Stratiomyidae	✓	✓
Dolichopodidae	✓	
Ephydridae	✓	✓
Muscidae		✓
Scatopsidae		✓
Procladius paludicola	✓	✓
Procladius villosimanus	✓	✓
Tanytarsus sp. A (nr. K10)	✓	✓
Chironomus occidentalis	✓	✓
Dicrotendipes conjunctus		✓
Dicrotendipes pseudoconjunctus	✓	
Polypedilum nubifer	✓	
Polypedilum sp.		✓
Cryptochironomus griseidorsum		✓
Cladopelma curtivalva		✓
HEMIPTERA		
Micronecta robusta	✓	✓
Anisops thienemanni		✓
Anisops sp.	✓	
Lepidoptera		✓
ODONATA		
Xanthagrion erythroneurum		✓
Austrolestes annulosus	✓	
Zygoptera		✓
TRICHOPTERA		
Notalina spira	✓	✓
Oecetis sp.	✓	✓
Leptoceridae		✓

Lake Coyrecup

The kidney-shaped Lake Coyrecup (33° 43'S 117° 49'E) (Fig. 20) lies at the confluence of two extensive drainage systems: the first from the north-east, draining the region west of Nyabing, and the second from the east. Lake Coyrecup in turn lies upstream of Lake Dumbleyung on the drainage line that is the Coblinine River. The lake is semi-permanent and approximately 448 ha in area, of which 80% is open water (Halse *et al.* 1993b). Soils, climate and vegetation are described by Lyons (1988). Vegetation associations around the margin of the lake were described as *Casuarina obesa* low forest and woodland, and *Melaleuca* woodland by Lyons (1988). Whilst Lake Coyrecup has been secondarily saline for several decades, groundwater is saline and still rising as a result of past land clearing in the catchment. Its proximity to the lakebed is seen as the main threat in terms of further change to the ecological health of the lake.

Lake Coyrecup was included in the monitoring program as an example of a secondarily saline wetland. There is considerable management activity occurring in the catchment and the lake has a history of collection of waterbird and depth data. It supports a relatively rich waterbird community for a saline lake (Jaensch *et al.* 1988), and is well-known for supporting high abundances of ducks (eg. Halse *et al.* 1995).

Water chemistry and physico-chemical parameters

Lake Coyrecup was about one-third full in both 1997 and 1999 and lake water was saline (55 000 µS/cm to 144 000 µS/cm) (Fig. 21). The pattern of cation dominance was Na>>Mg>Ca>K and the lake was mesotrophic with respect to total nitrogen and phosphorus, although levels became more elevated as water levels declined in March 2000 (maxima for TN was 10 000 µg/l and for TP 110 µg/l). Levels of phaeophytin (from the breakdown of algae) were also high at this time, indicating a late algal bloom.

Groundwater

A total of 10 bores were installed on the five vegetation transects at Lake Coyrecup. Depth to groundwater varied with location (range 0.73–4.69 m) and was, on average, 1 m greater in autumn than in spring (Fig. 22). Conductivity was greatest in bores on transects four and five, which are east of the lake proper. Groundwater was acidic on these transects with pH approaching 3. At other transects salinities were similar to those of the lake (range 38 400–68 000 µS/cm) and pH was 5–6.

Waterbirds

Twenty-one species of waterbirds were recorded at Lake Coyrecup during monitoring (Table 9), compared with the 32 recorded in 23 surveys between 1981 and 1985 (Jaensch *et al.* 1988), when the lake twice filled to overflowing. In 1997 and 1999, species richness tended to be greater in late winter and spring and low in autumn as the lake dried. In autumn of both years the fauna was dominated by Australian Shelduck. Total waterbird abundance was correlated with species richness (r = 0.85) (Fig. 23). Only 57% of species were sighted on more than two monitoring occasions, leaving a large group of occasional visitors. These occasional visitors were of low abundance (e.g. Freckled Duck, Wood Duck see Table 9) except for the Pink-eared Duck, with 689 individuals in spring 1997.

Waterbird surveys from 1997 and 1999 differed in their location in ordination space (Fig. 24). The 1999

Figure 20. Lake Coyrecup is a secondarily saline wetland with a fringing band of dead Casuarina obesa.

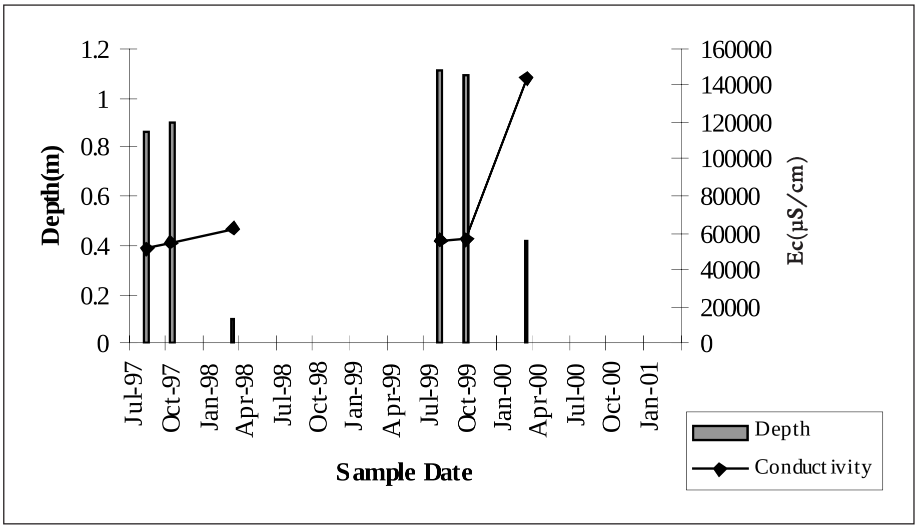

Figure 21. Gauged depth and electrical conductivity for Lake Coyrecup in the 1997 and 1999 sampling years.

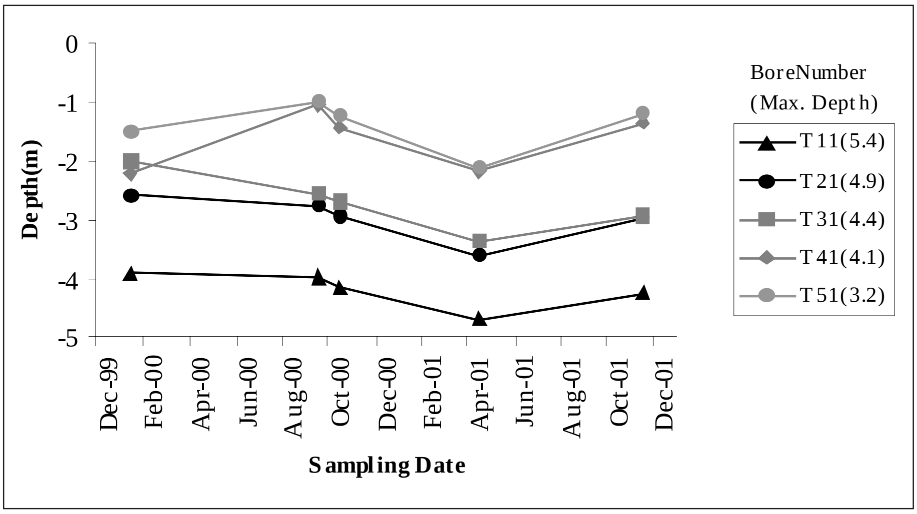

Figure 22. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Coyrecup. Legend values in parenthesis are depth of the bore in metres.

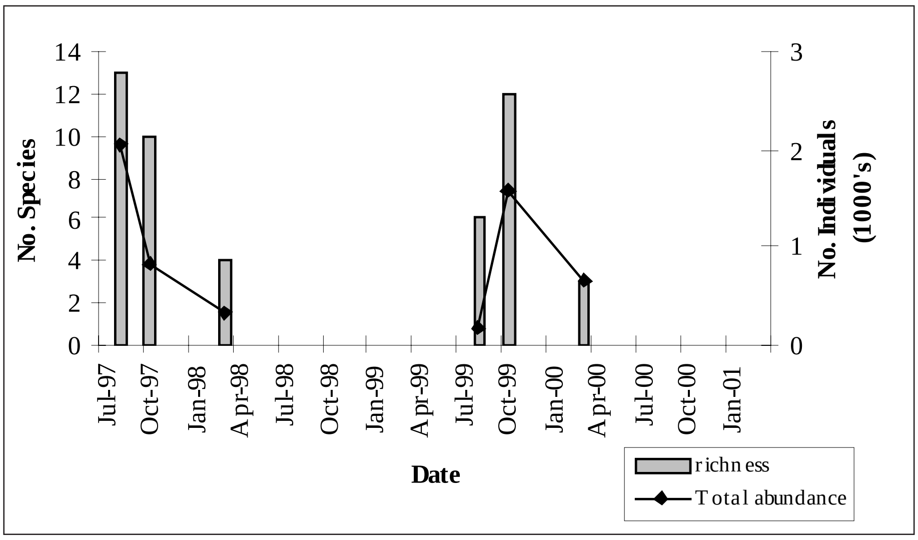

Figure 23. Waterbird species richness and abundance at Lake Coyrecup for the 1997 and 1999 sampling years.

TABLE 9
Waterbird species and their abundance on six sampling occasions at Lake Coyrecup.

	DATE					
	AUG-97	OCT-97	MAR-98	AUG-99	OCT-99	MAR-00
Australian Shelduck	11	385	220	70	916	640
Australian Wood Duck	0	0	0	0	3	0
Banded Stilt	27	0	35	0	119	0
Black Swan	76	99	0	32	13	0
Black-winged Stilt	66	10	0	0	0	0
Chestnut Teal	2	0	0	0	20	0
Common Greenshank	0	1	0	0	0	0
Eurasian Coot	82	50	0	0	0	0
Freckled Duck	1	0	0	0	0	0
Grey Teal	939	26	40	30	470	0
Hardhead	2	0	0	0	0	0
Hoary-headed Grebe	45	231	0	0	3	0
Hooded Plover	0	0	0	0	0	1
Musk Duck	0	0	0	0	2	0
Pacific Black Duck	0	0	0	0	4	0
Pink-eared Duck	689	0	0	0	0	0
Red-capped Plover	56	0	25	0	0	15
Red-necked Avocet	0	4	0	0	0	0
Silver Gull	50	7	0	25	25	0
White-faced Heron	0	0	0	7	16	0
Yellow-billed Spoonbill	0	1	0	2	1	0

survey lay closer to the saline marker wetlands, Altham and Goorly, because of the occurrence of Hooded and Red-capped Plovers and the absence of some species present in 1997. Both years showed differences from the 1982-1984 surveys as Coyrecup has moved further away from being a treed wetland like Toolibin, (e.g. 1997 data point) and sometimes become almost like a saline playa (e.g. 1999 data point).

Invertebrates

A total of 25 species of invertebrate were recorded at Lake Coyrecup during monitoring. Crustaceans dominated the fauna with 10 species (55%) in 1997 and 11 (47%) in 1999 (Table 10). Species richness increased from 18 in 1997 to 23 in 1999, with 1997 essentially containing a subset of the species present in 1999. The crustacean fauna differed between years only by the addition of Harpacticoida sp. 1 in 1999. Dominant species included *Daphniopsis pusilla*, *Mytilocypris tasmanica chapmani*, *Australocypris insularis*, *Calamoecia clitellata* and *Austrochiltonia subtenuis*, all of which have widespread distributions because of their tolerance of a wide range of environmental parameters (see Halse 1981). Insects recorded were typical of saline wetlands and included *Berosus discolor* and dipterans from the families Stratiomyidae, Ephydridae, Ceratopogonidae and Chironomidae.

Despite additional species in 1999, assemblages from Lake Coyrecup were very close to each other in ordination space (Fig. 25), both years lying midway between fresh and hypersaline marker wetlands on all three axes. The limited suite of species collected reflects the salinization of this wetland.

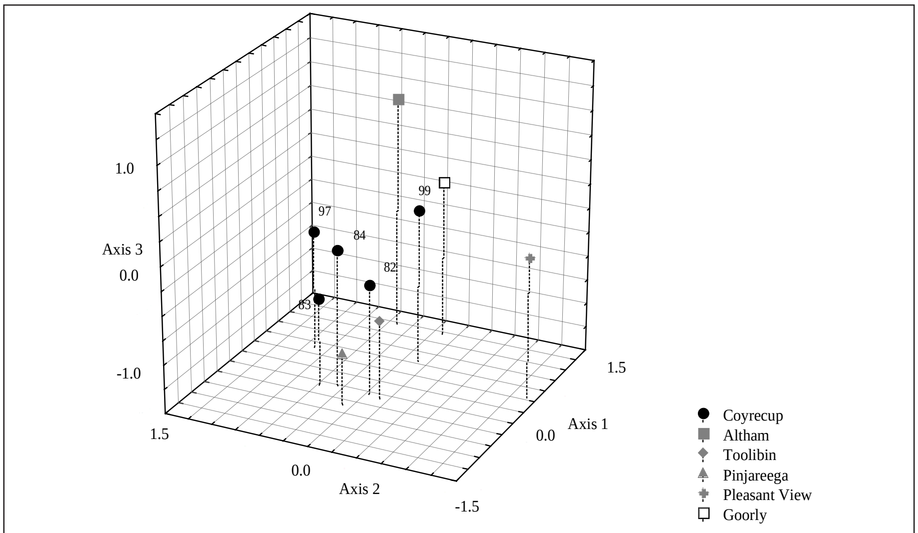

Figure 24. Ordination (PCR) of waterbird species data from Lake Coyrecup, showing historical and monitoring data for Lake Coyrecup and data for six marker wetlands.

TABLE 10
Invertebrate species collected from Lake Coyrecup in the 1997 and 1999 sampling years.

TAXA	1997	1999
Turbellaria	✓	✓
Nematoda	✓	✓
ROTIFERA		
Hexarthra sp.		✓
Brachionus plicatilis		✓
GASTROPODA		
Coxiella sp.	✓	✓
OLIGOCHAETA		
Tubificidae		✓
Enchytraeidae		✓
CLADOCERA		
Daphniopsis pusilla	✓	
Daphniopsis sp.		✓
OSTRACODA		
Australocypris insularis	✓	✓
Diacypris spinosa	✓	✓
Mytilocypris tasmanica chapmani	✓	✓
Platycypris baueri	✓	✓
COPEPODA		
Calamoecia clitellata	✓	✓
Apocyclops dengizicus	✓	✓
Mesochra nr *flava*	✓	✓
Harpacticoida sp. 1		✓
AMPHIPODA		
Austrochiltonia subtenuis	✓	✓
ISOPODA		
Haloniscus searlei	✓	✓
COLEOPTERA		
Berosus discolor	✓	✓
Berosus sp.	✓	✓
DIPTERA		
Monohelea sp. 1	✓	
Stratiomyidae		✓
Ephydridae		✓
Procladius paludicola	✓	✓
Tanytarsus sp. A (nr. K10)	✓	

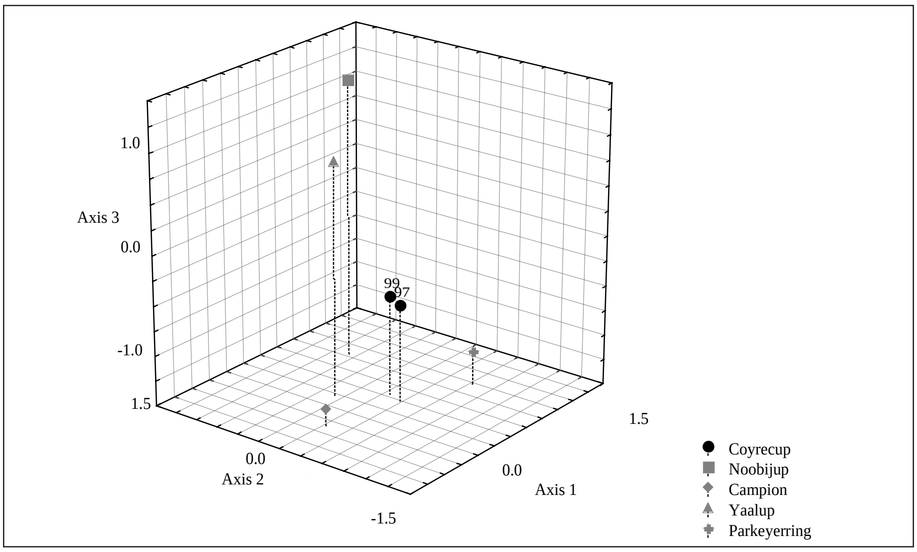

Figure 25. Ordination (SSH) of invertebrate data, showing Lake Coyrecup in 1997 and 1999 and four marker wetlands.

Lake Wheatfield

Lake Wheatfield (Fig. 26) is one of a chain of wetlands immediately north of Esperance (33° 48'S 116°46'E). With an area of approximately 50 ha, Lake Wheatfield is permanent and saline with a depth of 1–2 m. It receives water from Coramup Creek. Its outflow extends through to Woody Lake and, in years of high water levels, continues through Lake Windabout to Lake Warden. Wheatfield is located within *Banksia speciosa* woodlands and fringed by *Melaleuca cuticularis*, *Isolepis nodosa* and *Baumea juncea* in the littoral zone (Ogden and Froend 1998). *Melaleuca cuticularis*, *Spyridium globulosum* and *Sarcocornia quinqueflora* occur around the inflow.

Lake Wheatfield was selected as a monitoring site because it lies within a Ramsar wetland and because it has faunal and vegetation communities that are in good condition but susceptible to change because of salinization and urbanisation. Lake Wheatfield is in the Lake Warden Biodiversity Recovery Catchment and substantial management effort is being expended maintaining and restoring its ecological values.

Water chemistry and physico-chemical parameters

Depth data for Lake Wheatfield are estimates (and unreliable) because a gauge was not installed until 2001. Conductivity ranged from 24 000 µS/cm in March 1998 to 5050 µS/cm in March 1999 after heavy summer rains (Fig. 27). Cation dominance conformed to the pattern Na>Mg>Ca>K with Cl the dominant anion. Total nitrogen (1900 µg/l to 2500 µg/l) and phosphorus (20 µg/l –50 µg/l) levels were stable and algal activity appeared to be high. Total chlorophyll concentrations (all fractions) exceeded 30 µg/l in all water samples.

Groundwater

Paired monitoring bores were installed on vegetation transects 1, 2 and 3 and a single bore on transect 4. The bores were installed as part of a series of 13 bores on Lakes Wheatfield, Woody and Warden that are sampled and maintained by the Biodiversity Recovery Catchment staff. Depth to groundwater has been monitored monthly since September 2000 and has shown an average annual fluctuation in groundwater depth of 0.92 m (Fig. 28)

Waterbirds

A total of 33 waterbird species were recorded for Lake Wheatfield in 1997 and 1999, compared with 31 species recorded in 26 surveys by Jaensch *et al.* (1988). Twenty-two (67%) species were recorded in both 1997 and 1999 (Table 11). Most of the species recorded in only one year were seen in a single survey (e.g. Swamp Harrier, Silver Gull and Whiskered Tern), but the Freckled Duck, Pink-eared Duck and Hoary-headed Grebe were seen in all three 1997 surveys and not recorded in 1999. There were also marked reductions in the numbers of some other species in 1999 compared with 1997 (Table 11, Fig. 29. The lake was not a significant drought refuge in March 2000, presumably because the widespread summer rains in the region filled other wetlands.

Despite the substantial variation in abundance between years, species composition was sufficiently similar for the waterbird assemblages in 1997 and 1999 to separate from those of marker wetlands in ordination space (Fig. 30).

Figure 26. Lake Wheatfield is a relatively deep saline wetland on the southeast coast of Western Australia.

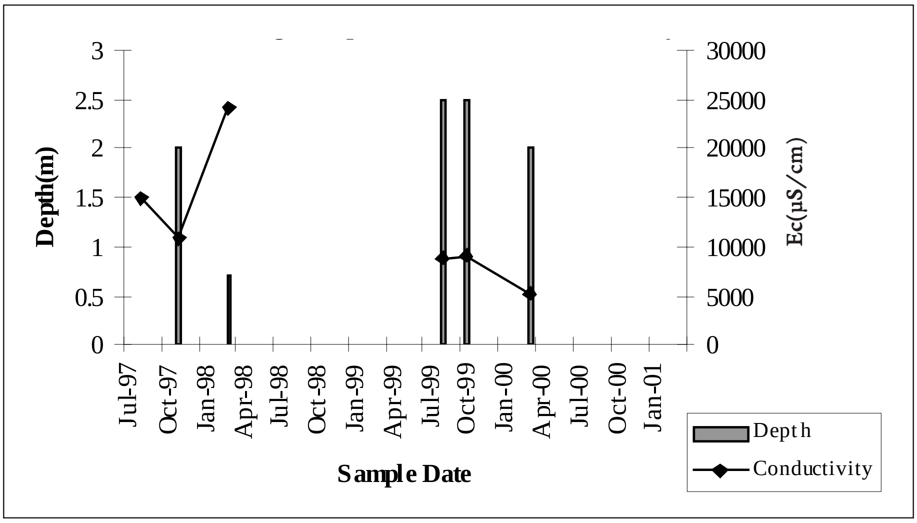

Figure 27. Gauged depth and electrical conductivity at Lake Wheatfield for 1997 and 1999 sampling years.

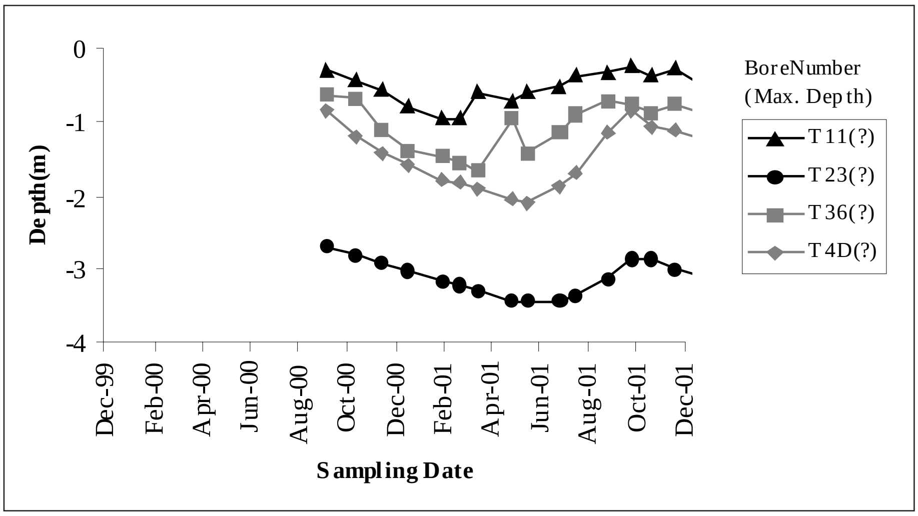

Figure 28. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Wheatfield. Depth data (parentheses) for each bore are currently unavailable.

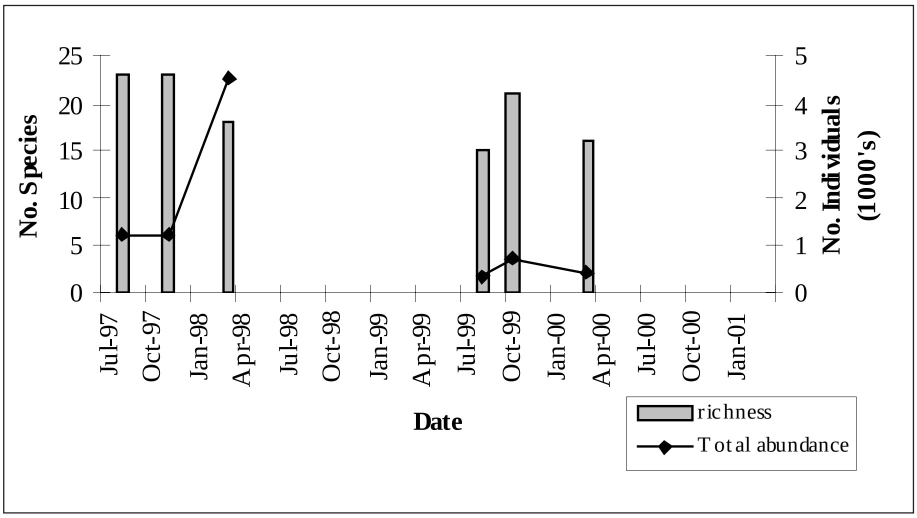

Figure 29. Waterbird species richness and abundance at Lake Wheatfield for 1997 and 1999 sampling years.

TABLE 11
Waterbird species and their abundance on six sampling occasions at Lake Wheatfield.

	SAMPLING DATE					
	AUG-97	NOV-97	MAR-98	AUG-99	OCT-99	MAR-00
Australasian Shoveler	60	3	430	0	0	2
Australian Shelduck	4	5	0	0	5	0
Australian White Ibis	0	0	1	2	12	5
Australian Wood Duck	3	0	0	0	0	0
Banded Lapwing	0	0	0	0	2	0
Black Swan	1	0	0	0	0	1
Black-fronted Dotterel	2	0	5	0	0	0
Blue-billed Duck	2	8	0	4	7	2
Chestnut Teal	429	320	17	55	76	40
Common Greenshank	0	1	15	0	0	0
Common Sandpiper	0	2	2	0	3	3
Darter	5	0	0	4	0	4
Eurasian Coot	350	216	226	7	6	2
Freckled Duck	3	1	3	0	0	0
Glossy Ibis	0	0	0	0	1	0
Great Cormorant	1	2	0	3	0	0
Great Crested Grebe	1	5	0	0	2	0
Great Egret	25	4	10	2	30	0
Grey Teal	51	258	1450	4	82	10
Hardhead	120	16	0	12	1	0
Hoary-headed Grebe	14	47	301	0	0	0
Little Black Cormorant	24	79	0	115	350	272
Little Pied Cormorant	15	10	5	60	47	6
Musk Duck	37	23	120	6	13	32
Nankeen Night Heron	0	1	0	0	2	0
Pacific Black Duck	78	92	250	55	57	18
Pink-eared Duck	6	84	1670	0	0	0
Silver Gull	0	0	0	0	1	0
Straw-necked Ibis	0	0	2	0	5	0
Swamp Harrier	0	0	0	0	0	1
Whiskered Tern	0	62	0	0	0	0
White-faced Heron	2	5	5	3	15	4
Yellow-billed Spoonbill	13	2	30	5	9	24

The position of historical surveys within the ordination suggests there has been a change in community composition between the early 1980s and late 1990s. The principal difference between surveys, however, is species richness. Historical surveys returned a mean annual species richness of 16 species while monitoring surveys recorded 26 and 29 species (mean 27.5 spp.). This discrepancy is probably a result of different sampling efforts: monitoring surveys were conducted by boat and had greater access to all regions of the lake than historical surveys, which were conducted from the shore.

Invertebrates

A total of 91 invertebrate species were recorded during monitoring, with 52 species in 1997 and 73 in 1999. Insects were the dominant group in both years, comprising 24 species (46%) in 1997 and 29 (40%) in 1999 (Table 12). The crustacean fauna consisted of 18 species (34%) in 1997 and 17 species (23%) in 1999. Ostracods were well represented each year with eight and seven species, respectively, and five of the 10 ostracod species recorded were common to both sampling years. Four slightly larger crustacean species, the shrimp *Paleomonetes australis*, the amphipods *Austrochiltonia subtenuis* and *Melita kauerti*, and the isopod *Exosphaeroma* sp., occurred both years. The latter two species have marine affinities and have not been collected from any other monitoring wetland.

While crustacean species composition was moderately constant with 12 species (52%) common to both years, insects were more variable with only 15 of 38 species occurring both years and additional species of most orders being recorded in 1999. Rotifers were a significant part of the fauna in 1999, with 15 species, but were represented by only three species in 1997. Despite the variation between years, the invertebrate assemblages of Lake Wheatfield separate clearly from those of other wetlands because of the significant marine element in the fauna (Fig. 31).

TABLE 12
Invertebrate species collected from Lake Wheatfield in the 1997 and 1999 sampling years.

TAXA	1997	1999
HYDRAZOA		
Cordylophora sp.	✓	✓
Turbellaria	✓	
Nematoda	✓	✓
ROTIFERA		
Macrotrachela sp. a	✓	
Philodinidae		✓
Hexarthra fennica	✓	✓
Hexarthra sp.		✓
Testudinella patina		✓
Brachionus rotundiformis	✓	✓
Brachionus sp.		✓
Keratella procurva		✓
Keratella quadrata		✓
Colurella adriatica		✓
Colurella sp.		✓
Lecane ludwigii		✓
Lecane sp.		✓
Lecanidae		✓
Synchaeta sp.		✓
Trichocerca sp.		✓
GASTROPODA		
Coxiella sp.	✓	✓
OLIGOCHAETA		
Tubificidae		✓
Dero digitata		✓
Paranais litoralis		✓
Enchytraeidae		✓
ACARINA		
Hydrachnidae	✓	
Koenikea sp. nov. nr. *australica*		✓
Pezidae		✓
Oribatida	✓	✓
Mesostigmata	✓	✓
Trombidioidea		✓
CLADOCERA		
Alonella sp.		✓
Daphnia carinata	✓	
OSTRACODA		
Cyprideis australiensis	✓	✓
Alboa worooa	✓	
Diacypris spinosa	✓	✓
Mytilocypris tasmanica chapmani	✓	
Reticypris clava	✓	✓
Cyprididae		✓
Sarscypridopsis aculeata	✓	✓
Leptocythere lacustris	✓	
Leptocythere sp.		✓
Kennethia cristata	✓	✓
COPEPODA		
Gladioferens imparipens	✓	✓
Halicyclops sp. 1 (nr *ambiguus*)	✓	✓
Mesocyclops brooksi		✓
Mesochra baylyi	✓	
Cletocamptus aff *deitersi*	✓	
Onychocamptus bengalensis	✓	✓
Nitocra reducta		✓
AMPHIPODA		
Austrochiltonia subtenuis	✓	✓
Melita kauerti	✓	✓
ISOPODA		
Exosphaeroma sp.	✓	✓
DECAPODA		
Palaemonetes australis	✓	✓
COLEOPTERA		
Paroster niger		✓
Sternopriscus multimaculatus	✓	✓
Necterosoma sp.	✓	
Lancetes lanceolatus	✓	
Berosus sp.	✓	✓
Gymnocthebius sp. 1	✓	
DIPTERA		
Clinohelea sp.		✓
Culicoides sp.	✓	✓
Monohelea sp.		✓
Nilobezzia sp. 2		✓
Stratiomyidae	✓	✓
Empididae		✓
Dolichopodidae	✓	✓
Ephydridae	✓	
Procladius paludicola	✓	✓
Procladius villosimanus	✓	
Paralimnophyes pullulus		✓
Cladotanytarsus sp. A		✓
Tanytarsus sp. A (nr. K10)	✓	✓
Chironomus occidentalis	✓	✓
Chironomus aff. *alternans*	✓	
Dicrotendipes pseudoconjunctus	✓	✓
Dicrotendipes sp. A (D. Edwards V47)	✓	✓
Kiefferulus intertinctus		✓
Polypedilum nubifer		✓
Polypedilum nr. *convexum*	✓	
Cryptochironomus griseidorsum		✓
Cladopelma curtivalva	✓	
HEMIPTERA		
Micronecta robusta	✓	✓
Anisops hackeri		✓
ODONATA		
Austrolestes annulosus	✓	✓
Austrolestes aridus		✓
Hemicordulia tau	✓	✓
TRICHOPTERA		
Ecnomus pansus/turgidus		✓
Notalina spira	✓	✓
Oecetis sp.	✓	✓
Symphitoneuria wheeleri		✓
Triplectides australis	✓	

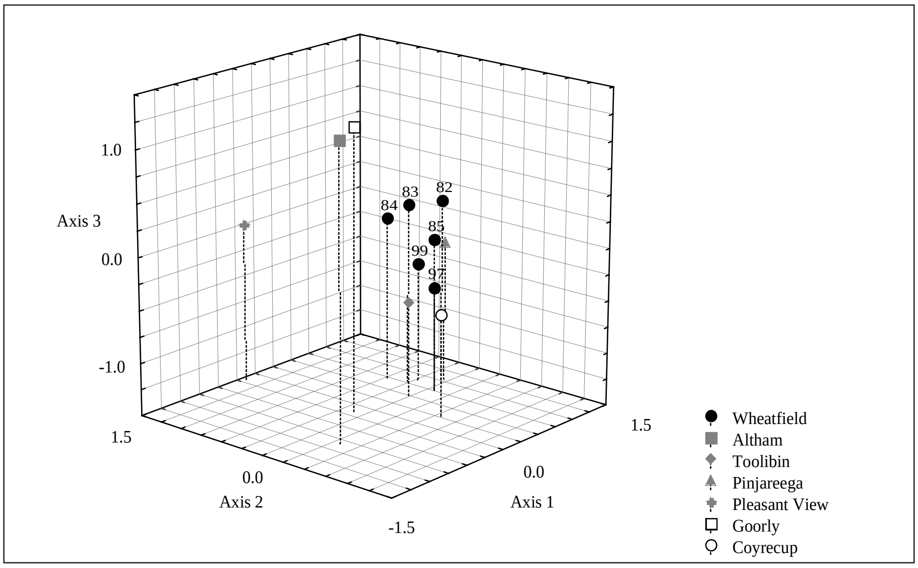

Figure 30. Ordination (PCR) of waterbird species data from Lake Wheatfield, showing historical and monitoring data for Lake Wheatfield and data for six marker wetlands.

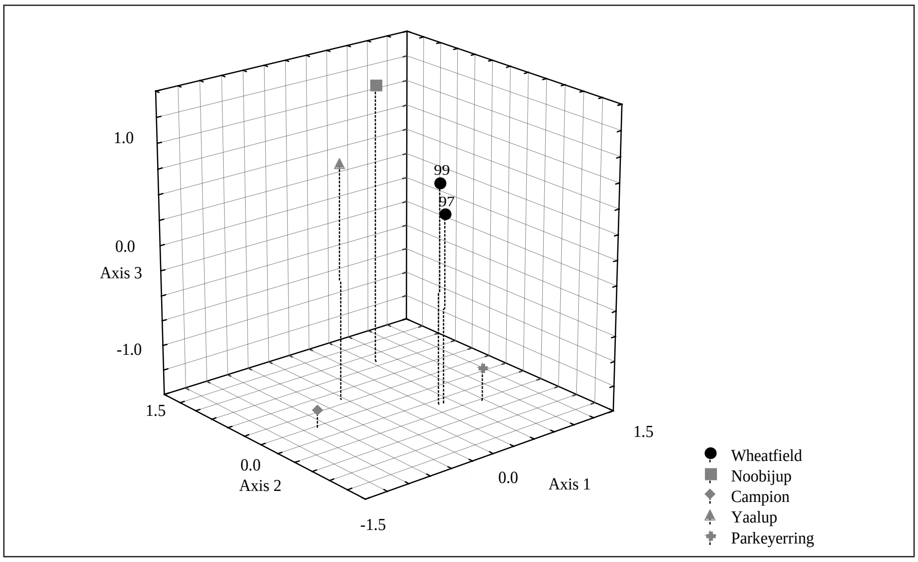

Figure 31. Ordination (SSH) of invertebrate data, showing Lake Wheatfield in 1997 and 1999 and four marker wetlands.

Lake Altham

Located within the Chinocup Nature Reserve (Reserve No. 28395) (33° 24'S 118° 27'E), Lake Altham (Fig. 32) is part of a large chain of saline lakes that includes Lake Grace to the north and Lakes Pingrup and Chinocup to the south. Lake Altham is typically a shallow, seasonal and hypersaline lake with an area of approximately 243 ha, almost all of which is open water (Halse *et al.* 1993b). In most years Lake Altham dries during summer but after major floods it fills to a depth of about 1.5 m and contains water all year (Jaensch *et al.* 1988). Natural vegetation is restricted to the west and northeast sides of the lake. Vegetation has been described by Gurner *et al.* (2000) as terrestrial woodlands of *Melaleuca lateriflora* and *Hakea preissii* on elevated ridges, replaced downslope by *M. uncinata*, *M. halmaturorum* and *M. hamulosa* as a closed low woodland over shrub-like understorey species that include *Halosarcia pergranulata*, *Lycium astrale*, *Maireana brevifolia* and *Sarcornia quinqueflora*. The lake was selected for monitoring because it is primarily saline, fills regularly, and has intact vegetation and a history of waterbird and depth data.

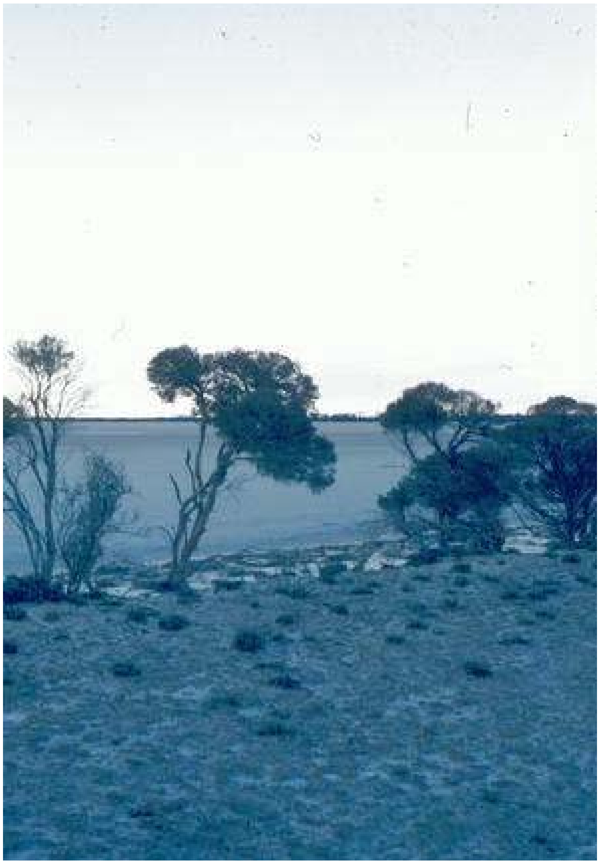

Figure 32. Lake Altham is a shallow naturally saline lake which dries in most years.

Water chemistry and physico-chemical parameters

Lake Altham was monitored in 1998 and 2000. During both years it was shallow, drying in autumn 1999 and 2001 and being almost dry in October 2000. The minimum recorded conductivity was 140 800 µS/cm (Fig. 33), with cation pattern being Na>Mg>Ca>K and Cl the major anion, although SO_4 concentration was significant. The shallowness and high turbidity (520 NTU) of the lake led to high water temperatures, particularly in spring 1998, when 28.4°C was recorded. The concentration of phaeophytin also rose in spring 1998, suggesting a collapse of the relatively high algal production observed in late winter, when total chlorophyll concentration was 54.5 µg/l. Lake Altham was eutrophic with respect to Total nitrogen and phosphorus throughout the study period (TN range 3100–7900 µg/l and TP range 40–220 µg/l). Nutrients are probably entering the lake in run-off from agricultural land to the west.

Groundwater

Bore pairs were installed on three vegetation-transects in April 2000. Groundwater lay between 0.33 and 2.89 m below ground level, depending on location (Fig. 34), with peak levels in late winter-spring. Electrical conductivity of bore-water was relatively constant spatially, averaging 121 600 µS/cm in spring and 89 000 µS/cm in late winter. Groundwater was less saline than lake water.

Waterbirds

Six species of waterbird were recorded at Lake Altham in 1998 and 2000, compared with 15 species recorded in 13 surveys between 1981 and 1985 (Jaensch *et al.* 1988). Many of the species recorded by Jaensch *et al.* (1988) were observed in 1983-84 when the lake flooded to a depth of almost 1.5 m and salinity dropped to about 8000 µS/cm. Large differences in the waterbird community were recorded between surveys during 1998 and 2000, with species richness ranging from one to six in seasons when water was present. However, the species lists for whole years were very similar, with the absence of Banded Stilts in 2000 being the only difference (Table 13, Fig. 35).

Lake Altham waterbird surveys (1998) were used in this study as a marker wetland in the ordination, and represent species poor saline wetlands. The similarity of bird assemblages in both monitoring years was apparent in the ordination (Fig. 36) with both years clearly defined from other marker wetlands. A clear shift in community structure between 1983 and 1998/2000 is also indicated. However, the 1983 survey coincided with a period of high water level and low salinity when waterbird use increased and there is no evidence of a long-term decline in waterbird use of Lake Altham. Nevertheless, the ability of ordination to detect changes in community structure is clearly indicated.

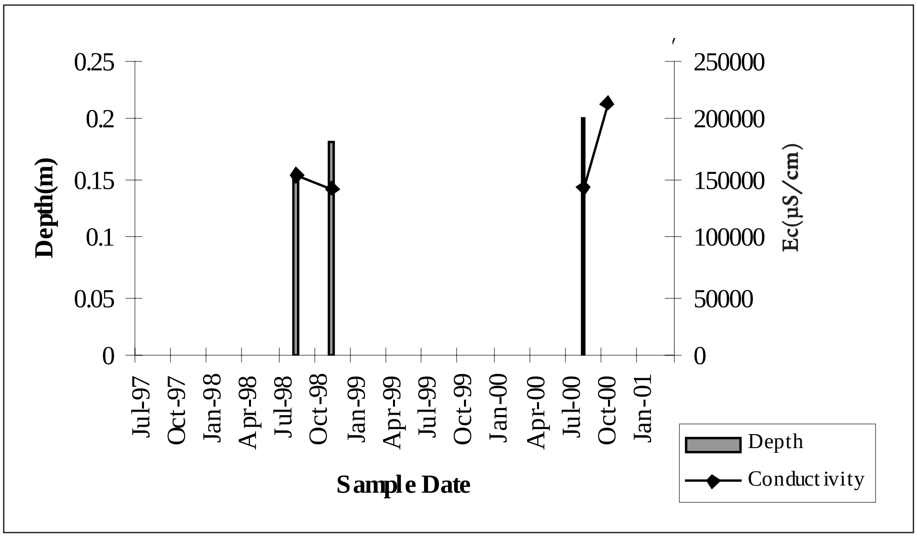

Figure 33. Gauged depth and electrical conductivity at Lake Altham for 1998 and 2000 sampling years.

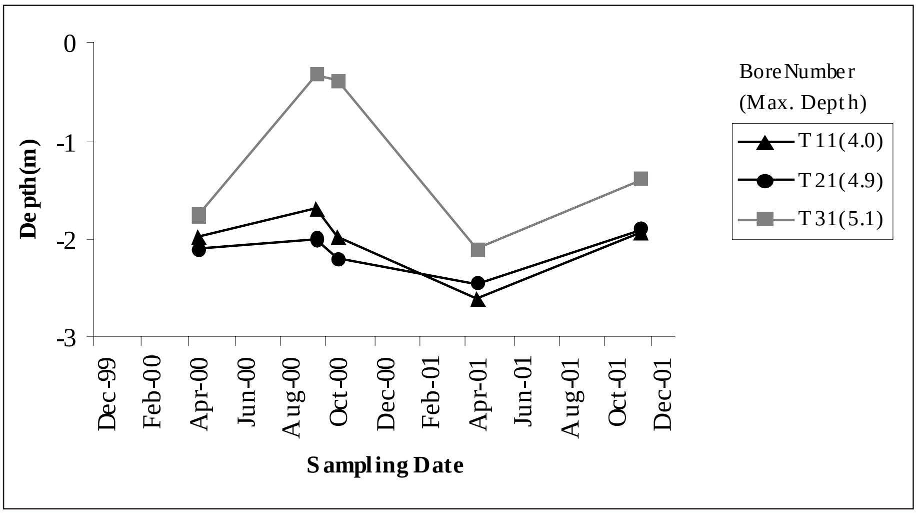

Figure 34. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Altham. Legend values in parenthesis are depth of the bore in metres.

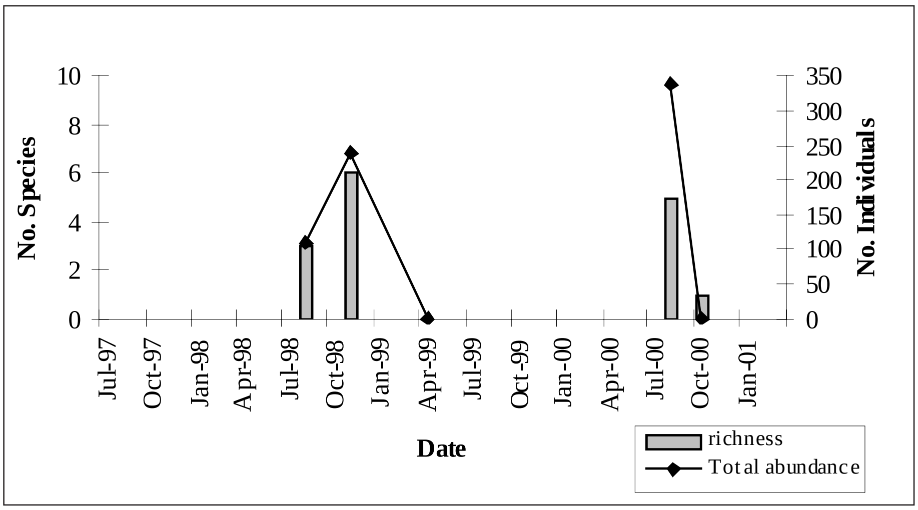

Figure 35. Waterbird species richness and abundance at Lake Altham for the 1998 and 2000 sampling years.

TABLE 13
Waterbird species and their abundance on five sampling occasions at Lake Altham.

	SAMPLING DATE				
	AUG-97	NOV-98	APR--99	AUG--00	OCT-00
Australian Shelduck	96	186	0	175	0
Banded Stilt	0	7	0	0	0
Grey Teal	1	2	0	159	0
Hooded Plover	13	20	0	2	1
Red-capped Plover	0	18	0	2	0
Red-necked Stint	0	8	0	1	0

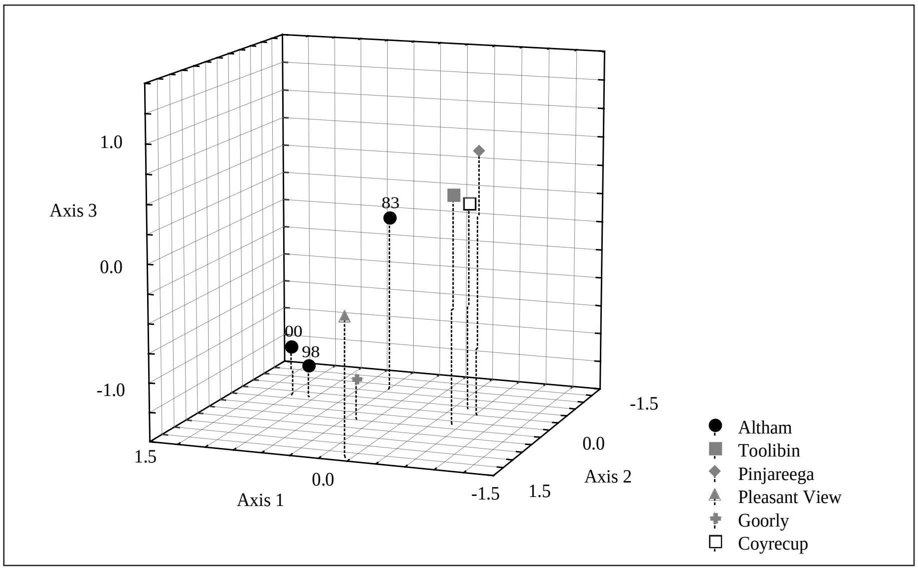

Figure 36. Ordination (PCR) of waterbird species data from Lake Altham, showing historical and monitoring data for Lake Altham and data for six marker wetlands.

Invertebrates

Fifteen species of aquatic invertebrate were collected in spring 1998 (Table 14) with species richness clearly constrained by salinity. Invertebrate abundance was also low with most species represented by individuals in samples. The fauna was dominated by salt-tolerant crustaceans, which comprised 10 species (67% of the fauna). Ostracods (four species) and cladocerans (three species) were the most diverse crustacean orders. Two cladocerans (family Chydoridae) recorded at Altham, *Alona* sp. and *Alonella* sp., occurred at a salinity (140 800 µS/cm) well above that at which chydorids have been recorded elsewhere (see Hammer 1986). While it is likely that these animals were dead on collection (and preserved in brine), the records nevertheless suggest that some extremely salt-tolerant cladocerans occur in south-west Western Australia.

The lake was largely unsuited to insects and these comprised only 20% of the fauna. Three salt-tolerant species of diptera (Dolichopodidae sp, *Tanytarsis barbitarsus* sp and *Procladius paludicola*) and a beetle (Carabidae sp.), which is likely to be only semi-aquatic, were collected.

In ordination space (Fig. 37), Lake Altham is distinctive from the marker wetlands but falls closest to the other saline wetlands (Parkeyerring and Campion).

TABLE 14
Invertebrate species collected from Lake Altham in the 1998 sampling year.

TAXA	1998	TAXA	1998
Nematoda	✓	*Diacypris* sp.	✓
ANOSTRACA		*Platycypris baueri*	✓
Parartemia longicaudata	✓	COPEPODA	
CLADOCERA		*Calamoecia clitellata*	✓
Alona sp.	✓	*Meridiecyclops baylyi*	✓
Alonella sp.	✓	COLEOPTERA	
Daphniopsis sp.	✓	Carabidae	✓
OSTRACODA		DIPTERA	
Australocypris insularis	✓	*Dolichopodidae* sp. A	✓
Diacypris compacta	✓	*Procladius paludicola*	✓
		Paratanytarsus sp. A	✓

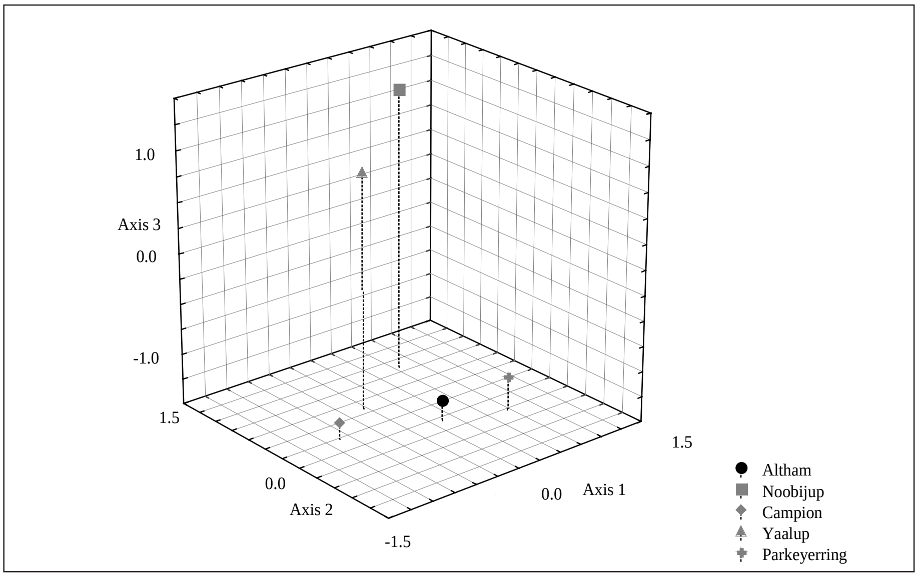

Figure 37. Ordination (SSH) of invertebrate data from Lake Altham in 1998 and four marker wetlands

Noobijup Swamp

Noobijup Swamp (Fig. 38) is located in Noobijup Nature Reserve (Reserve No. 26680) (34° 24'S 116° 46'E) and is part of the Muir-Byenup peat swamp system centred around Lake Muir, 65 km east of Manjimup. The swamp contains freshwater, although it appears to be becoming brackish and deeper. It has short steep banks ending in a flat lake-bed of peat. Ryder (2000) suggested that the lake might be perched, because of the existence of a gley/saprolite layer about 1.5 m below the lake sediments. Storey (1998) reviewed the available hydrological information and reported that Noobijup Swamp is "receiving saline water from seeps and a drain to the W[est] and S[outh]." Excluding interactions with groundwater, the majority of inflow appears to come from these two sources. Run-off from the east side of the lake is intercepted by Noobijup Creek and directed southward past Noobijup Swamp.

Vegetation of the littoral zone overstorey comprises *Melaleuca rhaphiophylla*, *Eucalyptus rudis*, *Banksia littoralis* and *Viminea juncea* over *Lepidosperma longitudinale*, *Baumea juncea*, *B. arthrophylla* and *B. articulata* (Ogden and Froend 1998). The latter two species continue across the lakebed leaving only small (<10%) areas of open water. Vegetation around the saline seep on the western side includes *Calothamnus lateralis*, *M. radula*, *M. viminea*, *Astartea fasicularis* and *Lepidoperma longitudinale*.

A study of the sources and fate of organic matter in Noobijup Swamp determined that the lake was a sink for carbon (Ryder 2000). At the wetland fringe terrestrial leaf litter fall was a major component of peat forming carbon and would be at risk in the case of wild fire. For most of the lake the majority of carbon came from macrophyte beds. These beds of macrophyte were identified as of 'paramount' importance to the ecological function of Noobijup Swamp, as they provide substrates for biofilms and micro flora and fauna crucial to the wetlands food webs (Ryder 2000). Changes to hydroperiod or water depth could alter the distribution or cause the loss of these macrophytes and result in changes to the ecological functioning of the wetland.

Noobijup Swamp was included in the monitoring program because it had a rich and intact invertebrate fauna, was a good example of a freshwater peat swamp and was in a listed Biodiversity Recovery Catchment (Muir-Byenup). More recently the area has been listed as a Ramsar wetland (Department of Conservation and Land Management 1990). As a result of management action, it is expected that conditions in the wetland will remain stable or improve.

Water chemistry and physico-chemical parameters

Physico-chemical parameters were monitored in 1998 and 2000. Water levels varied between 0.5 m and 1.4 m, although the lake may have become shallower in autumn 1999 when no depth measurement was taken (Fig. 39). Conductivity values indicated that the lake was marginally fresh (1865–5760 µS/cm). The pattern of cation dominance was Na>Mg>Ca>K and Cl was the dominant anion. In spring 1998, a distinct difference in salinity was observed between southern (1865 µS/cm) and northern (3800 µS/cm) ends of the lake. While the cause of the gradient was not identified, it is likely fresh water was seeping into the lake from the south and a salinity gradient became established because dense vegetation across the swamp limited the amount of mixing. This interpretation is at odds with Storey (1998), however.

Figure 38. Noobijup Swamp lies within the Muir-Byenup peat swamp system and may be under threat from increasing water depth and salinity.

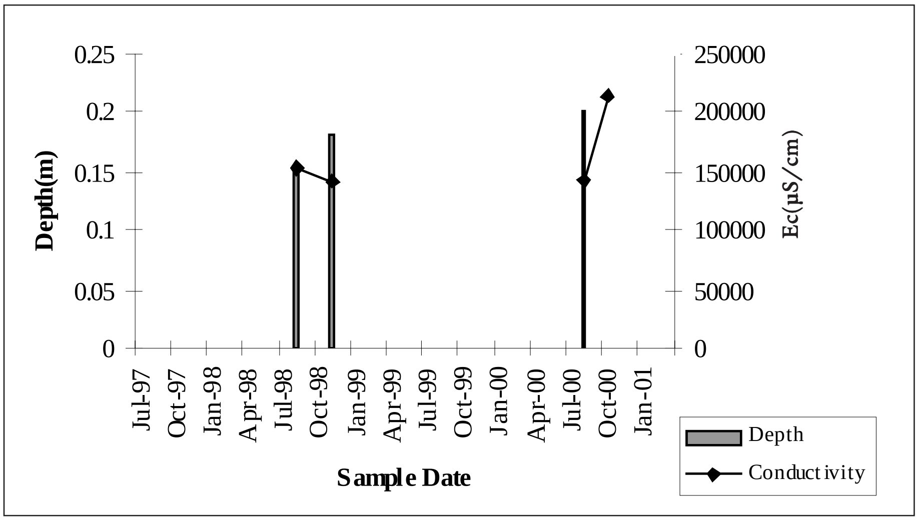

Figure 39. Gauged depth and electrical conductivity at Noobijup Swamp for the 1998 and 2000 sampling years. No depth measurement in April 1999.

Concentrations of Total nitrogen were moderate (740–2400 µg/l) but Total phosphorus concentrations were near detection limits (5 µg/l) throughout the study and appeared to limit algal production with total chlorophyll concentrations not exceeding 10 µg/l. Dissolved oxygen concentrations were less than saturated, probably reflecting a combination of low algal productivity and the high biological oxygen demand (BOD) of decomposing plant material in the lake-bed.

Groundwater

Bores were installed on all five vegetation transects. Monitoring commenced in January 2000. Depth to groundwater was greatest in autumn and least in winter (Fig. 40). Transects one and two are removed from the main waterbody and were underwater in August 2000. Groundwater was more saline (10 600 to 26 600 µS/cm) than lake water except in the case of bore T2/2 in December 2000, immediately after it had been flooded by lake water. Groundwater salinity was similar across all monitoring bores except at transect one where it was marginally higher.

Waterbirds

Thirteen waterbird species were recorded during monitoring, many of which are typical of reed swamps including the Purple Swamphen, Clamorous Reed Warbler, Musk Duck, Spotless Crake and Little Bittern (Table 15). Species richness was generally low with the greatest number of species (7) being recorded in February 2001 (Fig.41). All species occurred in low numbers and total waterbird counts for the swamp ranged from 20 to 49 birds, with Musk Duck and Purple Swamphen the most abundant species. In 1998, only the Musk Duck and Purple Swamphen were seen in all surveys; in 2000, these two species and the Swamp Harrier and Clamorous Reed Warbler were recorded in all surveys. The remaining taxa were recorded infrequently.

The waterbird community at Noobijup strongly reflected the sedge-swamp nature of the wetland and consequently, in the ordination, samples lay close to Lake Pleasant View (another sedge swamp) and were separated from other wetlands (Fig. 42). Low species richness at Noobijup increased the relative importance of changes in assemblages between years in the ordination; in fact, the assemblages were more stable than the ordination suggests.

Invertebrates

A total of 102 invertebrate species were recorded during monitoring in 1998 (Table 16). Fifty-four macroinvertebrate species were collected, compared with 44 collected by Storey (1998), who sampled in October 1996, and January and May 1997. Invertebrate abundances were low, in contrast to the high diversity observed, with only six species (*Calamoecia attenuata*, *Macrocyclops albidus*, *Dicrotendipes* sp. A, *Tanytarsus bispinosus*, *Paralimnophyes pullulus* and Oribatidae) represented by more than 100 individuals. The diverse rotifer fauna included new species belonging to the genera *Monomata* and *Lecane* (RJ Shiel[1], personal communication). The dominant crustaceans were Ostracoda and Cladocera and all species present are typical of fresh waters (eg *Candonopsis tenuis*, *Gomphodella* aff *maia* and *Paralimnocythere* sp. 262). Amongst the insects, beetles (nine species) and chironomids (eight species) were most diverse.

With high species richness, including a large suite of microcrustacean species with a preference for fresh to brackish water, community structure is distinctive at Noobijup Swamp (Fig. 43) and it was used in this study as a marker wetland typical of fresh sedge swamps. Noobijup Swamp had similar community structure to the other sedge swamps in the monitoring program (see Kulicup Swamp Fig. 66, Goonaping Swamp Fig. 76 and Lake Pleasant View Fig. 130).

[1] *R.J. Shiel, Department of Environmental Biology, The University of Adelaide, S.A.*

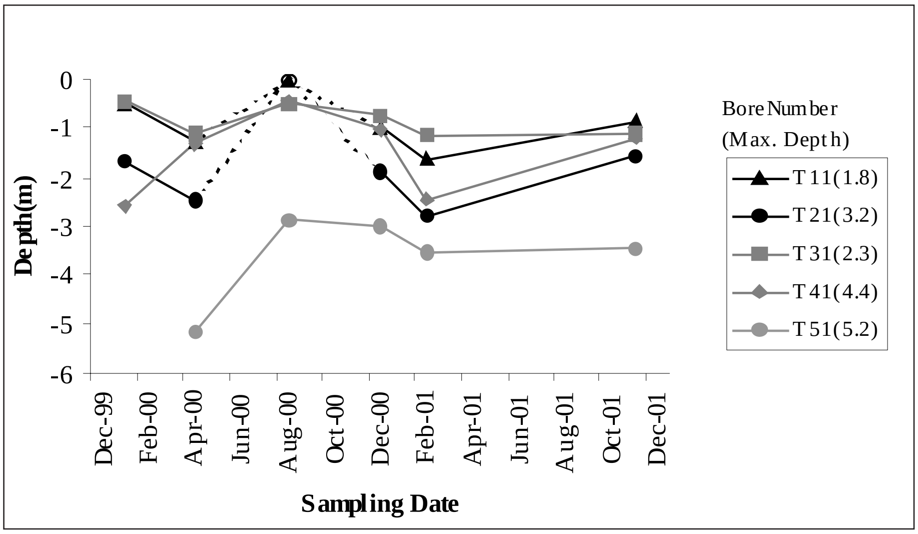

Figure 40. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Noobijup Swamp. Legend values in parenthesis are depth of the bore in metres. Bores T11 and T21 were underwater in August 2000 (Open symbols).

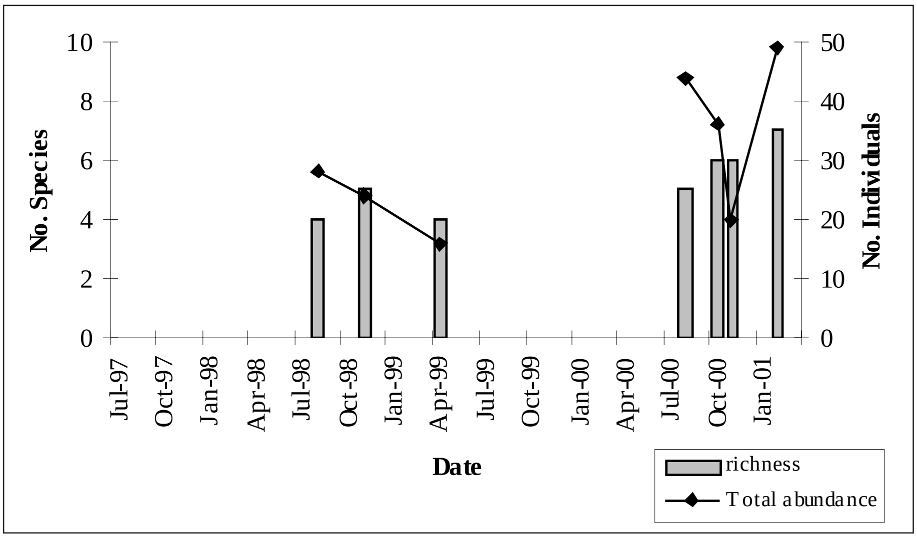

Figure 41. Waterbird species richness and abundance at Noobijup Swamp.

TABLE 15
Waterbird species and their abundance on seven sampling occasions at Noobijup Swamp.Oct-00 and Nov-00 surveys were only 3 weeks apart; only the Nov-00 survey was used in analyses.

	SAMPLING DATA						
	AUG-98	NOV-98	APR-99	AUG-00	OCT-00	NOV-00	FEB-01
Australian Shelduck	0	0	0	2	0	0	0
Black Swan	0	0	0	0	3	2	0
Clamorous Reed-Warbler	0	9	0	6	8	5	8
Darter	0	1	0	0	0	0	0
Little Bittern	0	3	0	0	0	0	0
Little Grassbird	0	0	0	0	2	0	0
Little Pied Cormorant	1	0	1	0	0	0	5
Musk Duck	13	5	6	20	11	3	7
Pacific Black Duck	3	0	0	0	0	2	13
Purple Swamphen	11	6	7	15	10	7	7
Spotless Crake	0	0	0	0	0	0	6
Swamp Harrier	0	0	0	1	2	1	0
White-faced Heron	0	0	2	0	0	0	3

TABLE 16
Invertebrate species collected from Noobijup Swamp in the 1998 sampling year.

TAXA	1998
Spongillidae	✓
Nematoda	✓
Tardigrada	✓
ROTIFERA	
Philodinidae	✓
Testudinella sp.	✓
Lophocharis sp.	✓
Keratella procurva	✓
Platyias quadricornis	✓
Euchlanis sp.	✓
Lecane bulla	✓
Lecane closterocerca	✓
Lecane flexilis	✓
Lecane hamata	✓
Lecane ludwigii	✓
Lecane lunaris	✓
Lecane quadridentata	✓
Lecane sp.	✓
Lindiidae	✓
Cephalodella sp.	✓
Monommata sp.	✓
Monommata sp. A	✓
Trichocerca elongata	✓
Trichocerca longiseta	✓
Trichocerca rattus	✓
Trichotriidae	✓
Trichotria cf. *pocillum*	✓
GASTROPODA	
Ferrissia petterdi	✓
Glyptophysa cf. *gibbosa*	✓
OLIGOCHAETA	
Insulodrilus bifidus	✓
Tubificidae	✓
Dero furcata	✓
Pristina longiseta	✓
Enchytraeidae	✓
ACARINA	
Limnochares australica	✓
Diplodontus sp.	✓
Oxus sp. 1	✓
Arrenurus sp.	✓
Pezidae	✓
Oribatida	✓
Mesostigmata	✓
Trombidioidea	✓
CLADOCERA	
Alona macrocopa	✓
Alonella sp.	✓
Camptocercus sp.	✓
Chydorus sp.	✓
Graptoleberis sp.	✓
Ceriodaphnia sp.	✓
Scapholeberis cf. *kingi*	✓
Ilyocryptus sp.	✓
OSTRACODA	
Gomphodella aff. *maia*	✓
Paralimnocythere sp. 262	✓
Candonopsis tenuis	✓
Alboa worooa	✓
Cypretta baylyi	✓
Cypretta sp. 587	✓
Ilyodromus amplicolis	✓
Newnhamia sp. FC	✓
COPEPODA	
Calamoecia attenuata	✓
Calamoecia tasmanica subattenuata	✓
Metacyclops sp. 4	✓
Macrocyclops albidus	✓
Mesocyclops brooksi	✓
Paracyclops sp 1 (nr *timmsi*)	✓
Canthocamptid nsp 5	✓
Nitocra reducta	✓
Harpacticoida	✓
AMPHIPODA	
Perthia branchialis	✓
COLEOPTERA	
Allodessus bistrigatus	✓
Sternopriscus browni	✓
Megaporus solidus	✓
Lancetes lanceolatus	✓
Spencerhydrus pulchellus	✓
Helochares tenuirostris	✓
Paracymus pygmaeus	✓
Ochthebius sp.	✓
Scirtidae sp.	✓
DIPTERA	
Tipulidae	✓
Bezzia sp. 2	✓
Dolichopodidae sp. A	✓
Ephydridae	✓
Paramerina levidensis	✓
Corynoneura sp.	✓
Paralimnophyes pullulus	✓
Gymnometriocnemus sp.	✓
Tanytarsus nr *bispinosus*	✓
Chironomus aff. *alternans*	✓
Dicrotendipes sp. A (D. Edwards V47)	✓
Parachironomus sp. 1	✓
EPHEMEROPTERA	
Cloeon sp.	✓
HEMIPTERA	
Mesoveliidae	✓
Microvelia sp.	✓
Saldidae	✓
Diaprepocoris barycephala	✓
Anisops sp.	✓
LEPIDOPTERA	
Lepidoptera sp. 3	✓
ODONATA	
Austroagrion coeruleum	✓
Procordulia affinis	✓
TRICHOPTERA	
Acritoptila globosa	✓
Hellyethira litua	✓
Ecnomus pansus/turgidus	✓
Lectrides sp. AV1	✓
Triplectides niveipennis	✓

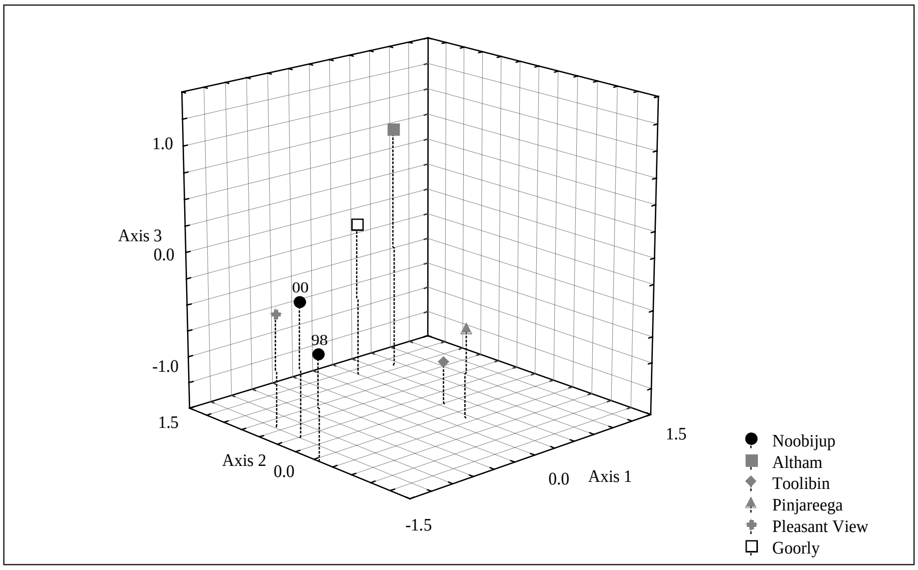

Figure 42. Ordination (SSH) of waterbird species data, showing Noobijup Swamp from 1998 and 2000 and the five marker wetlands.

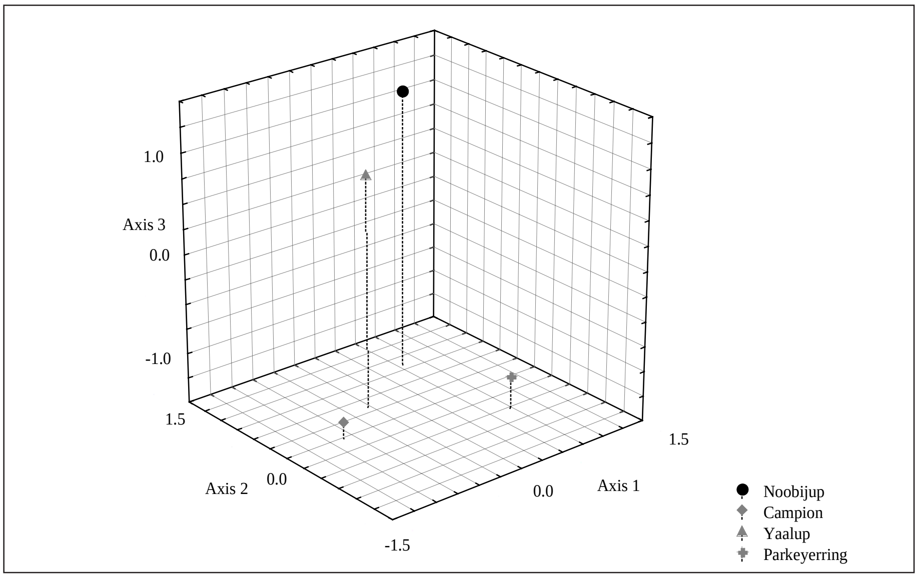

Figure 43. Ordination (SSH) of invertebrate data, showing Noobijup Swamp in 1998 and three marker wetlands.

Bennett's Lake

Bennetts Lake (Fig. 44) lies within the Dunn Rock Nature Reserve (Reserve No. 36445) (33° 17'S 119° 36'E) at the southern end of Lake King. Two drainage lines empty into Bennett's Lake; the southern channel drains a well-vegetated catchment within the nature reserve. The upper half of the catchment of the eastern channel is cleared. Bennett's Lake overflows during floods and empties into Lake Ronnerup to the north. When fully flooded (depth *ca.* 2 m), a series of channels form on the eastern side of the lake as several parallel dune swales fill. The lake area is approximately 58 ha and the area of the southern and eastern catchments 12 000 ha and 2000 ha, respectively (Watkins and McNee 1987). The wetland vegetation of Bennett's Lake has been described elsewhere (Watkins and McNee 1987; Gurner *et al.* 2000). The lake bank supports a closed low woodland of *Melaleuca strobophylla*, *M. hamulosa* and *M. halmaturorum* over an understorey dominated by *Sarcocornia* and *Halosarcia*. Further upslope, and on dune crests to the east, there is an open woodland of *Eucalyptus occidentalis* and *M. hamulosa*.

Bennett's Lake was selected for monitoring as a primarily saline lake with intact vegetation and some historical invertebrate, waterbird and salinity data.

Water chemistry and physico-chemical parameters

Bennett's Lake was monitored in 1998 and 2000. In 1998, the lake was almost dry and salinity levels were very high (216 000 µS/cm) by autumn (Fig. 45). The lake filled as a result of record summer rains in January 2000 and again in March 2000 (Bureau of Meteorology 2000a; Bureau of Meteorology 2000b). Water levels remained high (*ca.* 2.5 m) in August 2000, and lake water was brackish (8400 µS/cm). Despite the variability of lake salinity, the pattern of cationic dominance remained constant with Na>Mg>K>Ca. Nutrient levels were generally low (Total nitrogen <1200 µg/l Total phosphorus <30 µg/l) although concentrations increased dramatically in April 1999 due to evapo-concentration. Total chlorophyll concentration (44 µg/l) also peaked in April 1999 as nutrients were concentrated and again, in November 2000, at high water levels.

Groundwater

Some monitoring bores were installed on both vegetation transects in May 2000. However, high water levels in 2000 and further flooding in 2001 have prevented satisfactory monitoring (Fig. 46). Despite high water levels bore T11 was dry in April 2001 and August 2001. Groundwater conductivity ranged from 4610–6000 µS/cm during the 2000 sampling year and was therefore less saline than surface waters. The threat of groundwater induced secondary salinisation at Bennett's Lake in the short term appears less significant than the threat of increased surface water.

Waterbirds

A total of 24 species of waterbird were recorded during monitoring, with 16 species recorded each year (Table 17). Watkins and McNee (1987) recorded 12 species in two surveys in December 1986. Jaensch *et al.* (1988) reported seven species from three surveys in 1987. During monitoring 11 species were recorded on only one occasion, with several shorebird species (Red-necked Stint, Red-kneed Dotterel, Sharp-tailed Sandpiper, Common

Figure 44. Bennett's Lake is a naturally saline wetland. Depicted here at low water levels, the lake may fill to several metres depth and flood adjacent dune swales.

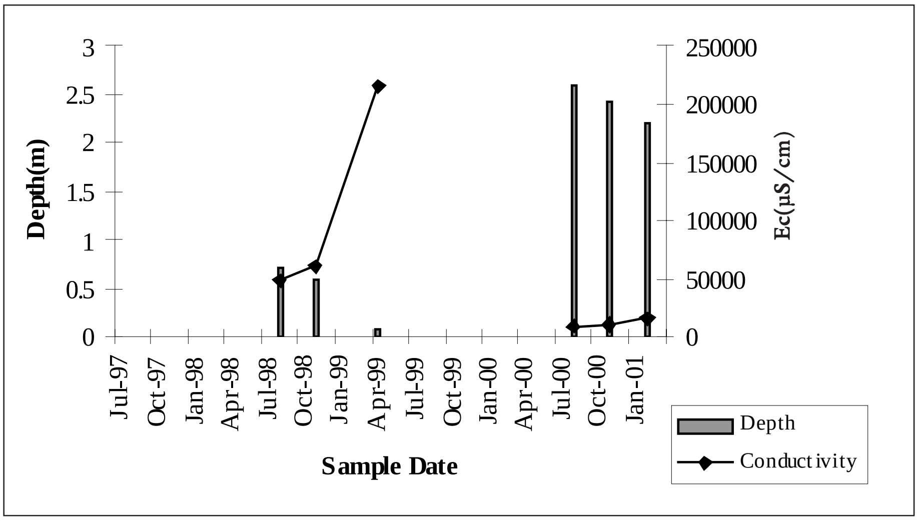

Figure 45. Gauged depth and electrical conductivity at Bennett's Lake for 1998 and 2000 sampling years.

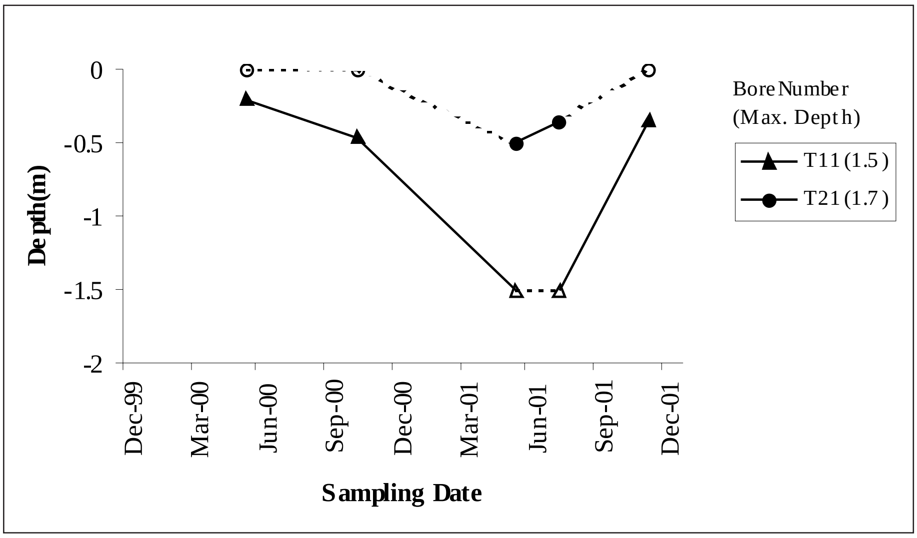

Figure 46. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Bennett's Lake. Open symbols represent dry bores or bores underwater. Legend values in parenthesis are depth of the bore in metres.

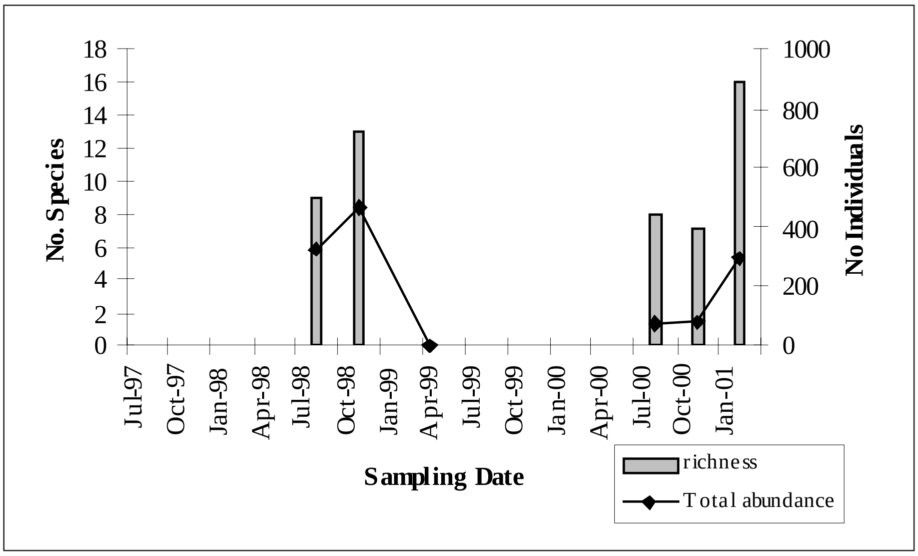

Figure 47. Waterbird species richness and abundance at Bennett's Lake for 1998 and 2000.

Greenshank and Hooded Plover) seen only prior to lake filling, when extensive areas of shallows were present (Table 17). Waterbird abundance was higher in 1998 than in 2000 and species richness varied between surveys (Fig. 47).

Ordination of the 1998 and 2000 assemblages reflected the differences in salinity and depth between years, with both years reflecting different ecological communities that could not be easily characterised in relation to the marker wetlands (Fig. 48).

Invertebrates

A total of 19 species of aquatic invertebrate were collected in spring 1998 (Table 18). Crustaceans (nine species) and insects (eight species) displayed similar levels of diversity. Amongst crustaceans, the ostracods were most diverse represented by four salt-tolerant species. Insects present were typically salt-tolerant species of wide distribution (e.g. *Berosus* sp. and *Necterosoma penicillatus*). Watkins and McNee (1987) recorded 15 species of invertebrates from a single December sample. These samples differed in season of collection and sampling effort, but showed some similarity of species with those collected during monitoring.

In ordination space, the combination of low species richness and salt-tolerant species caused Bennett's Lake to lie closest to the saline marker wetlands Campion and Parkeyerring (Fig. 49).

TABLE 17
Waterbird species and their abundance on six sampling occasions at Bennett's Lake.

	SAMPLING DATE					
	AUG-97	NOV-98	APR-99	AUG-00	NOV-00	FEB-01
Australasian Grebe	0	0	0	0	0	8
Australasian Shoveler	1	0	0	0	0	4
Australian Shelduck	27	239	0	4	1	3
Australian White Ibis	0	0	0	0	0	2
Australian Wood Duck	0	0	0	0	0	12
Black Swan	63	3	0	0	0	1
Blue-billed Duck	0	0	0	15	8	5
Chestnut Teal	0	1	0	0	0	0
Common Greenshank	0	5	0	0	0	0
Eurasian Coot	66	0	0	31	9	39
Grey Teal	103	95	0	12	2	24
Hardhead	1	2	0	0	0	0
Hoary-headed Grebe	52	22	0	8	56	116
Hooded Plover	0	39	0	0	0	0
Little Pied Cormorant	0	0	0	1	0	17
Musk Duck	0	0	0	5	2	7
Pacific Black Duck	0	2	0	1	0	3
Pink-eared Duck	5	0	0	0	1	48
Red-capped Plover	4	57	0	0	0	0
Red-kneed Dotterel	0	1	0	0	0	0
Red-necked Stint	0	1	0	0	0	0
Sharp-tailed Sandpiper	0	1	0	0	0	0
Unidentified duck	0	0	0	0	0	1
White-faced Heron	0	0	0	0	0	4

TABLE 18
Invertebrate species collected from Bennett's Lake in the 1998 sampling year.

TAXA	1998	TAXA	1998
Nematoda	✓	AMPHIPODA	
ROTIFERA		*Austrochiltonia subtenuis*	✓
Hexarthra fennica	✓	COLEOPTERA	
CLACOCERA		*Necterosoma penicillatus*	✓
Daphniopsis sp.	✓	*Necterosoma* sp.	✓
OSTRACODA		*Berosus* sp.	✓
Australocypris insularis	✓	DIPTERA	
Diacypris compacta	✓	*Culicoides* sp.	✓
Mytilocypris tasmanica chapmani	✓	Stratiomyidae	✓
Platycypris baueri	✓	*Procladius paludicola*	✓
COPEPODA		*Cladopelma curtivalva*	✓
Calamoecia clitellata	✓	HEMIPTERA	
Apocyclops dengizicus	✓	*Saldula* sp.	✓
Nitocra reducta	✓		

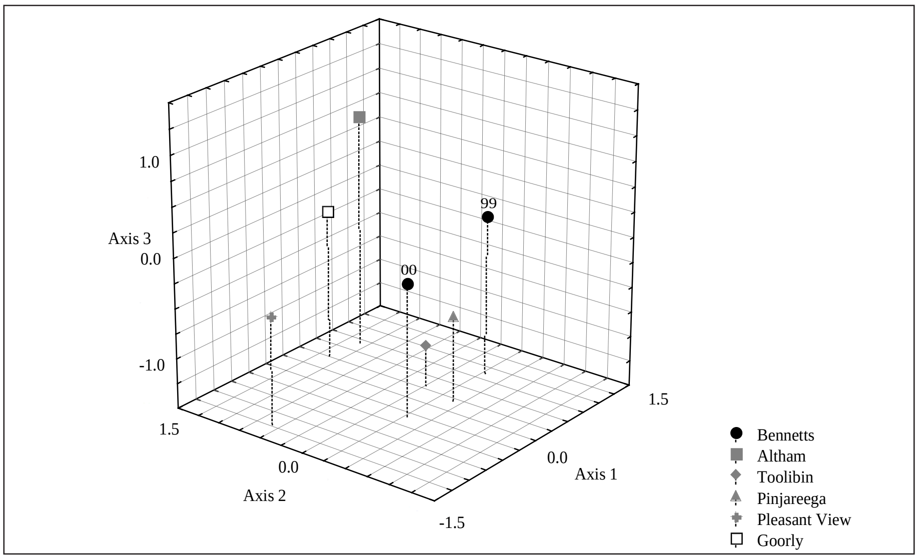

Figure 48. Ordination (SSH) of waterbird species data, showing Bennett's Lake from 1998 and 2000, and the five marker wetlands.

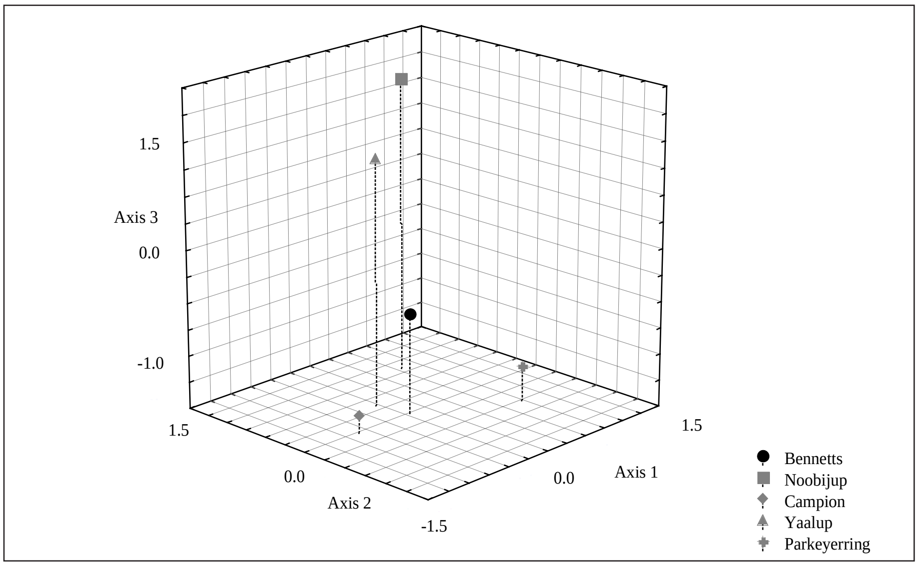

Figure 49. Ordination of invertebrate species presence/absence at Bennett's Lake

Ardath Lake

Lake Ardath (Fig. 50) is 25km south of Bruce Rock (32° 05'S 118° 09'E) and is a small naturally saline wetland situated at the edge of a braided, valley floor drainage channel. It has a maximum depth of approximately 1 m. The lake fills from an inflow channel on the south-western side that directs water out of the braided channel, which flows north and includes many other saline wetlands. Ardath Lake is used for recreational skiing when water levels are sufficiently high and earthworks have been built on the north-west side of the water-body to retain water in the lake. Increased inundation has resulted in some degradation of the riparian vegetation. On the northern side of the lake, the original vegetation was principally an overstorey of *Casuarina obesa* with an understorey of *Melaleuca thyoides* and *M. lateriflora* and *Halosarcia* sp. The eastern side has more terrestrial vegetation dominated by *Eucalyptus yilgarnensis*. The south-western section has been severely salt-affected, with most trees and shrubs now dead, leaving *Halosarcia* sp. as dominant vegetation (Gurner *et al.* 1999).

Ardath Lake was selected as a monitoring site because it was naturally saline and supported an intact aquatic invertebrate community.

Water chemistry and physico-chemical parameters

A surveyed depth gauge was not installed at Lake Ardath until April 2000, so depth was estimated in 1998 and 2000 and values may be misleading (Fig. 51). Conductivity values showed that lake-water was hypersaline, ranging between 32 300 µS/cm in autumn 1999 and 224 000 µS/cm in autumn 2000, as the lake dried. Cation dominance was Na>Mg>Ca>K and Cl was the dominant anion. Alkalinity was low, with bicarbonate <1 mg/l, and pH ranged between 2.5 and 4.0. In all surveys, lake water was clear and the lake-bed clearly visible; this was reflected by low turbidity, colour and chlorophyll

Figure 50. Lake Ardath is a small naturally saline wetland with some secondary salinisation from groundwater and surface inflow.

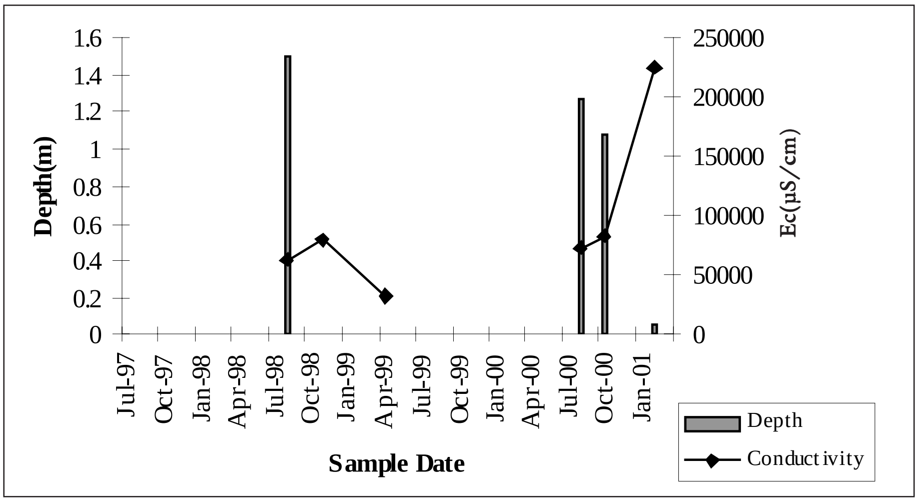

Figure 51. Gauged depth and electrical conductivity at Lake Ardath

concentrations. Total phosphorus concentrations were also low (*ca.* 5 µg/l) except in autumn 2000 (20 µg/l) at low lake depths.

Groundwater

Monitoring bores were installed on both vegetation transects at Lake Ardath and data collection commenced in December 1999. Groundwater was shallow at some bores and appeared to be connected to the lake (Fig. 52). Groundwater was slightly more saline than lakewater and highly acidic (pH mostly between 3.0 and 3.5).

Waterbirds

Waterbirds were monitored in 1998 and 2000. Six species were recorded, with a maximum of 18 individuals at any one time (Table 19, Fig. 53). Ardath Lake was not an important waterbird site and is unlikely to ever be so because of its small size and high salinities. The waterbird assemblages in 1998 and 2000 were reasonably close in ordination space and distinct from any of the marker wetlands, separating from Altham (another saline lake) on both axis 1 and 2 (Fig. 54). Ardath has lower waterbird value than any of the markers.

Invertebrates

A total of 16 species were recorded during monitoring in spring 1998 (Table 20). While the invertebrate assemblage was not species-rich, it was significant because it contained a new species of calanoid copepod *Calamoecia trilobata* (Halse *et al.* 2002). The ostracod *Retycypris* sp. 566 is likely to be a new species, as is the rotifer *Ptygura* cf *melicerata* which was collected from Ardath prior to monitoring (A. Pinder[2], personal communication). Not withstanding these new taxa, the community included a core of typical salt-tolerant species, which in combination with low species richness caused Ardath to be moderately close in ordination space to the saline marker wetland, Parkeyerring (Fig. 55).

2. A. Pinder, Department of Conservation and Land Management, Woodvale, W.A.

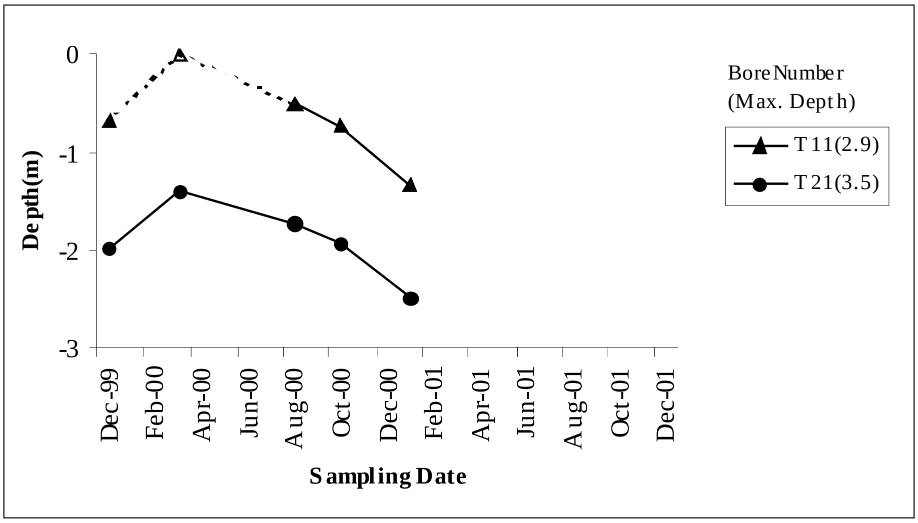

Figure 52. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Ardath Lake. Open symbols represent bores underwater. Legend values in parenthesis are depth of the bore in metres.

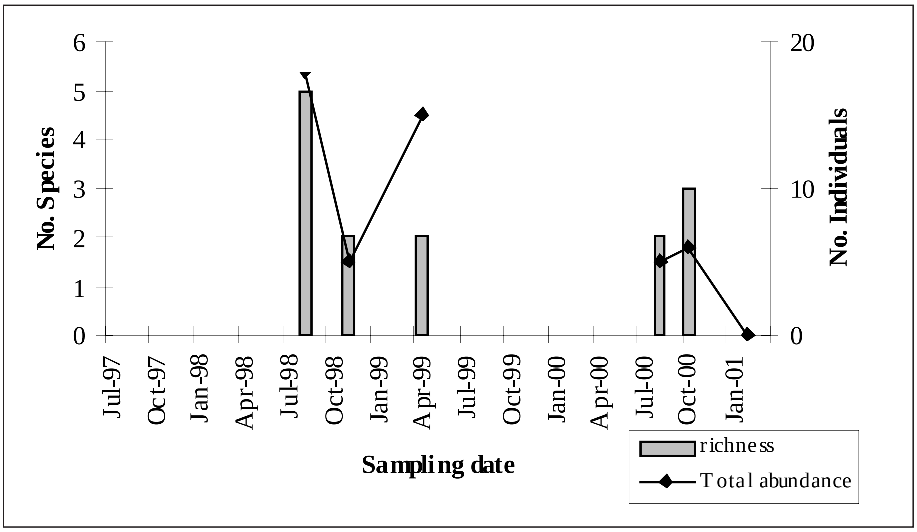

Figure 53. Waterbird species richness and abundance at Lake Ardath.

TABLE 19
Waterbird species and their abundance on six sampling occasions at Lake Ardath.

	SAMPLING DATE					
	AUG-98	NOV-98	APR-99	AUG-00	OCT-00	FEB-01
Australian Shelduck	2	0	2	0	4	0
Black-tailed Native-hen	3	0	0	0	0	0
Black-winged Stilt	7	0	0	0	0	0
Grey Teal	5	1	13	4	1	0
Hoary-headed Grebe	1	4	0	0	1	0
White-faced Heron	0	0	0	1	0	0

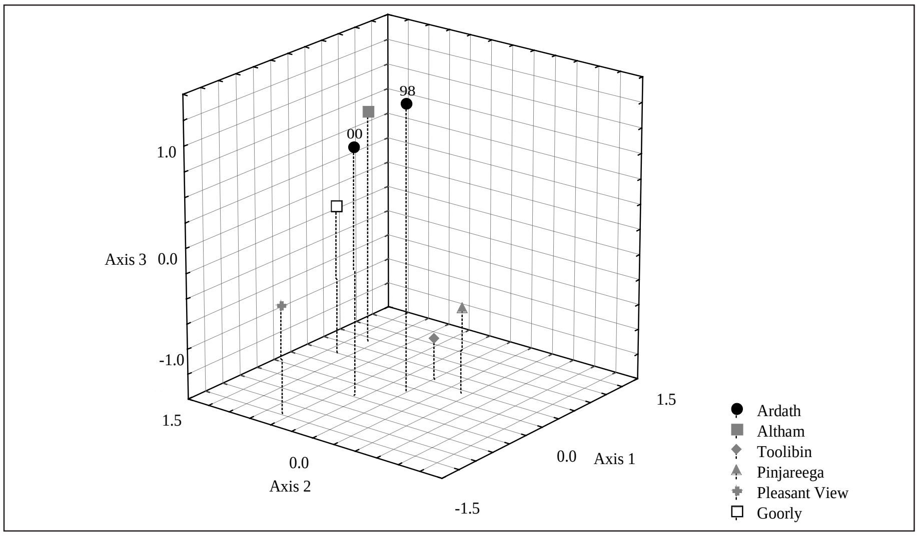

Figure 54. Ordination (SSH) of waterbird species data, showing Lake Ardath from 1999 and 2000, and the five marker wetlands.

TABLE 20
Invertebrate species collected from Ardath lake in the 1998 sampling year.

TAXA	1998	TAXA	1998
Turbellaria	✓	*Diacypris dictyote*	✓
ROTIFERA		*Mytilocypris tasmanica chapmani*	✓
Hexarthra intermedia	✓	*Reticypris* sp. nov. 556	✓
GASTROPODA		COPEPODA	
Coxiella (*Coxiellada*) *gilesi*	✓	*Calamoecia trilobata*	✓
ACARINA		COLEOPTERA	
Oribatida	✓	*Necterosoma penicillatus*	✓
ANOSTRACA		*Berosus munitipennis*	✓
Parartemia serventii	✓	Limnichidae	✓
OSTRACODA		DIPTERA	
Australocypris insularis	✓	*Culicoides* sp.	✓
		Muscidae sp. A	✓
		Orthocladiinae S03	✓

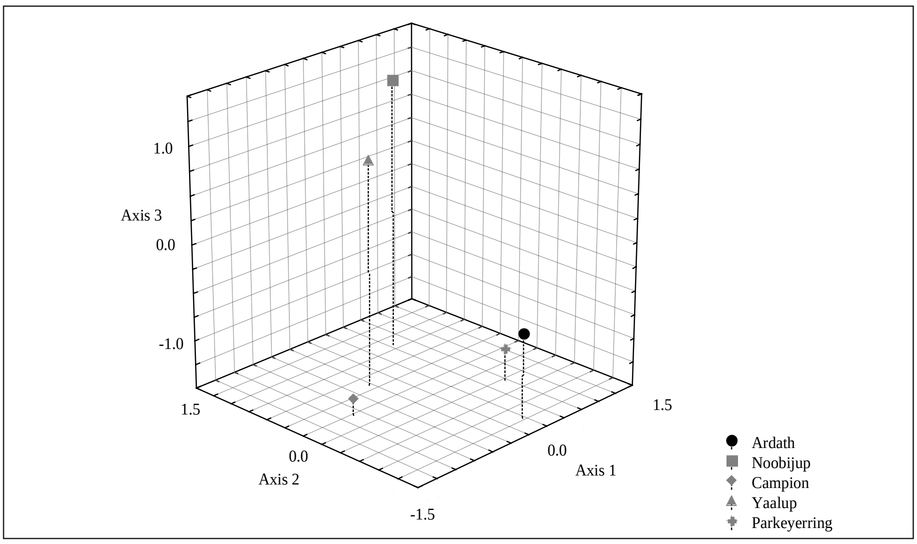

Figure 55. Ordination of invertebrate species presence/absence at Lake Ardath in 1998.

Blue Gum (Lake View) Swamp

Blue Gum Swamp (Fig. 56) is a small seasonal or semi-permanent wetland 10 km north-west of Moora (30° 35'S 115° 58'E) on Lake View Farm. This farm contains many wetlands, including Streets, Racecourse and the long, winding Melaleuca Swamp. The Department of Fisheries and Wildlife (now Conservation and Land Management) banded ducks and studied survival rates and shooting mortality on the Lake View wetlands from 1968 to 1976 (Halse *et al.* 1993a). Until the cessation of public duck hunting in 1992, Lake View Farm was one of the major hunting sites in Western Australia, although participation was by invitation only.

Blue Gum Swamp is surrounded by 40 ha of bushland but most of its local catchment lies in cleared farmland. The swamp is at the south-western end of a long chain of naturally or secondarily saline lakes that extends north to the Yarra Yarra Lakes and includes Lake Eganu, another northern Wheatbelt monitoring wetland. In most years, there is no direct connection between Blue Gum and the chain of salt lakes, which drain into the Moore River, but large flood events result in sheet flow from the Moore River into wetlands in the Lake View complex. Such events may produce a significant proportion of the salt load in Blue Gum Swamp. For example, when the lake dried in 2000, after filling during the 1999 Moore River flood event, salt precipitation was apparent in some lakes in the Lake View complex where it had not been observed in the previous 50 years (J. Cusack[3], personal communication).

Riparian woodland vegetation around Blue Gum is dominated by mature *Eucalyptus rudis* and *Casuarina obesa*, which are replaced downslope by *Melaleuca viminea*, *C. obesa* and *M. strobophylla* (Gurner *et al.* 1999). Blue Gum Swamp was selected for monitoring because it is a wetland where salinization is likely to increase. The Lake View complex is used by a large number of waterbirds in summer and historically supported significant breeding activity. There is some information available on waterbird use of wetlands on Lake View Farm (Jaensch *et al.* 1988) and there is a known history of water depth in Streets Lake (Lane and Munro 1983).

Water chemistry and physico-chemical parameters

Blue Gum Swamp was monitored in 1998 and 2000. The swamp contained water in August 1998 but dried by the end of May 1999 (Fig. 57). The swamp filled during winter 1999 as a result of heavy rain and Moore River flooding. It still contained water in August 2000 but was almost dry by March 2001. Salinity showed a dramatic increase between 1998 and 2000, with spring conductivity values increasing from 5400 µS/cm to 38 200 µS/cm at similar water depths (Fig. 57). Cation dominance fitted the pattern Na>Mg>Ca>K and Cl was the dominant anion.

Nutrient concentrations were dynamic: high concentrations of Total phosphorus (160–360 µg/l) and moderate concentrations of Total nitrogen (2500–4450 µg/l) were recorded in 1998, but phosphorus concentrations were low (5–10 µg/l) in 2000 while nitrogen concentrations remained moderate (1900–6000 µg/l). Despite variable nutrient levels, chlorophyll concentrations were relatively low throughout the monitoring period.

Figure 56. Blue Gum Swamp is a seasonal wetland situated above a chain of salt lakes. The swamp has become more saline recently.

3. J. Cusack, Lake View Farm, Moora,W.A.

Groundwater

Monitoring bores were established on both vegetation transects in February 2000. Depth to groundwater has varied between 0.3 and 1.6 m (Fig. 58). There appears to be a slight salinity gradient beneath the lake with more saline water at the southern end (34 600–47 800 µS/cm) than the north (range 25 700–36 300 µS/cm). The salinity of ground water was several times greater than lake water when Blue Gum was full and rising groundwater poses an imminent threat to the ecology of the wetland.

Waterbirds

A total of 17 species of waterbird were recorded from Blue Gum during monitoring in 1998 and 2000 (Table 21). Species richness was greater in 1998 (16 species) than 2000 (nine species). No species were recorded in March 2001 when the lake was dry. The maximum richness in a single survey (12 species) coincided with maximum abundance (180 individuals) in November 1998 (Fig. 59).

In 1998, waterbird community structure at Blue Gum Swamp (Fig. 60) was similar to that of the brackish marker wetland Pinjareega. With the exception of the Little Pied Cormorant, the fauna present in 2000 was a subset of the species present in 1998, but lower species richness resulted in the two samples showing a moderate separation in ordination space.

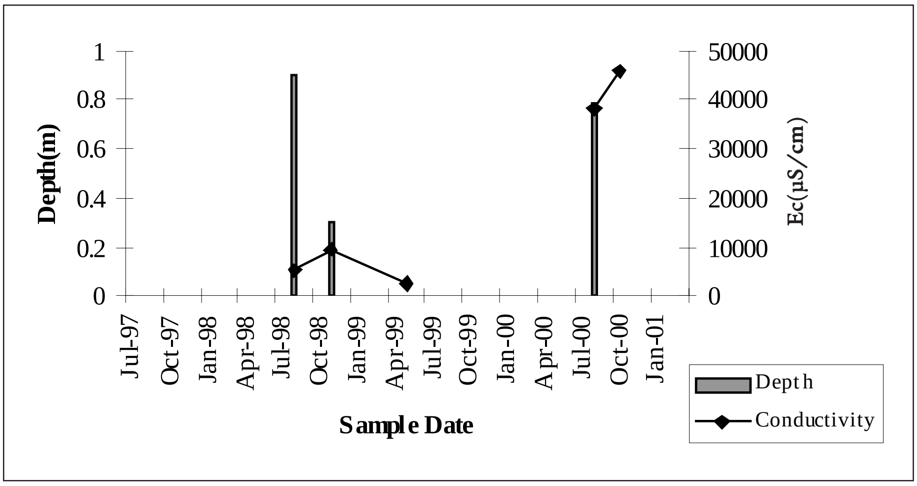

Figure 57. Gauged depth and electrical conductivity at Blue Gum Swamp for 1999 and 2000 sampling years. Depth values are estimates and may be misleading, depths were not recorded in May-99 or Oct-00 and the lake was dry in Mar-01.

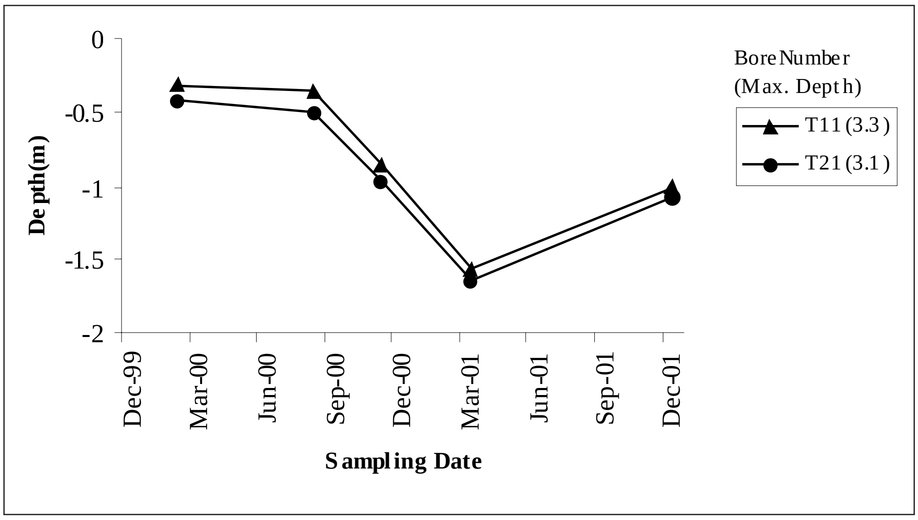

Figure 58. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Blue Gum Swamp. Legend values in parenthesis are depth of the bore in metres.

TABLE 21
Waterbird species and their abundance on five sampling occasions at Blue Gum Swamp.

	SAMPLING DATE				
	AUG-98	NOV-98	MAY-99	AUG00	OCT-00
Australasian Grebe	0	4	2	0	0
Australasian Shoveler	0	0	1	0	0
Australian Shelduck	6	0	4	2	1
Australian Wood Duck	0	2	0	0	0
Black-fronted Dotterel	2	3	0	0	3
Eurasian Coot	10	8	6	0	0
Grey Teal	50	125	22	60	48
Hardhead	0	2	0	0	0
Hoary-headed Grebe	1	14	0	5	6
Little Pied Cormorant	0	0	0	3	0
Musk Duck	0	0	1	0	0
Pacific Black Duck	0	4	5	1	0
Pink-eared Duck	15	12	11	2	0
Red-kneed Dotterel	0	3	0	0	0
Straw-necked Ibis	0	1	0	0	0
White-faced Heron	1	2	0	0	8
Yellow-billed Spoonbill	2	0	0	1	0

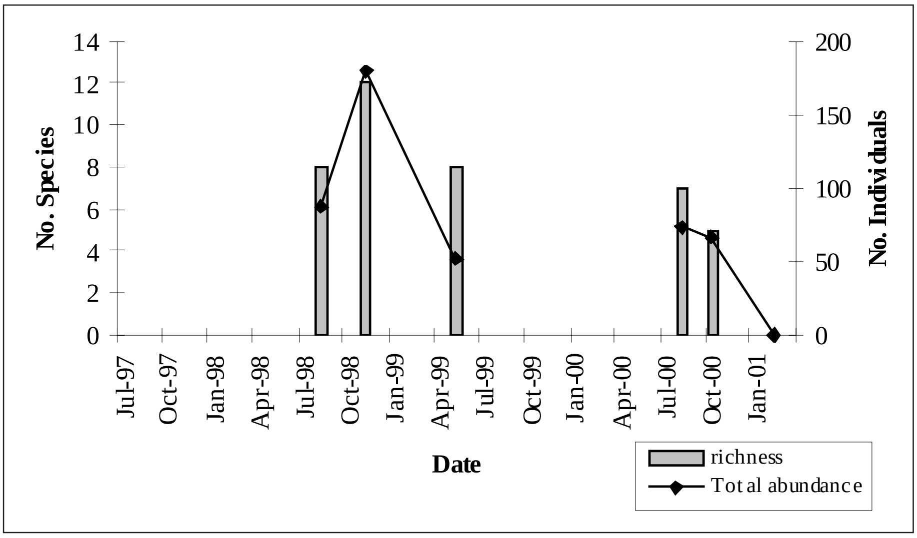

Figure 59. Waterbird species richness and abundance at Blue Gum Swamp.

Invertebrates

Invertebrates were sampled in November 1998, when a rich fauna comprising 80 species was collected (Table 22). Fifty-eight per cent of these were insects including Coleoptera (18 species), Diptera (14 species) and Hemiptera (six species). Odonata were represented by five species in low abundance and three ubiquitous species of Trichoptera were collected.

While crustaceans comprised only 30% of species present, they were numerically dominant with the copepods *Boeckella triarticulata* and *Calamoecia ampulla* collected in 100 000s and several ostracods collected in 10 000s. The ostracod fauna of the lake consisted of nine species typical of fresh to brackish waters (e.g. *Candonocypris novaezealandiae* and *Bennelongia* spp.) and brackish to saline waters (e.g. *Diacypris spinosa*, *Ilyocypris* sp. nov.). In 1998, the overall invertebrate community was similar to that found at Yaalup Swamp (Fig. 61).

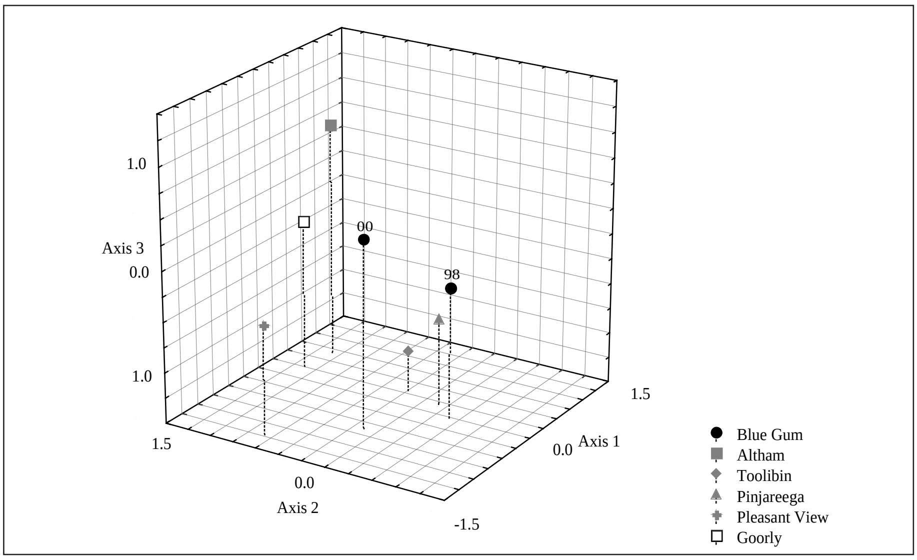

Figure 60. Ordination (SSH) of waterbird species data, showing Blue Gum Swamp from 1998 and 2000 and the five marker wetlands.

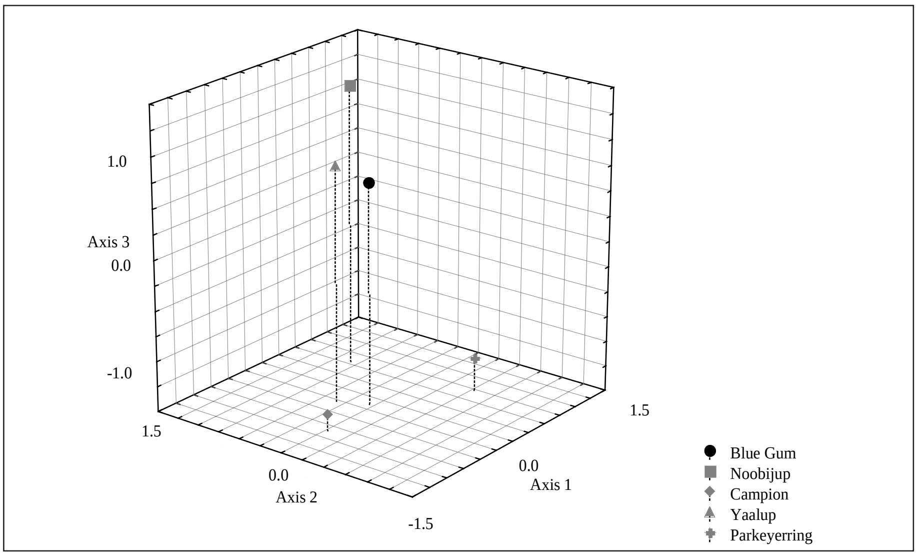

Figure 61. Ordination of invertebrate species presence/absence at Blue Gum Swamp.

TABLE 22
Invertebrate species collected from Blue Gum Swamp in the 1998 sampling year.

TAXA	1998	TAXA	1998
Nematoda	✓	*Liodessus dispar*	✓
ROTIFERA		*Antiporus* sp.	✓
Hexarthra sp.	✓	*Sternopriscus multimaculatus*	✓
Testudinella patina	✓	*Necterosoma penicillatus*	✓
Brachionus rotundiformis	✓	*Megaporus howitti*	✓
Brachionus sp.	✓	*Lancetes lanceolatus*	✓
Lecane sp.	✓	*Berosus macumbensis*	✓
OLIGOCHAETA		*Enochrus elongatus*	✓
Tubificidae	✓	*Enochrus eyrensis*	✓
ACARINA		*Limnoxenus zelandicus*	✓
Acercella falcipes	✓	*Paracymus pygmaeus*	✓
Mesostigmata	✓	*Gymnocthebius* sp. 1	✓
CLADOCERA		*Gymnocthebius* sp. 3	✓
Latonopsis sp.	✓	*Hydrochus australis*	✓
Alona rigidicaudis s.l.	✓	DIPTERA	
Leydigia sp.	✓	*Bezzia* sp. 1	✓
Pleuroxus sp.	✓	*Culicoides* sp.	✓
Daphnia sp.	✓	*Monohelea* sp. 1	✓
Daphniopsis sp.	✓	*Nilobezzia* sp. 1	✓
Macrothrix sp.	✓	Stratiomyidae	✓
OSTRACODA		Ephydridae	✓
Ilyocypris spiculata	✓	*Procladius paludicola*	✓
Alboa worooa	✓	*Procladius villosimanus*	✓
Bennelongia australis	✓	*Paramerina levidensis*	✓
Bennelongia barangaroo	✓	*Tanytarsus* nr *bispinosus*	✓
Candonocypris novaezelandiae	✓	*Chironomus* aff. *alternans*	✓
Diacypris spinosa	✓	*Dicrotendipes conjunctus*	✓
Ilyodromus candonites	✓	*Polypedilum nubifer*	✓
Cypericercus salinus	✓	*Cryptochironomus griseidorsum*	✓
Sarscypridopsis aculeata	✓	EPHEMEROPTERA	
COPEPODA		*Tasmanocoenis tillyardi*	✓
Boeckella triarticulata	✓	HEMIPTERA	
Calamoecia ampulla	✓	*Sigara mullaka*	✓
Calamoecia sp. 342 (*ampulla* variant)	✓	*Agraptocorixa eurynome*	✓
Metacyclops sp.	✓	*Agraptocorixa parvipunctata*	✓
Metacyclops sp. 442 (*salinarum* in Morton)	✓	*Micronecta robusta*	✓
Mesocyclops brooksi	✓	*Anisops thienemanni*	✓
Apocyclops dengizicus	✓	*Anisops baylii*	✓
AMPHIPODA		ODONATA	
Austrochiltonia subtenuis	✓	*Xanthagrion erythroneurum*	✓
COLEOPTERA		*Austrolestes annulosus*	✓
Haliplus sp.	✓	*Austrolestes aridus*	✓
Hyphydrus sp.	✓	*Orthetrum caledonicum*	✓
Allodessus bistrigatus	✓	*Hemicordulia tau*	✓
Liodessus inornatus	✓	TRICHOPTERA	
		Ecnomus pansus/turgidus	✓
		Oecetis sp.	✓
		Triplectides australis	✓

Kulicup Swamp

A small reed swamp of approximately 24.5 ha, Kulicup Swamp (Fig. 62) is situated in Kulicup Nature Reserve (Res. No. 18239) at the old Kulicup Rail Siding 30 km east of Boyup Brook (33^o 49'S 116^o 40'E). The lake fills seasonally and is fresh though shallow (*ca.* 20cm).

Ogden and Froend (1998) describe the vegetation around the edge of the wetland as a woodland of *Melaleuca cuticularis* over *Baumea* sp. and *B. juncea*. The lake basin is completely covered with *B. articulata*. Upslope the reserve supports a woodland dominated by *Eucalyptus wandoo* and *E. decipiens*.

Lake Kulicup was included in the monitoring program as an example of a fresh wetland with a history of depth and waterbird data collection and no immediate threat of change.

Water chemistry and physico-chemical parameters

Lake Kulicup contained water only in winter and spring in 1998 and 2000, with conductivity values increasing as the lake dried out (Fig. 63). The concentration of cations followed a typical Na>Mg>Ca>K hierarchy and the lake was slightly alkaline with HCO_3 being the major anion. Nutrient and chlorophyll concentrations were relatively low with Total nitrogen ranging from 750–1500 µg/l, Total phosphorus ranging from 10–20 µg/l and chlorophyll ranging from 2–5 µg/l.

Groundwater

Monitoring bores were installed on all four vegetation transects at Lake Kulicup. Hard subsoil and the need for comparatively deep boreholes to intercept groundwater delayed construction. The hydrology of the area is complex, with perched lenses of fresh water above the regional watertable at around 6–7m below local ground level. As a result, depth to groundwater is highly variable between bores on the same transect as well as between transects (C.D. Walker unpublished data), however, during the monitoring period most bores were dry (Fig. 64). The monitoring data suggest Lake Kulicup is under no immediate threat from salinization. Other investigations have indicated that the watertable is over 9 m below the surface and slightly brackish (4 500 µS/cm) (George and McFarlane 1993)

Waterbirds

The waterbird fauna at Lake Kulicup was depauperate with only a single record of two White-faced Heron from six sampling occasions (Fig. 65, Table 23). The lake was excluded from the waterbird ordination analysis because only one species was recorded.

Five species were recorded from five surveys between 1983 and 1984 (Jaensch *et al.* 1988). Abundances were similarly low with a total of only seven individuals recorded (Jaensch *et al.* 1988). It seems likely the lake held more water in the early 1980s but Jaensch *et al.* (1988) do not

Figure 62. Kulicup Swamp is a shallow freshwater reed swamp dominated by Baumea spp. and fringed by Melaleuca cuticularis.

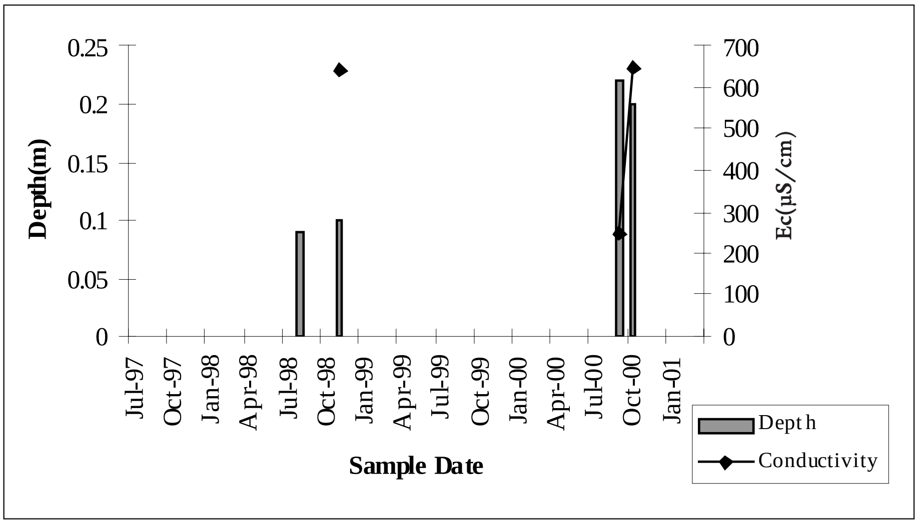

Figure 63. Gauged depth and electrical conductivity at Kulicup Swamp. Conductivity was not measured in Jul-98.

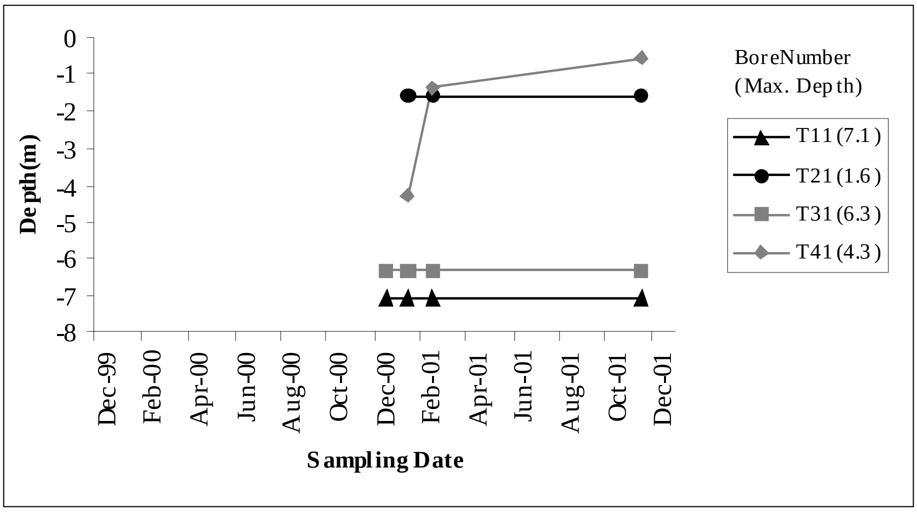

Figure 64. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Kulicup Swamp. Legend values in parenthesis are depth of the bore in metres.

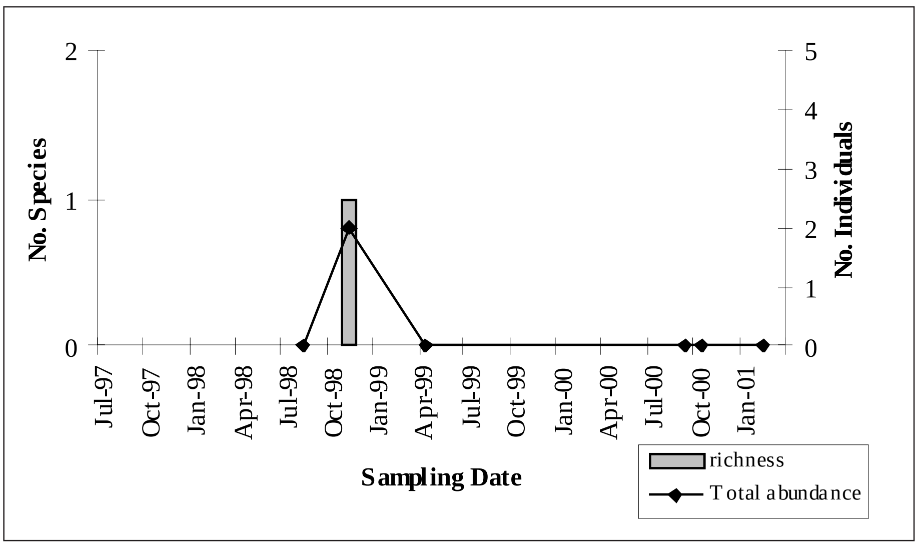

Figure 65. Waterbird species richness and abundance at Kulicup Swamp.

TABLE 23
Waterbird species and their abundance on five sampling occasions at Kulicup Swamp.

	SAMPLING DATE				
	NOV-98	APR-99	SEP-00	OCT-00	FEB-01
White-faced Heron	2	0	0	0	0

give details of water levels. Thick stands of *Baumea* spp. and shallow water made the lake unsuitable to most waterfowl during monitoring. Whilst the lake may superficially appear suitable for various species of crake, bittern and reed-warbler, its annual period of inundation is probably too short.

Invertebrates

Invertebrates were sampled at Lake Kulicup in November 1998 when water depth was about 10 cm and 92 species were collected (Table 24). Insects accounted for 36% of the fauna (34 species), crustaceans 35% (32 species) and rotifers 12% (11 species). Cladocerans were particularly well represented with 16 species present. Given that about 170 species are currently known from Western Australia (Shiel 1995, Russel Shiel and Stuart Halse unpublished data), the Lake Kulicup list represents almost 10% of the State's cladoceran fauna.

The seasonal nature of the lake was reflected by the insect fauna, with large numbers of Coleoptera (15 species) Diptera (12 species) and Hemiptera (five species) collected. Odonata were represented by *Austrolestes analis* only and no Trichoptera were found.

Some aspects of its invertebrate community structure, in particular the diverse cladoceran fauna, make Kulicup quite distinct from other wetlands sampled. However, high species richness and the high diversity of a large number of groups results in Kulicup being similar overall to other sedge swamps (e.g. the marker wetland Noobijup) (Fig. 66).

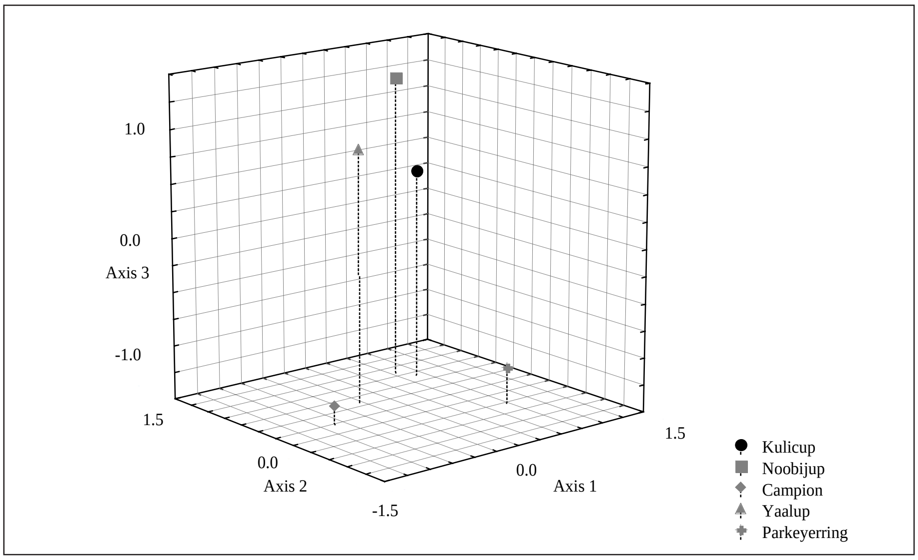

Figure 66. Ordination (SSH) of invertebrate data, showing Kulicup Swamp in 1998 and four marker wetlands.

TABLE 24
Invertebrate species collected from Kulicup Swamp in the 1998 sampling year.

TAXA	1998	TAXA	1998
HYDRAZOA		*Ilyodromus* sp. 255	✓
Hydra sp.	✓	*Newnhamia* sp. 295	✓
PLATYHELMINTHIDAE		COPEPODA	
Zygopella pista	✓	*Boeckella robusta*	✓
Turbellaria	✓	*Calamoecia attenuata*	✓
Nematoda	✓	*Calamoecia tasmanica subattenuata*	✓
Tardigrada	✓	*Microcyclops varicans*	✓
ROTIFERA		*Mesocyclops brooksi*	✓
		Canthocamptus australicus	✓
Macrotrachela sp.	✓	Canthocamptidae sp. 5	✓
Philodinidae	✓	AMPHIPODA	
Flosculariidae	✓		
Keratella procurva	✓	*Austrochiltonia subtenuis*	✓
Platyias quadricornis	✓	DECAPODA	
Euchlanis sp.	✓		
Lecane bulla	✓	*Cherax preissii*	✓
Lecane luna	✓	COLEOPTERA	
Trichocerca rattus	✓		
Trichocerca sp.	✓	*Haliplus fuscatus*	✓
Trichotriidae	✓	*Uvarus pictipes*	✓
GASTROPODA		*Allodessus bistrigatus*	✓
		Liodessus inornatus	✓
Glyptophysa cf. *gibbosa*	✓	*Liodessus dispar*	✓
OLIGOCHAETA		*Antiporus femoralis*	✓
		Sternopriscus multimaculatus	✓
Tubificidae	✓	*Megaporus* sp.	✓
Dero nivea	✓	Bidessini	✓
Pristina longiseta	✓	*Berosus* sp.	✓
Enchytraeidae	✓	*Paracymus pygmaeus*	✓
ACARINA		Hydrophilidae	✓
		Scirtidae sp.	✓
Acercella falcipes	✓	Heteroceridae	✓
Arrenurus sp.	✓	*Hydrochus australis*	✓
Oribatida	✓	DIPTERA	
Mesostigmata	✓		
Trombidioidea	✓	*Anopheles annulipes*	✓
CLADOCERA		*Culicoides* sp.	✓
		Monohelea sp. 1	✓
Diaphanosoma sp.	✓	*Procladius paludicola*	✓
Alona diaphana vermiculata	✓	*Paramerina levidensis*	✓
Alona rigidicaudis s.l.	✓	*Corynoneura* sp.	✓
Alona setigera	✓	*Paralimnophyes pullulus*	✓
Alona macrocopa	✓	*Tanytarsus* nr *bispinosus*	✓
Alonella sp.	✓	*Chironomus* aff. *alternans*	✓
Chydorus sp.	✓	*Polypedilum nubifer*	✓
Dunhevedia crassa	✓	*Paraborniella tonnoiri*	✓
Euryalona cf. *orientalis*	✓	*Cladopelma curtivalva*	✓
Kurzia cf. *latissima*	✓	HEMIPTERA	
Pleuroxus sp.	✓		
Rak sp.	✓	*Microvelia* sp.	✓
Ceriodaphnia sp.	✓	*Saldula* sp.	✓
Simocephalus sp.	✓	*Agraptocorixa* sp.	✓
Macrothrix sp.	✓	*Micronecta* sp.	✓
Neothrix sp.	✓	*Anisops* sp.	✓
OSTRACODA		LEPIDOPTERA	
Limnocythere mowbrayensis	✓	Lepidoptera sp. 3	✓
Paralimnocythere sp. 262	✓	ODONATA	
Alboa worooa	✓		
Cypretta sp. 587	✓	*Austrolestes analis*	✓
Ilyodromus amplicolis	✓		

Lake Campion

Lake Campion (Fig. 67) is situated 40km north of Merredin (31° 09'S 118° 21'E) and is one of the two largest lakes in a chain of salt lakes occupying an ancient paleo-drainage channel (Coates 1990). The lake chain continues south into the Avon River at Brookton, but some 27 km of its length are contained within the 10 000 ha Lake Campion Nature Reserve (Res. No. 24789) (Coates 1990). Lake Campion is hypersaline and contains no emergent vegetation (Halse *et al.* 1993b). In the 1970s, a dam was constructed between Lakes Brown and Campion to raise water levels in Campion for recreational purposes. As a result, the lake has a potential depth of 1.4 m in the south arm according to Coates (1990), although substantially higher depths were recorded in 1999. The area surrounding Lake Campion Nature Reserve has been cleared for agriculture and run-off is greater than it would have been prior to clearing.

The vegetation of the Lake Campion Nature Reserve was described by Coates (1990) while Gurner *et al.* (1999) described lake vegetation. Elevated areas around the lake are dominated by woodland of mature *Eucalyptus yilgarnensis* and *E. loxophleba* over a shrub understorey. In the littoral zone Eucalypt woodland is replaced by dense stands of live and dead *Melaleuca uncinata* and *M. pauperiflora*. The understorey includes species of *Carpobrotus*, *Halosarcia*, *Atriplex* and *Frankenia*. The southeastern corner of the lake has extensive pans and samphire marshes, which flood when the lake is full, as occurred in April 1999.

Water chemistry and physico-chemical parameters

Lake Campion filled prior to sampling in late winter 1998, when depth was 1.3 m (Fig. 68). Further inflow occurred in March 1999 (Bureau of Meteorology 1999) because of widespread rainfall in the northern and eastern Wheatbelt. There was no significant inflow between then and August 2000, when depth was 0.83 m and depth continued to decline to 0.2 m in February 2001. Throughout the monitoring period, lake water remained hypersaline with the lowest conductivity being 96 800 µS/cm and the maximum 225 000 µS/cm (although at this conductivity the lakebed was covered by a continuous sheet of crystalline salt, suggesting the water was supersaturated) (Fig. 68). Cations fitted a typical Na>Mg>Ca>K dominance hierarchy with Cl the dominant anion. Lake Campion was acidic for most of the monitoring period, approaching neutral (6.5) only after recent flooding in April 1999. As water level fell, pH declined to a minimum of 2.68 in February 2001.

Total nitrogen concentrations were moderate (1300–6200 µg/l) when the lake was fully flooded but increased to 24 000 µg/l in February 2001. Total phosphorus was consistently below detection level (10 µg/l) except following flooding in April 1999 when 10 µg/l was recorded, suggesting additional inputs from flood waters. The concentration of chlorophyll (<10 µg/l on all sampling occasions) suggested primary production within the lake was low.

Groundwater

Monitoring bores were installed on four vegetation transects at Lake Campion. Depth to groundwater in downslope bores ranged between 1.04 and 2.09 m (Fig. 69) with average depths increasing about 0.5 m over the monitoring period as the watertable beneath the lake, elevated by the heavy rains in 1999, subsequently fell. Electrical conductivity of groundwater varied substantially (78 200–171 000 µS/cm) between transects and across sampling dates without discernible pattern, suggesting a

Figure 67. Lake Campion is a large hypersaline wetland. Maximum lake level has been artificially elevated with the construction of a weir, however the lake is periodically dry.

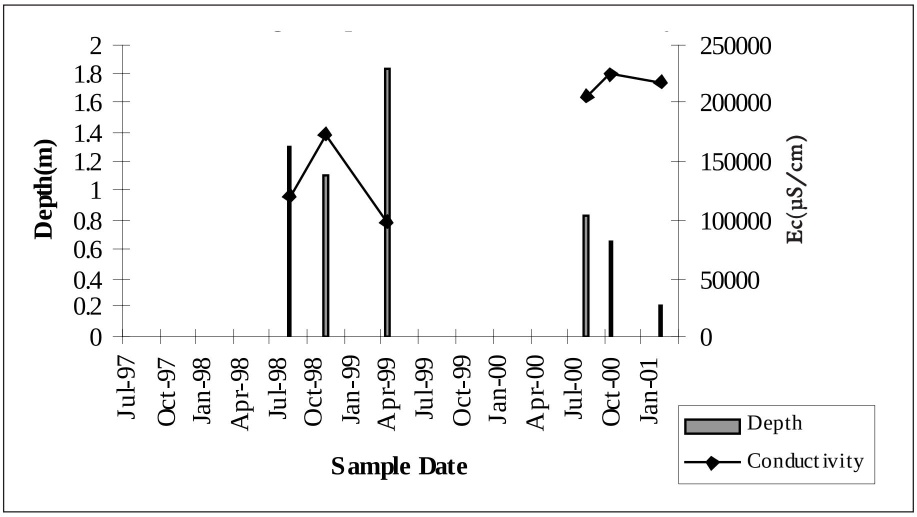

Figure 68. Gauged depth and electrical conductivity at Lake Campion.

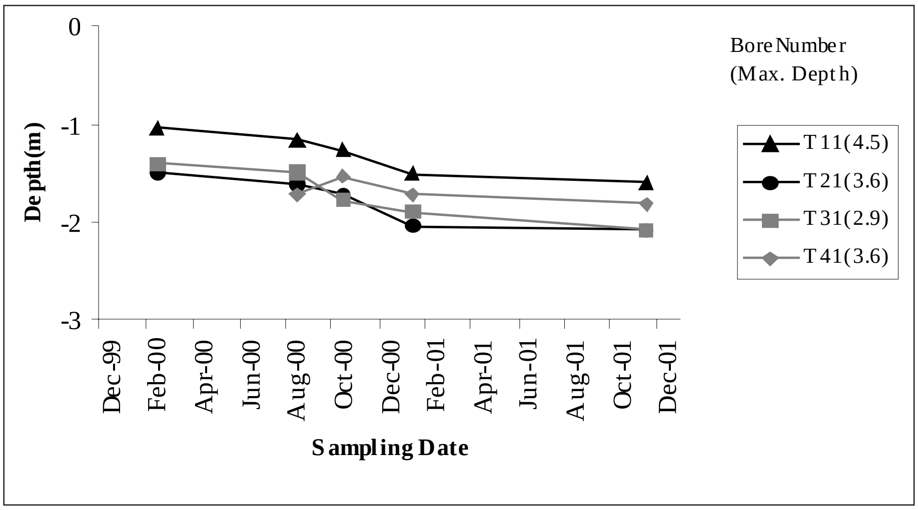

Figure 69. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Campion. Legend values in parenthesis are depth of the bore in metres.

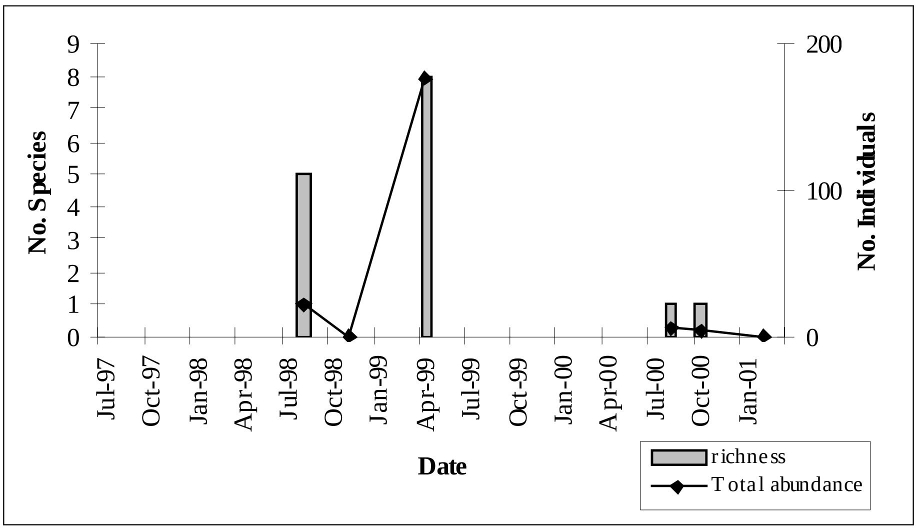

Figure 70. Waterbird species richness and abundance at Lake Campion.

complex pattern of movement and interaction of groundwater. Groundwater was strongly acidic, like lake water, with pH varying from 3.18 to 6.31. Higher pH values were recorded on transect three than elsewhere but the reasons for this were not obvious.

Waterbirds

Nine species of waterbird were recorded during the monitoring period compared with 11 recorded by Jaensch *et al.* (1988) during 13 surveys. Only six species were common to both sets of surveys but this probably reflects different water levels during the two periods rather than long-term changes in the avifauna of Lake Campion. During the monitoring period, most birds were recorded during April 1999 (Table 25, Fig. 70) when water levels were unusually high and the surrounding samphire marshes were extensively flooded. At this time, 177 individuals from eight species were seen. Grey Teal comprised the majority of these birds with 131 individuals and the total number of birds using the south-eastern corner would have been greater than recorded. Given the high salinity of the main waterbody (96 800 µS/cm), it is surprising that so many birds were recorded, including species like Pacific Black Ducks and Pink-eared Ducks that are not particularly salt-tolerant. However, most birds were found in the pans and marshes around the lake, rather than in the main waterbody, and it is likely that water in these was less saline.

The waterbird communities in both 1998 and 2000 were ones that could be expected in a hypersaline lake and its surrounding waterbodies. Although there were differences between years (Fig. 71) these are principally because of additional species recorded during periods of high water and reduced salinity, as discussed above.

Invertebrates

Nine invertebrate species were recorded in spring 1998 (Table 26). Insects were represented by five species, of which four were Diptera (Tipulidae, Ceratopogonidae and Muscidae). Crustaceans were represented by four species restricted to saline habitats: the cladoceran *Daphniopsis* sp., the undescribed ostracods *Australocypris* sp. nov. and *Reticypris* sp. nov. and the calanoid copepod *Calamoecia trilobata*. All species were recorded at densities of less than 100 individuals per sample.

With low species richness and a suite of saline species, the invertebrate community was easily distinguished from that of other marker wetlands in a presence/absence species ordination (Fig. 72).

TABLE 25
Waterbird species and their abundance on six sampling occasions at Lake Campion.

	SAMPLING DATE					
	AUG-98	NOV-98	APR-99	AUG-00	OCT-00	FEB-01
Australian Shelduck	3	0	18	6	0	0
Black-winged Stilt	15	0	0	0	0	0
Grey Teal	2	0	131	0	4	0
Hoary-headed Grebe	1	0	2	0	0	0
No Species	0	0	0	0	0	0
Pacific Black Duck	0	0	4	0	0	0
Pink-eared Duck	0	0	4	0	0	0
Red-necked Avocet	0	0	14	0	0	0
Silver Gull	1	0	1	0	0	0
White-faced Heron	0	0	3	0	0	0

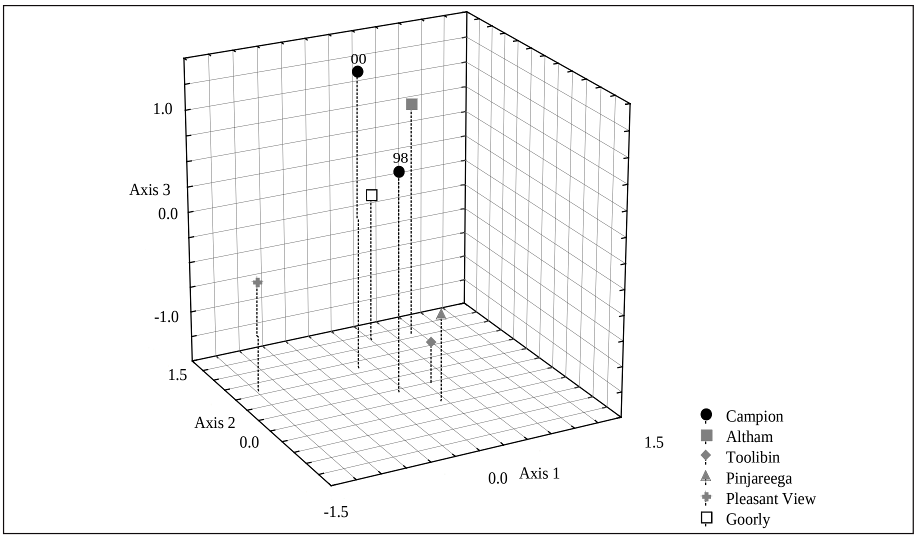

Figure 71. Ordination (SSH) of waterbird species data, showing Lake Campion from 1998 and 2000 and the five marker wetlands.

TABLE 26
Invertebrate species collected from Lake Campion in the 1998 sampling year.

TAXA	1998	TAXA	1998
Nematoda	✓	COPEPODA	
ACARINA		*Calamoecia trilobata*	✓
Oribatida	✓	COLEOPTERA	
CLADOCERA		Curculionidae	✓
Daphniopsis sp.	✓	DIPTERA	
OSTRACODA		Tipulidae	✓
		Bezzia sp. (not 1 or 2)	✓
Australocypris 'bennetti' type	✓	*Culicoides* sp.	✓
Reticypris sp. nov. 556	✓	Muscidae sp. A	✓

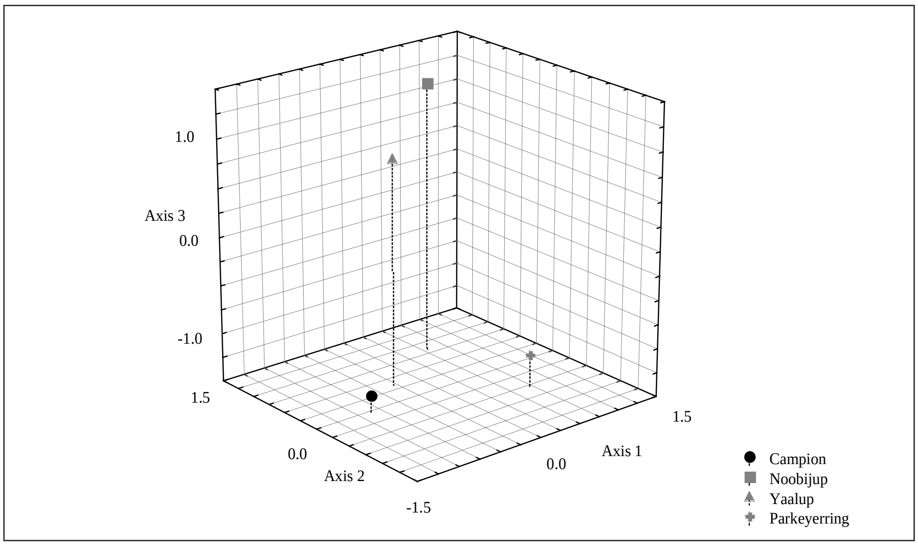

Figure 72. Ordination (SSH) of invertebrate data, showing Lake Campion in 1998 and three marker wetlands.

Goonaping Swamp

Goonaping Swamp (Fig 73) (32° 09'S 116° 35'E) is located in the Wandoo Conservation Area, south west of York (Capill 1984). Goonaping is a fresh seasonal wetland. Lake sediments are rich in clay and parts of the swamp may be perched above the regional aquifer; it fills to shallow depth as a result of rainfall and discharge from very local, perched groundwater. It appears to have little interaction with the underlying regional groundwater. The lakebed is flat but includes an obvious depression 10 m long and 5 m wide, which may have been enlarged in the past to provide water in summer. One set of invertebrate samples was collected from this depression each monitoring occasion. The swamp and surrounds are similar to the nearby Dobaderry Swamp in the Dobaderry Nature Reserve.

The vegetation of the lakebed is predominantly *Melaleuca viminea* which grows in relatively dense stands. At the boundary of the wetland, *Eucalyptus wandoo* woodland dominates over a species-poor understorey that includes *Bossiaea spinescens* and *Acacia pulchella* (Gurner *et al.* 1999). The terrestrial vegetation higher upslope is a richer mosaic of *E. wandoo*, *E. marginata*, *Corymbia calophylla* and *Banksia* woodlands.

Water chemistry and physico-chemical parameters

Lake Goonaping filled in winter and dried before autumn in both monitoring years. Maximum depth recorded was 20 cm in October 2000 (Fig. 74). Salinity of surface water is low, and the pattern of cation concentrations was Na>K=Ca=Mg, with Cl the dominant anion. In spring 2000, chlorophyll concentration was comparatively high (25 µg/l, including phaeophytin) and pH rose to 8.0. Nutrient levels were consistently low.

Groundwater

Monitoring bores were installed on all three transects (Fig. 75). Hydrology appears to be complex, with seasonal lenses of fresh water perched above a more saline aquifer. Perched groundwater is driving the monitoring results in transect two; while results in transect one mostly reflect the underlying regional aquifer. There does not appear to be an immediate threat from this aquifer, although it is only 5–6 m below the swamp and has a conductivity of 1389-3950 µS/cm and may constitute a long-term threat. Groundwater is weakly acidic.

Waterbirds

The densely vegetated, shallow nature of Goonaping Swamp in conjunction with strong seasonality (so that it is dry much of the year) makes it unsuitable for most waterbirds. The only waterbird recorded during the study period was a single Pacific Black Duck sighted in spring 1998 (Table 27). However, it is likely that wading species such as the White-faced Heron occasionally use the wetland. Goonaping Swamp was excluded from the waterbird ordination because only one species had been recorded.

Invertebrates

Invertebrates were monitored in spring 1998 when 71 taxa were collected (Table 28). There were 28 insect species (39% of the fauna) and 29 crustaceans (40%). The most notable feature was the diversity of Cladocera and Ostracoda, each being represented by 11 species. Species of the family Chydoridae were the most abundant cladocerans in the shallow water covering most of the wetland, but in the deeper depression, species of Daphnidae including *Scaphobleberis* cf. *kingi*, *Simocephalus* sp. and *Ceriodaphnia* sp., were more common.

Figure 73. Goonaping swamp is shallow and the lake bed is dominated by Melaleuca viminea. Photograph by Adrian Pinder.

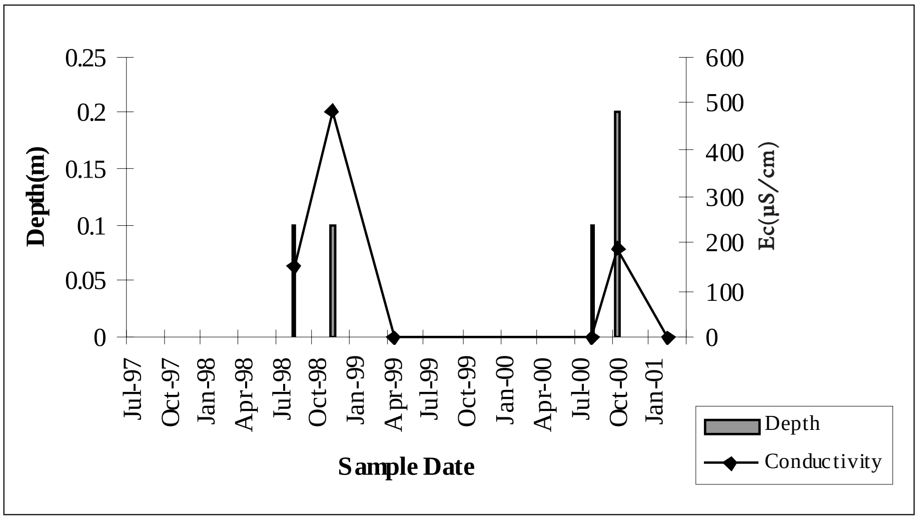

Figure 74. Gauged depth and electrical conductivity at Goonaping Swamp.

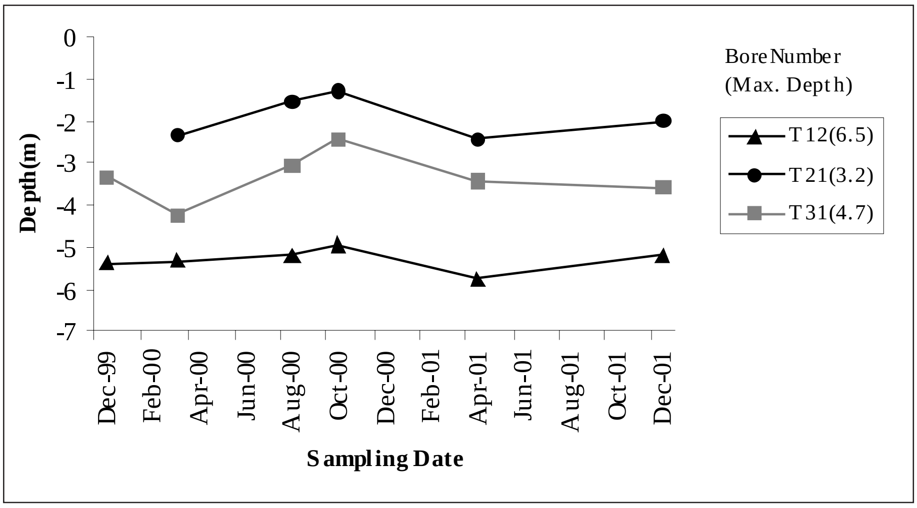

Figure 75. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Goonaping Swamp. Legend values in parenthesis are depth of the bore in metres.

TABLE 27
Waterbird species and their abundance on four sampling occasions at Goonaping Swamp.

	SAMPLING DATE			
	NOV-98	APR-99	SEP-00	OCT-00
Pacific Black Duck	0	2	0	0

Conchostracans, rarely collected during the monitoring program, were represented by two species, *Lynceus* sp. and *Eulimnadia* sp., which reflect the highly seasonal nature of Goonaping. Conchostracans are typical of ephemeral waterbodies, especially clay pans, where their dessication-resistant eggs enable quick colonisation of the wetland even after lengthy dry periods.

Among the insects, Coleoptera and Diptera were the most diverse orders with 11 and 10 species, respectively. Odonata were represented by three species including *Hemianax papuensis* and *Diplacodes bipunctata* which, while tolerant of brackish water, are more commonly found in freshwater wetlands. The ubiquitous *Triplectides australis* was the only trichopteran collected.

The overall invertebrate community at Goonaping was similar to that of Noobijup Swamp (Fig. 76) and Lake Kulicup (see Fig. 66), reflecting the fresh water and extensive lake-bed vegtation in all three.

TABLE 28
Invertebrate species collected from Goonaping Swamp in the 1998 sampling year.

TAXA	1998
Turbellaria	✓
Nematoda	✓
ROTIFERA	
Rotaria sp.	✓
Brachionus quadridentatus	✓
Lecane quadridentata	✓
Lecane sp.	✓
Monommata sp.	✓
GASTROPODA	
Ferrissia petterdi	✓
Glyptophysa cf. *gibbosa*	✓
ACARINA	
Eylais sp.	✓
Limnesia dentifera	✓
Oribatida	✓
Mesostigmata	✓
Trombidioidea	✓
CONCHOSTRACA	
Eulimnadia sp. ✓	✓
Lynceus sp.	✓
CLADOCERA	
Latonopsis sp.	✓
Alona affinis	✓
Alona setigera	✓
Alona macrocopa	✓
Celsinotum sp.	✓
Chydorus sp.	✓
Rak sp.	✓
Ceriodaphnia sp.	✓
Scapholeberis cf. *kingi*	✓
Simocephalus sp.	✓
Macrothrix sp.	✓
OSTRACODA	
Limnocythere dorsicula	✓
Limnocythere sp. 447	✓
Paralimnocythere sp. 262	✓
Candonopsis tenuis	✓
Bennelongia australis	✓
Candonocypris sp.	✓
Cypretta baylyi	✓
Cypretta sp. 527	✓
Ilyodromus sp. 566	✓
Ilyodromus sp. 255	✓
Cabonocypris nunkeri	✓
COPEPODA	
Calamoecia attenuata	✓
Microcyclops varicans	✓
Australocyclops palustrium	✓
Mesocyclops brooksi	✓
Canthocamptidae sp. 5	✓
COLEOPTERA	
Haliplus fuscatus	✓
Allodessus bistrigatus	✓
Sternopriscus sp.	✓
Megaporus howitti	✓
Lancetes lanceolatus	✓
Onychohydrus scutellaris	✓
Hydrochus sp.	✓
Berosus approximans	✓
Paranacaena littoralis	✓
Enochrus eyrensis	✓
Paracymus pygmaeus	✓
DIPTERA	
Anopheles annulipes	✓
Culicoides sp.	✓
Sciomyzidae	✓
Paramerina levidensis	✓
Tanypodinae sp. C (nr *Tanypus*)	✓
Corynoneura sp.	✓
Tanytarsus fuscithorax	✓
Chironomus aff. *alternans*	✓
Polypedilum nr. *convexum*	✓
Cladopelma curtivalva	✓
HEMIPTERA	
Saldula brevicornis	✓
Anisops thienemanni	✓
Anisops hyperion	✓
ODONATA	
Austrolestes analis	✓
Hemianax papuensis	✓
Diplacodes bipunctata	✓
TRICHOPTERA	
Triplectides australis	✓

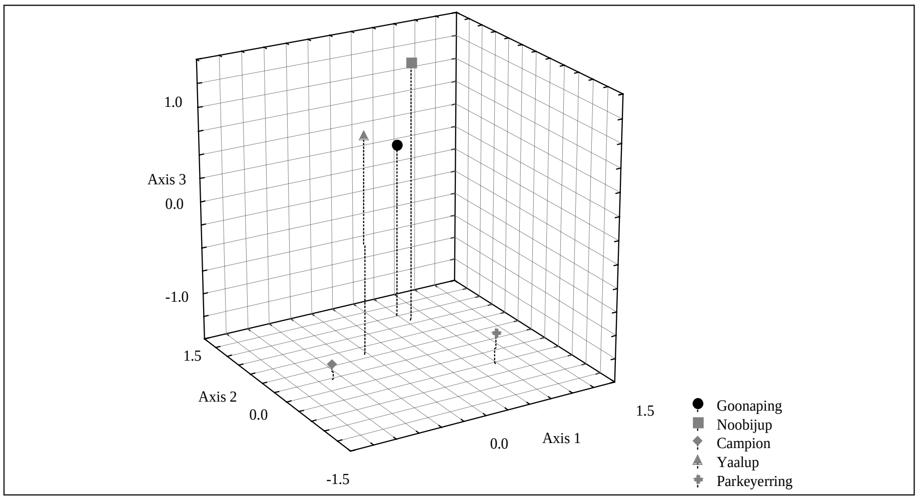

Figure 76. Ordination (SSH) of invertebrate data, showing Goonaping Swamp in 1998 and four marker wetlands.

Lake Coomelberrup

Lake Coomelberrup (Fig. 77) is a medium-sized, secondarily saline wetland, situated in the Coomelberrup Nature Reserve (33° 24'S 117° 47'E). It has an area of approximately 91 ha, of which 46% is open water (Halse *et al.* 1993b). The lake fills from the Datatine drainage system immediately above the confluence of Dongolocking and Coblinine Creeks. Coblinine Creek continues past Lake Coomelberrup to empty into Lake Dumbleyung 10 km farther north. The Datatine catchment is very flat and, during periods of flooding, water may sometimes flow back from Lake Dumbleyung into Lake Coomelberrup. The wetland receives water most years (probably largely because of the amount of farm drainage in the catchment) and may hold water for several years in succession. Between 1978 and 1982, lake depth in November ranged from dry (two years) to 0.89 m (Lane and Munro 1983).

Lake Coomelberrup is recognised as a valuable wetland for waterbirds, ranking third highest for abundance of Freckled Duck and ranked equal 22nd in terms of species richness in a survey of 197 wetlands between 1981 and 1985 (Jaensch *et al.* 1988). The National Parks and Nature Conservation Authority (replaced by the Conservation Commission) recommended Lake Coomelberrup be included in the monitoring program because of the large amount of drainage occurring in the catchment, with likely effects on the hydrology of Coomelberrup.

Remnant vegetation consists predominantly of a belt of dead trees, 50–100 m wide around the north, west and south-western shores. *Halosarcia lepidosperma* and *H. pergranulata* persist as a sparse understorey (Halse *et al.* 1993b). Within the littoral zone, there is a narrow ring of *Casuarina obesa*, *Melaleuca hamulosa* and *M. halmaturorum* (Gurner *et al.* 2000).

Water chemistry and physico-chemical parameters

Lake Coomalberrup received substantial inflow in 1998 as a result of spring rainfall and depth was 1.33 m when monitored in spring 1998. Maximum depth in 2000 occurred in August (0.93 m) and the lake was dry by autumn that year (Fig. 78). Conductivity ranged from 32 800–96 000 µS/cm and, while salinity was inversely proportional to depth within each annual hydrological cycle, there was a discontinuity between years with more salt apparently present in 2000. The significance of this pattern is unclear because dissolved salt loads in south-western Australian lakes can show substantial inter-annual variation according to lake depth and other factors (see Halse *et al.* 2000b).

The concentration of cations showed a pattern Na>Mg>Ca>K and Cl was the dominant anion, although SO_4 occurred in significant concentrations. The lake was strongly alkaline (pH of 9.87) in spring 1998 but neutral to moderately alkaline on other sampling occasions. Chlorophyll concentrations were low except in spring 1998 when they reached 55 µg/l. This was probably the result of an algal bloom occurring before macrophyte beds became re-established in the lake. Nutrient concentrations remained comparatively low, for a secondarily saline lake, throughout monitoring.

Figure 77. Historically Lake Coomelberrup supported a belt of Casuarina obesa along the western shore, however, these trees are dead now.

Groundwater

Depth to groundwater in the monitoring bores varied from 0.93 m to 3.6 m, depending on location, and electrical conductivity ranged from 39 100–68 700 µS/cm. The seasonal pattern of change in groundwater levels is shown in Fig. 79, using bores placed well up the wetland shore. The lakebed itself was intercepting groundwater and Coomelberrup is a groundwater discharge area much of the time. Interestingly, except shortly after significant surface inflow, surface water in the lake was more saline than the groundwater below as a result of salt accumulating in lake-bed sediments.

Waterbirds

Twenty waterbird species were seen at Coomelberrup during five monitoring surveys (Fig. 80, Table 29), compared with 37 species recorded by Jaensch *et al.* (1988) from 28 surveys between 1981 and 1985. There were larger floods during 1981–85 than during the monitoring period and at times the lake was substantially fresher (5000 µS/cm *cf.* 39 100–68 700 µS/cm during monitoring). Thus, it is difficult to determine whether the reduction in waterbird use of the lake is the result of a fundamental decline in lake condition or simply an effect of lower rainfall. However, there has been significant death of trees around the lake since Jaensch *et al.*'s surveys (see Halse *et al.* 1993b) and very few live trees remain. Species such as Little Grassbirds and Clamorous Reed-Warblers, which were recorded in 1981-85, are unlikely to occur now because of a lack of habitat.

The most abundant birds during monitoring were the Australian Shelduck, Grey Teal and Black Swan, but numbers fluctuated throughout the year. The abundance of waterbirds was greater in 1998 than 2000, largely owing to the lack of water in February 2001 (Fig. 80). The waterbird community was that of a secondarily saline lake but showed only loose affinities with Lake Pinjarrega (another secondarily saline wetland) in the waterbird ordination (Fig. 81). Despite the loss of some species discussed above, community structure was very similar in 1998 and 1982–83 surveys. However, the low species

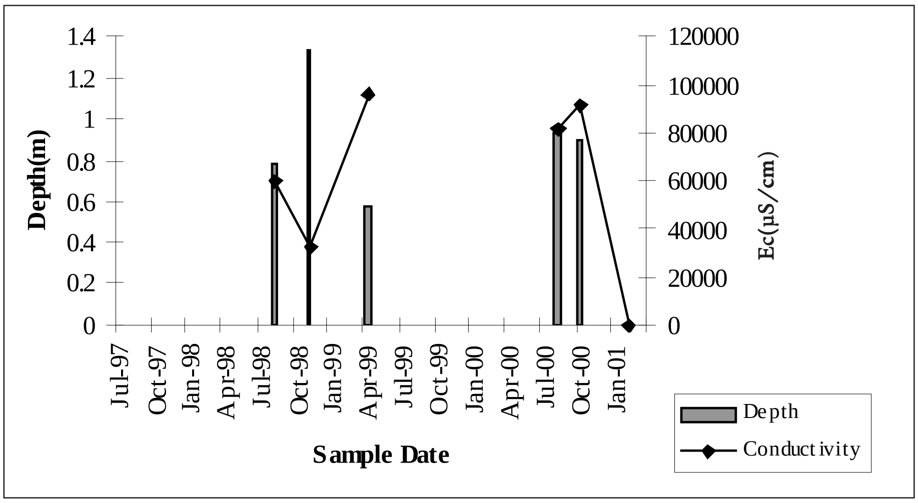

Figure 78. Gauged depth and electrical conductivity at Lake Coomelberrup

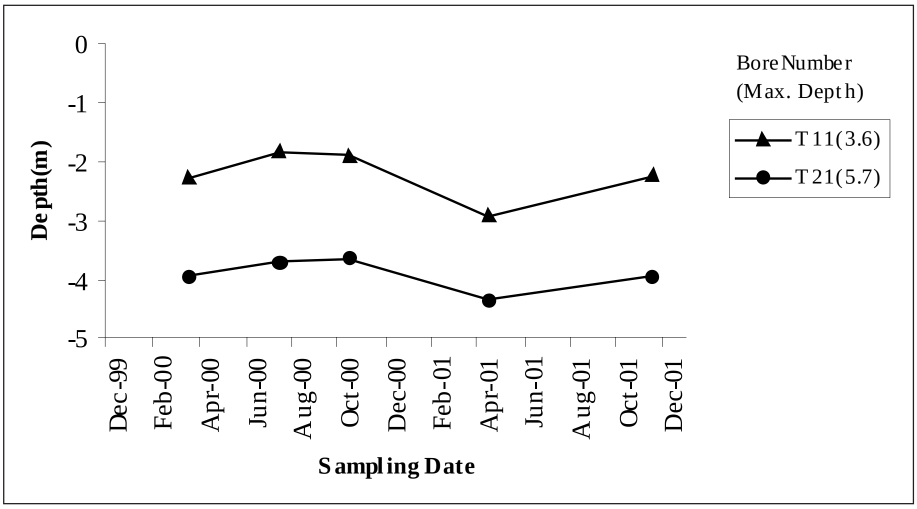

Figure 79. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Coomelberrup. Legend values in parenthesis are depth of the bore in metres.

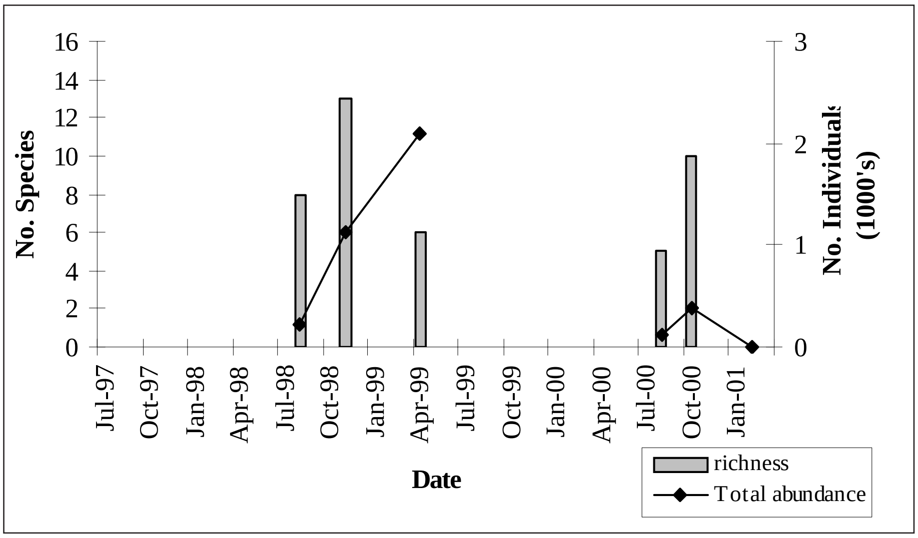

Figure 80. Waterbird species richness and abundance at Lake Coomelberrup.

TABLE 29
Waterbird species and their abundance on 6 sampling occasions at Lake Coomelberrup.

	SAMPLING DATE					
	AUG-98	NOV-98	APR-99	AUG-00	OCT-00	FEB-01
Australasian Shoveler	2	5	0	1	0	0
Australian Shelduck	10	71	1900	3	61	0
Australian Wood Duck	0	7	0	0	0	0
Banded Stilt	0	0	0	0	32	0
Black Swan	106	50	0	18	0	0
Black-winged Stilt	0	9	0	0	0	0
Chestnut Teal	0	1	2	0	0	0
Common Greenshank	0	1	0	0	0	0
Eurasian Coot	1	70	0	0	0	0
Grey Teal	85	904	179	102	229	0
Hardhead	5	10	0	0	0	0
Hoary-headed Grebe	10	0	0	0	1	0
Musk Duck	0	0	0	0	12	0
Pacific Black Duck	0	1	6	0	0	0
Red-capped Plover	7	0	0	0	25	0
Red-kneed Dotterel	0	0	1	0	0	0
Red-necked Stint	0	0	0	0	8	0
Sharp-tailed Sandpiper	0	0	0	0	2	0
Silver Gull	0	2	1	0	1	0
White-faced Heron	0	2	0	1	3	0

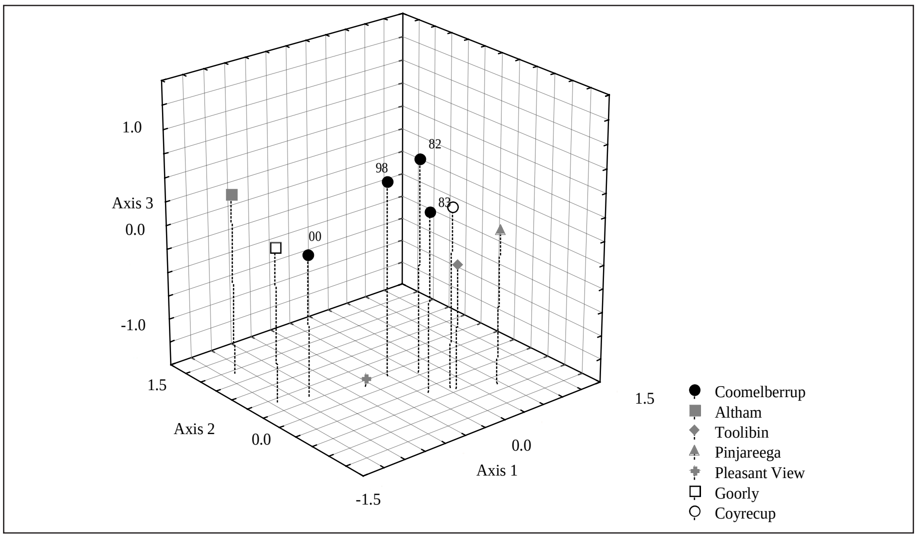

Figure 81. Ordination (PCR) of waterbird species data from Lake Coomelberrup, showing historical and monitoring data for Lake Coomelberrup and data for six marker wetlands.

richness associated with low water levels in February 2001 resulted in the 2000 waterbird community being distinct from other years. This pattern was observed at other wetlands (e.g. Coyrecup, Eganu) and appears to reflect wetlands undergoing a change of ecological character in dry years as they become more salinized.

Invertebrates

Invertebrates were monitored in November 1998. A total of 35 species were identified with 12 crustaceans (34% of fauna) and 18 species (51%) of insects (Table 30). Dipterans were the most diverse group with 12 species belonging to seven families, most of which were opportunistic salt-tolerant taxa such as the Ceratopogonidae, Ephydridae and Stratiomyidae. The Chironomidae species that were present have widespread distributions and included the halophilic *Tanytarsis barbitarsis*. Odonata were represented by three species of the damselfly genus *Austrolestes*, all of which are salt tolerant. Amongst the crustaceans, the most diverse group were ostracods with 5 species, all typical of saline waters.

The invertebrate community at Coomelberrup was that of a secondarily saline wetland but with lower salinity than Lake Parkerreying, the marker wetland used in Fig.82.

TABLE 30
Invertebrate species collected fromLake Coomelberrup in the 1998 sampling year.

TAXA	1998
Turbellaria	✓
GASTROPODA	
Coxiella spp	✓
OLIGOCHAETA	
Ainudrilus nharna	✓
Enchytraeidae	✓
ACARINA	
Trombidioidea	✓
CLADOCERA	
Daphniopsis sp.	✓
OSTRACODA	
Alboa worooa	✓
Australocypris insularis	✓
Diacypris spinosa	✓
Mytilocypris tasmanica chapmani	✓
Platycypris baueri	✓
COPEPODA	
Calamoecia clitellata	✓
Metacyclops arnaudi (sensu Kieffer)	✓
Apocyclops dengizicus	✓
Mesochra nr *flava*	✓
AMPHIPODA	
Austrochiltonia subtenuis	✓
ISOPODA	
Haloniscus searlei	✓
COLEOPTERA	
Antiporus sp.	✓
Necterosoma penicillatus	✓
Berosus discolor	✓
DIPTERA	
Culicoides sp.	✓
Monohelea sp. 3	✓
Tabanidae	✓
Stratiomyidae	✓
Empididae	✓
Ephydridae	✓
Muscidae sp. A	✓
Muscidae sp. C	✓
Procladius paludicola	✓
Tanytarsus barbitarsis	✓
Dicrotendipes conjunctus	✓
Cladopelma curtivalva	✓
ODONATA	
Austrolestes analis	✓
Austrolestes annulosus	✓
Austrolestes io	✓

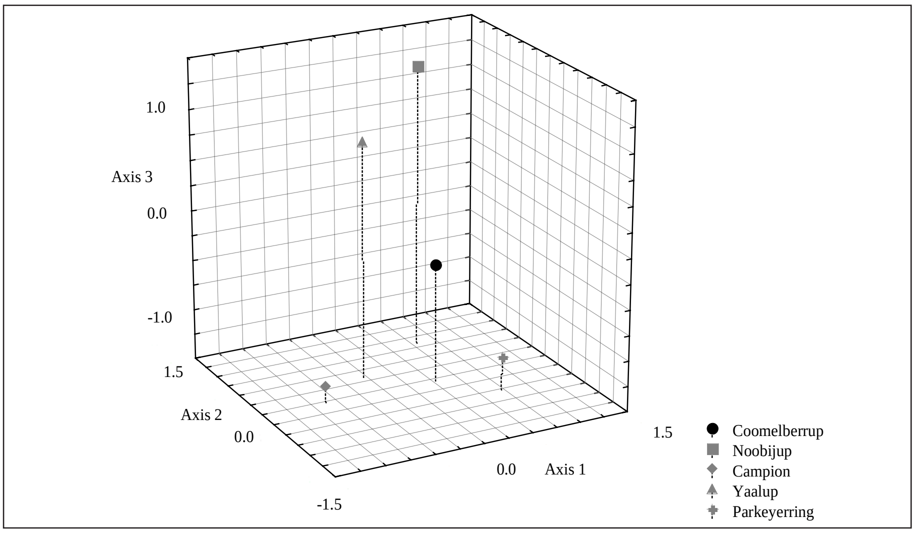

Figure 82. Ordination (SSH) of invertebrate data, showing Lake Coomelberrup in 1998 and four marker wetlands.

Lake Walyormouring

Lake Walyormouring (31° 08'S 116° 51'E) lies partly within Walyormouring Nature Reserve (No.17186) and partly within extensively cleared, privately owned farmland (Fig. 83). The nearest town is Goomalling, 16 km to the south. Surrounding land is undulating, causing the shoreline of the lake to be steep and short in some places. The lakebed, however, is broad and very flat with an area of 1010 ha, of which over 80% is open water (Halse *et al.* 1993b).

Lake Walyormouring is saline and generally seasonal although occasionally it holds water over consecutive years. Between 1979 and 1985, lake level fluctuated annually from dry in summer to partially filled with maximum depth in spring (Lane and Munro 1983; Jaensch *et al.* 1988). The lake has a long history of waterlogging and salinity and large areas of the northern and southern shores support a wide belt of trees killed by the altered hydrology. The extensive clearing that has taken place on the lake-bed at the southern end of the lake suggests the area of lake regularly inundated now is greater than at the time the area was opened for farming. While most lake inflow probably comes from the local catchment, Beard (1999) pointed out that Lake Walyormouring is the western end of a south-westward flowing drainage channel from Cowcowing Lakes.

Jaensch *et al.* (1988) listed Walyormouring as equal 16th most important wetland for breeding waterbirds among 197 wetlands surveyed in south-west Western Australia. Its abundant waterbird fauna and the extensive depth gauge records were the reasons for its inclusion in the monitoring program. Vegetation has been described previously (Halse *et al.* 1993ba; Gurner *et al.* 1999). Live vegetation occurs mainly on elevated parts of the northern and western shorelines, and comprises mature stands of *Casuarina obesa* and *Melaleuca strobophylla*. Lower on the shoreline, and extending across the lake-bed, trees are dead but *Halosarcia pergranulata* grows beneath them.

Water chemistry and physico-chemical parameters

Water levels were slightly higher in winter and spring 1998 than in 2000. The lake received inflow from summer rain in 1999 that maintained water levels in the autumn of the first sampling year. The lake was dry in autumn 2001 (Fig. 84). The biggest difference between years was in salinity, with conductivities in 1998 ranging from 11 320 to 36 100 µS/cm, whereas in 2000 they were 60 600 and 99 700 µS/cm. Although it is difficult to compare salt loads between years, it appears likely there is significant salt accumulation in Walyormouring in years that the lake does not overflow. There is little evidence of long-term salt accumulation over the past 20 years, however (see Jaensch *et al.* 1988). Cation concentrations fitted a pattern of Na>Mg>Ca>K and Cl was the dominant anion.

Total nitrogen levels were typical of Wheatbelt salt lakes (range 1700–6950 µg/l) and total phosphorus concentrations were relatively low (maximum 20 µg/l). Chlorophyll concentrations were also low (<5 µg/l).

Groundwater

Monitoring bores on both vegetation transects during 1999 showed that the groundwater was substantially less than 1 m below local ground level on both transect one (the lower-lying transect) and transect two (Fig. 85). The lake is a discharge zone for saline groundwater and, as a result of salt accumulation in the sediments, is sometimes

Figure 83. Lake Walyormouring is a large seasonal saline wetland.

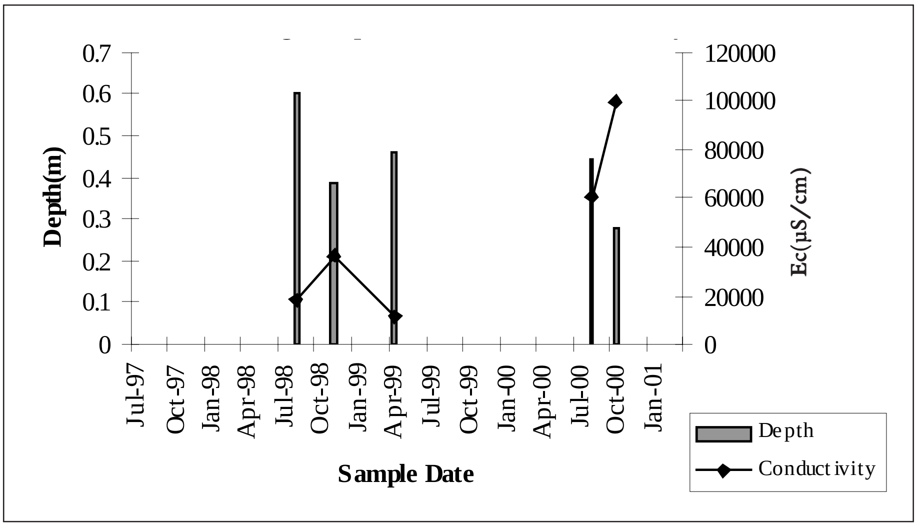

Figure 84. Gauged depth and electrical conductivity at Lake Walyormouring.

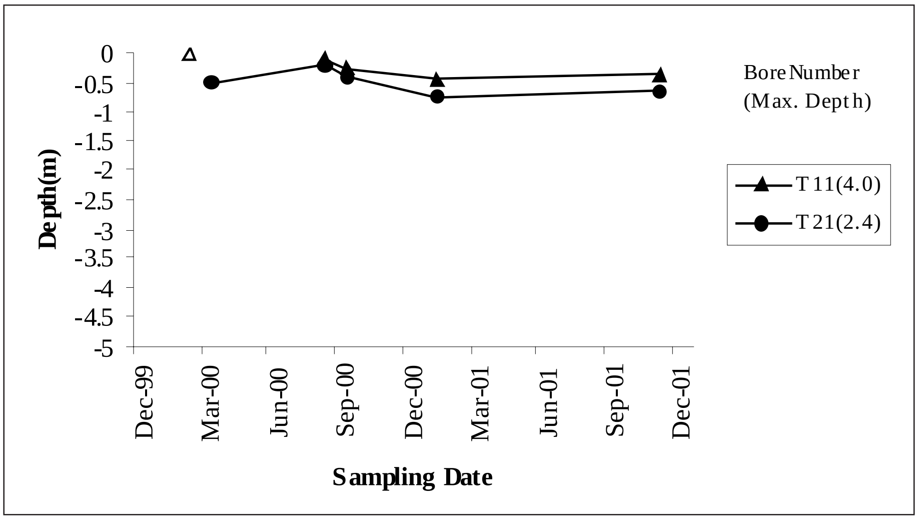

Figure 85. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Walyormouring. Open symbols represent bores underwater. Legend values in parenthesis are depth of the bore in metres.

substantially more saline than underlying groundwater. Conductivities of groundwater ranged from 5010 to 21 980 µS/cm, with considerable temporal and spatial variation. pH was circum-neutral. Two additional bores have also been monitored adjacent to the lake; one (transect 4) receives throughflow from a granite rock and was relatively fresh (minimum conductivity 1710 µS/cm). This small flow of fresh water is probably responsible for the continued growth of the thicket of *Casuarina obesa* along the northeast margin.

Waterbirds

A total of 20 species were recorded during monitoring in 1998, with the 12 species recorded in 2000 a subset of these (Table 31, Fig. 86). The lake consistently supported large numbers of birds, with almost 10 000 present in November 1998 when extensive shallows at the southern end supported large numbers of shorebirds such as Banded Stilts, Red-capped Plovers, Red-necked Stints and Sharp-tailed Sandpipers, in addition to the ducks in the main water-body.

Jaensch *et al.* (1998) recorded 28 species during 38 surveys between 1981 and 1985, with higher water levels than recorded during monitoring. Overall, community composition was similar to that in 1998 and 2000 and there is little evidence of a long-term change in the ecology of Walyormouring from a waterbird perspective (Fig. 87). Annual variation appears moderately significant with 1981 (dryest year) and 1984 (wettest year) having the two most different communities.

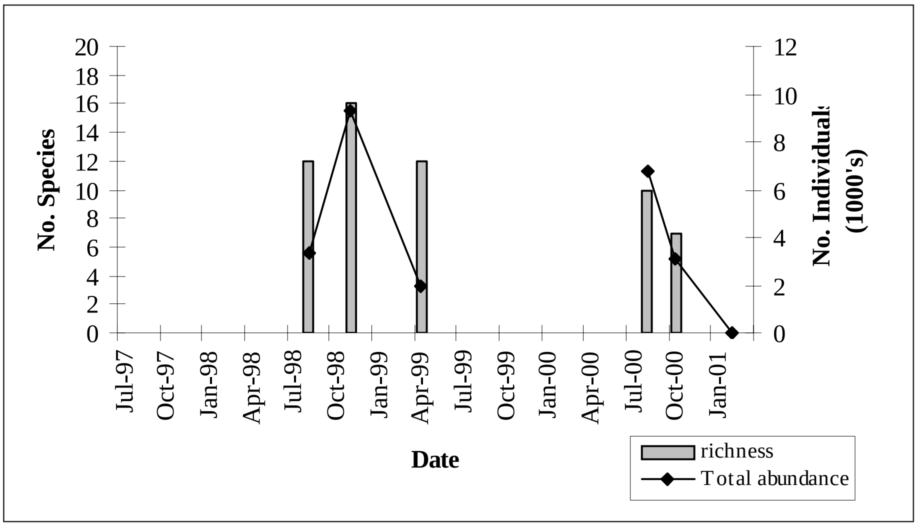

Figure 86. Waterbird species richness and abundance at Lake Walyormouring.

TABLE 31
Waterbird species and their abundance on six sampling occasions at Lake Walyormouring.

	SAMPLING DATE					
	AUG-98	NOV-98	APR-99	AUG-00	OCT-00	FEB-01
Australasian Shoveler	55	0	7	0	0	0
Australian Shelduck	22	369	749	1588	1800	0
Banded Stilt	0	2738	0	9	2	0
Black Swan	56	38	28	18	0	0
Black-winged Stilt	221	84	4	0	0	0
Chestnut Teal	0	0	1	0	0	0
Curlew Sandpiper	0	1	0	0	0	0
Eurasian Coot	1073	1010	250	109	0	0
Grey Teal	1286	3645	626	4855	1200	0
Hardhead	30	36	0	0	0	0
Pacific Black Duck	2	3	173	35	0	0
Pink-eared Duck	543	75	38	18	0	0
Red-capped Plover	0	724	0	86	44	0
Red-kneed Dotterel	0	3	0	0	0	0
Red-necked Avocet	3	0	0	0	0	0
Red-necked Stint	0	492	0	9	0	0
Sharp-tailed Sandpiper	0	123	0	0	34	0
Silver Gull	23	4	37	0	2	0
White-faced Heron	1	1	55	14	2	0
Yellow-billed Spoonbill	0	0	1	0	0	0

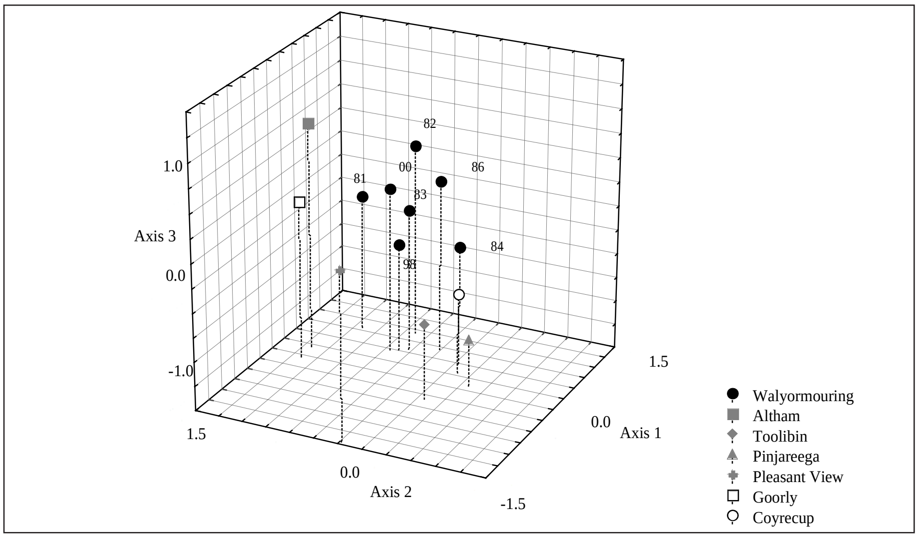

Figure 87. Ordination (PCR) of waterbird species data from Lake Walyormouring, showing historical and monitoring data for Lake Walyormouring and data for six marker wetlands.

Invertebrates

The invertebrate fauna of Lake Walyormouring was monitored in November 1998, when 18 species were collected (Table 32). Ten of them were crustaceans, all of which were collected in high abundance. For example, the ostracods *Diacypris spinosa*, *Mytilocypris chapmani tasmanica*, and *Cyprinotus edwardi* were recorded in 100 000s or 10 000s. So, too, was the salt lake gastropod *Coxiella* sp. By contrast, the six insect species occurred as < 10 individuals per species. The most abundant of them was the chironomid *Procladius paludicola*. The salt-tolerant and ubiquitous *Austrolestes annulosus* was the only species of odonate collected.

Walyormouring has an invertebrate community typical of secondarily saline lakes, albeit not as saline as Parkeyerring (Fig. 88). It is well displaced in an ordination from samples occurring in a naturally saline system (Campion).

TABLE 32
Invertebrate species collected from Walyormouring Lake in the 1998 sampling year.

TAXA	1998	TAXA	1998
ROTIFERA		*Apocyclops dengizicus*	✓
Hexarthra fennica	✓	*Mesochra* nr *flava*	✓
GASTROPODA		AMPHIPODA	
Coxiella sp. 2(Aus. Mus. Code)	✓	*Austrochiltonia subtenuis*	✓
CLADOCERA		COLEOPTERA	
Daphniopsis sp.	✓	*Berosus munitipennis*	✓
OSTRACODA		DIPTERA	
Australocypris insularis	✓	Stratiomyidae	✓
Cyprinotus edwardi	✓	*Procladius paludicola*	✓
Diacypris spinosa	✓	*Tanytarsus* sp. A (nr. K10)	✓
Mytilocypris tasmanica chapmani	✓	*Cladopelma curtivalva*	✓
COPEPODA		ODONATA	
Boeckella triarticulata	✓	*Austrolestes annulosus*	✓
Mesocyclops brooksi	✓		

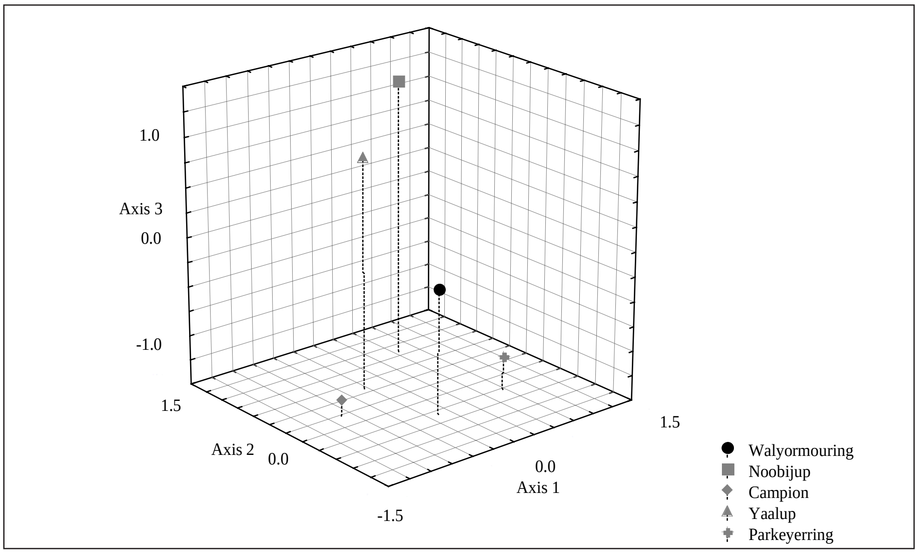

Figure 88. Ordination (SSH) of invertebrate data, showing Lake Walyormouring in 1998 and four marker wetlands.

Lake Eganu

Lake Eganu (30° 00'S 115° 52'E) (Fig. 89) is a medium-sized wetland (82.2 ha) located on the northern sandplain 20 km south-west of Coorow. The lake has shown a decline in condition since the late 1960s and is now clearly secondarily saline. At the centre of the Pinjarrega Nature Reserve (Res. No. 25210), Lake Eganu is surrounded by remnant vegetation. It is likely that the lake's hydrology is affected by drainage from the north via a series of salt lakes and drainage lines that connect to both Yarra Yarra Lake (in the most exceptionally wet years) and Lake Moore (Beard 2000). Lake Eganu has been seasonal in recent years, although under higher rainfall regimes it frequently holds water over consecutive years (see Jaensch *et al.* 1988).

The vegetation has been described by Halse *et al.* (1993b) and Gurner *et al.* (1999): the lake fringe above high water supports a belt of live *Casuarina obesa* with scattered *Eucalyptus rudis* and *E. loxophleba*. These tree species used to continue across the lakebed but are now dead below the high water mark (and in some elevated areas). Understorey below the live trees includes *Chenopodium* sp., *Sclerolaena dicantha*, *Enchyleana* sp. and *Hakea recurva*. *Halosarcia pergranulata* grows under dead trees down to the high water mark, in association with *Baumea vaginalis* and *Scholtzia* sp. Vegetation at the lake's northern end is in better condition and includes live *C. obesa*, *Melaleuca strobophylla* and *Melaleuca lateriflora* growing below the maximum flood level.

Lake Eganu was one of the many wetlands studied in a large survey of waterbirds in south-western nature reserves (Jaensch *et al.* 1988). It was also depth-gauged, so that there is a long record of salinity and depth (Lane and Munro 1983). Just prior to the surveys of Jaensch *et al.*(1988), aquatic invertebrates at Eganu and surrounding lakes were studied by Halse (1981). The lake was selected for monitoring because of the availability of historical information about its condition and because further effects of salinization seemed likely.

Water chemistry and physico-chemical parameters

Lake Eganu was monitored in 1998 and 2000. In 1998 the lake filled from winter rains reaching a maximum depth of 2.5 m and held water through 1999 (Fig. 90). Further unrecorded inflow occurred in January 2000 as a result of cyclonic rain and the lake was moderately full when monitored in August 2000. However, evaporation during spring and early summer meant the lake was almost dry by February 2001. In 1998, salinities varied between moderately saline and seawater concentrations (26 800–55 700 µS/cm) but in 2000 the lake was hypersaline (107 800–226 000 µS/cm). The likely reason for the dramatic difference in salinities between years is that water levels reached outflow height during the flooding in winter 1998 and saline water was flushed out of the lake by fresher inflow water. This did not occur in autumn 2000. During monitoring cation concentrations fitted a pattern of Na>Mg>Ca>K and Cl was the dominant anion. Total phosphorus concentrations were low throughout monitoring (maximum 20 µg/l in May 1999), while Total nitrogen showed the effects of evapo-concentration, ranging from 1200 to 11000 µg/l. A small algal bloom occurred in February 2001 (26.5 µg/l total chlorophyll), although the biological meaning of this is unclear, given the extremely shallow water depth and hypersaline conditions.

Figure 89. Lake Eganu is secondarily saline with a continuous decline in condition since the 1960s.

It is difficult to quantify long-term changes in salinity of wetlands, given the substantial annual fluctuations that occur as a result of flushing, variable depths and other factors. However, data in Halse (1981), Lane and Munro (1983) and Jaensch *et al.* (1988) suggest that salinity has increased substantially at Lake Eganu over the past 20 years. The minimum salinity recorded during monitoring was 26 800 µS/cm whereas in the late 1970s and early 1980s salinities of 17 000 µS/cm or slightly less were common at similar depths.

Groundwater

Monitoring bores were installed on three vegetation transects. Depth to groundwater varied from 0.3 m to 2.6 m depending on location and time sampled (Fig. 91). Groundwater levels were highest when monitoring began in December 1999. Conductivity of groundwater showed some spatial and temporal variation (42 300–71 100 µS/cm) but was substantially lower than surface water conductivity in 2000.

Waterbirds

A total of 16 species were seen at Eganu but only the Australian Shelduck, Black Swan, Grey Teal and Hoary-headed Grebe were recorded in both 1998 and 2000 (Table 33, Fig. 92). Within each year, waterbird abundance was highest in spring, with 5396 birds in November 1998 and 441 birds in November 2000. Australian Shelduck were the most abundant species. Eganu is well-known as a moulting site for shelduck (Halse *et al.* 1990).

Jaensch *et al.* (1988) recorded 24 species of waterbird during 19 surveys between 1981 and 1985; including 8 species breeding. The maximum number of waterbirds counted by Jaensch *et al.* (1988) was 10 940 with very high counts, for the south-west, of Pink-eared Ducks and Hardheads. Hardheads were frequently numerous at Eganu in the 1970s (SA Halse personal observation) whereas only five of them were seen during the six monitoring surveys.

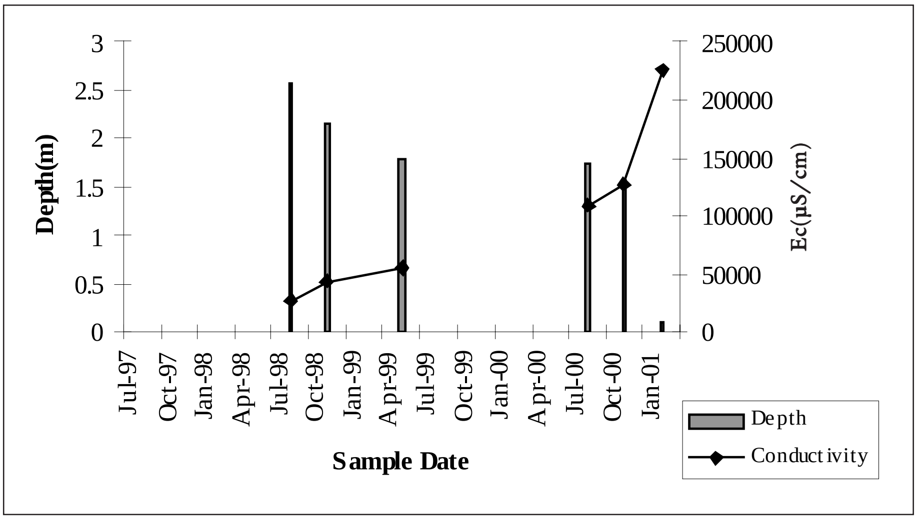

Figure 90. Gauged depth and electrical conductivity at Lake Eganu.

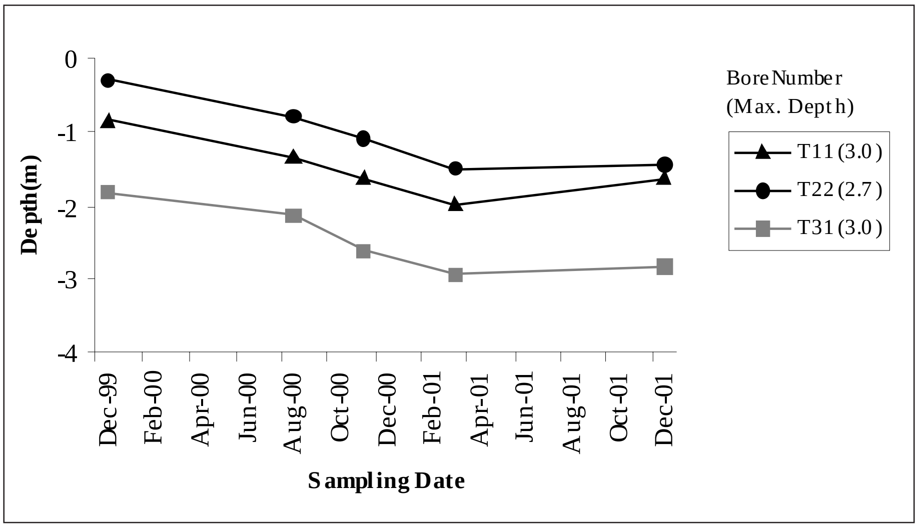

Figure 91. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Eganu. Legend values in parenthesis are depth of the bore in metres.

TABLE 33
Waterbird species and their abundance on six sampling occasions at Lake Eganu.

	SAMPLING DATE					
	AUG-98	NOV-98	MAY-99	AUG-00	NOV-00	FEB-01
Australasian Shoveler	17	72	0	0	0	0
Australian Shelduck	0	3224	10	193	387	0
Banded Stilt	0	0	0	0	41	0
Black Swan	3	297	0	0	7	0
Chestnut Teal	2	0	1	0	0	0
Eurasian Coot	200	1215	0	0	0	0
Grey Teal	115	377	32	0	3	0
Hardhead	5	0	0	0	0	0
Hoary-headed Grebe	12	104	0	6	0	0
Little Black Cormorant	0	0	0	0	0	1
Musk Duck	3	1	7	0	0	0
Pacific Black Duck	3	2	6	0	0	0
Pink-eared Duck	49	104	3	0	0	0
Red-capped Plover	0	0	0	0	2	0
Silver Gull	0	0	0	0	1	0
White-faced Heron	0	0	0	8	0	0

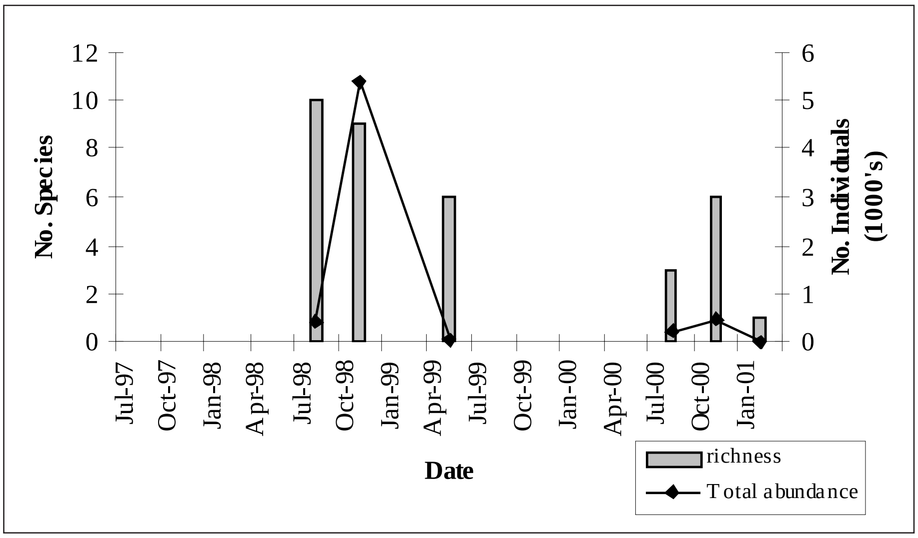

Figure 92. Waterbird species richness and abundance at Lake Eganu

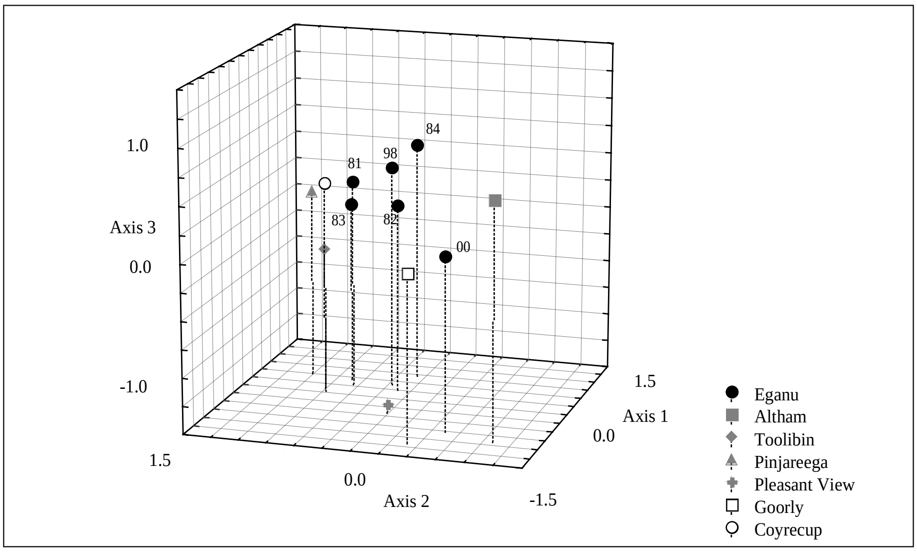

Figure 93. Ordination (PCR) of waterbird species data from Lake Eganu, showing historical and monitoring data for Lake Eganu and data for six marker wetlands.

There appear to have been significant changes in the waterbird community at Eganu over the past 20 years (Fig. 93). The 1998 community had affinities with surveys from the 1980s and to a lesser extent with the communities at Lake Pinjarrega, an adjacent, large and secondarily saline wetland. However, the 2000 community was more similar to that of Lake Goorly and Lake Altham, two naturally saline wetlands. The 1998 survey was from a period of unusually high water level, and consequent low salinity, in all sampling seasons. In contrast, the 2000 survey was conducted at lesser depths more similar to those occurring in the 1980s .

Invertebrates

Invertebrates were sampled at Lake Eganu in November 1998. A total of 26 species were collected (Table 34), with 19 species (73%) collected at both sub-sites, suggesting that habitat within the lake is relatively homogeneous and species were relatively evenly distributed. Fifty-three percent of the fauna were crustaceans (14 species). Ostracods were represented by eight species of which the halophilic *Autsralocypris insularis*, *Cyprinotus edwardi*, *Diacypris dictyote* and *Mytilocypris tasmanica chapmani* were most abundant. The salt lake gastropod *Coxiella* sp. was also numerous with abundances in excess of 10 000 individuals/sample. Eight species of insects (30% of fauna) were collected, including four dipteran families, the beetle *Berosus* sp. and two damselfly species of the genus *Austrolestes*.

The 1998 invertebrate community at Eganu was typical of a secondarily saline wetland (Fig. 94) but contained far more species than recorded by Halse (1981) (26 *vs* 8), despite substantially higher salinity in 1998. Halse (1981) towed a small plankton net through the water column and dense beds of *Lamprothamnion papulosum* growing in the lake; he did no benthic sampling and, unfortunately, his 1979 surveys cannot be compared with the 1998 monitoring. It is significant, however, that the amphipod *Austrochiltonia subtenuis*, which was abundant in 1979, was absent in the 1998. The salinity at the time of monitoring was within the tolerance of *A. subtenuis* but it is likely that this tolerance is exceeded more often than previously. If, as seems likely, neighbouring wetlands have also increased in salinity, it is possible that source popuations of *A. subtenuis* are no longer close enough to recolonise Lake Eganu. This can be contrasted with less tolerant species such as *Austrolestes* spp., which more easily recolonise the wetland because of their winged adult stage. The isopod *Haloniscus searlei*, which was present in 1998, has a greater salinity tolerance than *A. subtenuis* and may be a functional replacement for this species. The fish *Pseudogobius olorom* found by Halse (1981) was not present during monitoring.

TABLE 34
Invertebrate species collected from Lake Eganu in the 1998 sampling year.

TAXA	1998	TAXA	1998
Turbellaria	✓	*Metacyclops arnaudi* (sensu Kieffer)	✓
Nematoda	✓	*Apocyclops dengizicus*	✓
ROTIFERA		*Mesochra nr flava*	✓
Hexarthra fennica	✓	ISOPODA	
GASTROPODA		*Haloniscus searlei*	✓
Coxiella sp.	✓	COLEOPTERA	
CLADOCERA		*Berosus* sp.	✓
Daphniopsis sp.	✓	DIPTERA	
OSTRACODA		Stratiomyidae	✓
Australocypris insularis	✓	Dolichopodidae sp. A	✓
Cyprinotus edwardi	✓	Ephydridae	✓
Diacypris dictyote	✓	*Procladius paludicola*	✓
Diacypris spinosa	✓	*Cladopelma curtivalva*	✓
Diacypris compacta	✓	ODONATA	
Mytilocypris tasmanica chapmani	✓	*Austrolestes analis*	✓
Reticypris clava	✓	*Austrolestes io*	✓
Platycypris baueri	✓		
COPEPODA			
Calamoecia clitellata	✓		

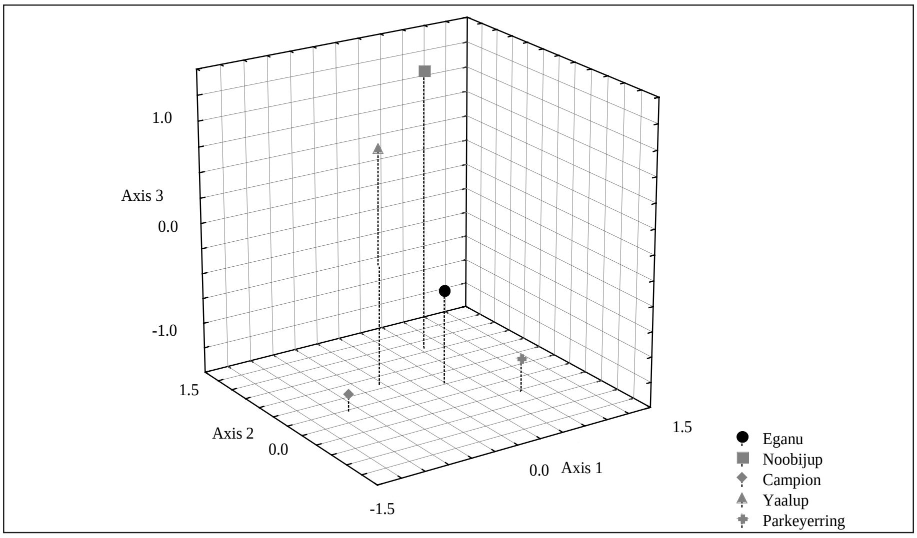

Figure 94. Ordination (SSH) of invertebrate data, showing Lake Eganu in 1998 and four marker wetlands.

Fraser Lake

Fraser Lake (Fig. 95) is situated on Mr Peter Maisey's farm immediately east of Lake Dowerin (31° 15'S 117° 04'E). This small (approximately 14 ha) ephemeral lake is fresh with a flat lakebed. Minor modification of the lakebed has occurred with the digging of two small dams to extend the period the lake holds surface water. The surrounding banks are relatively steep (except on the north-eastern side where inflow occurs) with a narrow belt of vegetation. Surrounding land has been cleared for agriculture. Inflow to the lake is principally from local run-off and there is no surface interaction with the secondarily saline Lake Dowerin, which lies west of Fraser.

Vegetation is dominated by *Austrostipa elegantissima*, which covers the lake-bed and grows to a height of 1.5 m (Gurner *et al.* 1999). Scattered *Melaleuca strobophylla* occur among the *Austrostipa* and on the western and southern shoreline, in association with scattered *Casuarina obesa*. These trees are replaced up-slope and elsewhere on the shoreline by an open eucalypt woodland of *Eucalyptus loxophleba* and *E. salmonophloia*. The understorey is species-poor and dominated by *Chenopodium* sp. and *Sclerolaena* sp.

Fraser Lake was selected for monitoring as an example of a fresh water wetland.

*Figure 95. Fraser Lake has a small man-made dam, however, the majority of the lakebed is dominated by Cane Grass (*Austrostipa elegantissima*). Photograph by Sheila Hamilton-Brown.*

Water chemistry and physico-chemical parameters

Fraser Lake was sampled in 1999 and 2000, although some water quality measurements and waterbird counts were made in spring 1998 as well. The lake held little water during 1998 and dried in spring. In 1999, it received winter inflow and then flooded to 1.5 m in March 2000 (Fig. 96). Water levels declined by the end of 2000, despite some winter inflow and the lake was close to dry in February 2001. Water was fresh in both years with electrical conductivity ranging from 508–4850 µS/cm. In March 1999, salinity did not decrease, despite a substantial increase in water depth, suggesting that inflowing water was of similar concentration to lake water. There was a pronounced increase in conductivity, however, in late summer 2001 as evapo-concentration occurred. Cation concentrations fitted a pattern of Na> K ≥ Ca >Mg and Cl was the dominant anion.

Water samples from August 1998 were collected in one of the dams in the lakebed and contained a high level of Total phosphorus (820 µg/l). Total nitrogen concentrations, throughout monitoring, were typical of wheatbelt wetlands (170–4600 µg/l). Total phosphorus was variable in 1999 and 2000, with occasional high values (20–140 µg/l). Chlorophyll concentrations also varied as a result of some minor algal blooms.

Groundwater

Monitoring bores were constructed on both vegetation transects at Fraser Lake in 1998, as well as at Maisey's Lagoon (also known as the 'Occurrence 2 wetland') to the north-west where additional vegetation transects were located (see Gurner *et al.* 1999). At Fraser Lake in March 1999, when the lake was dry, groundwater was between 1.5 and 3.4 m below the ground. After the lake filled in winter 1999, the lower bores on each transect were underwater continuously. Local groundwater was only 1.6 to 2.2 m below ground level in the upslope bores (Fig. 97), suggesting that it was likely to be generally recharging with lake-water unless the lake-bed was impermeable.

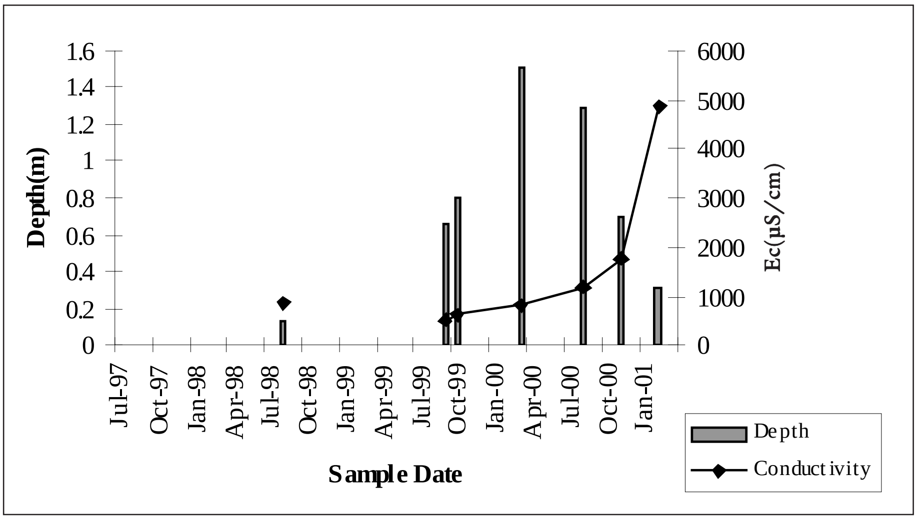

Figure 96. Gauged depth and electrical conductivity at Fraser Lake.

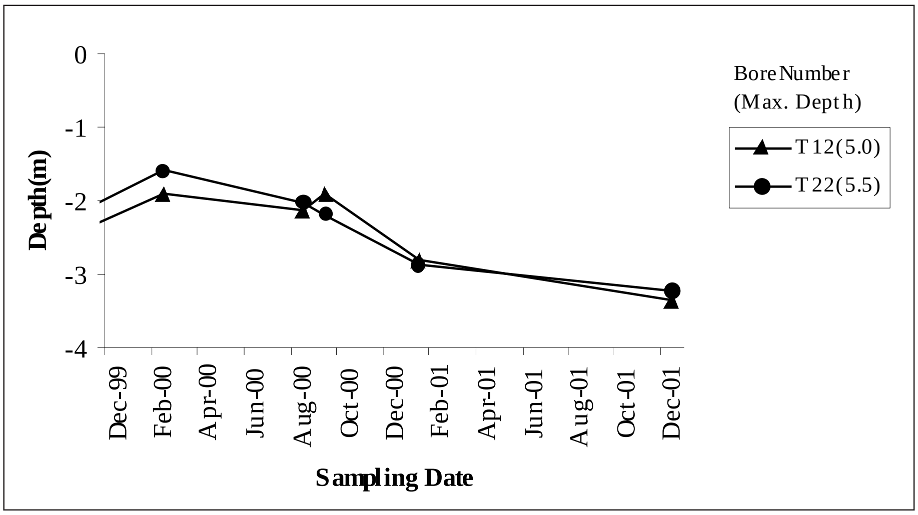

Figure 97. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Fraser Lake. Legend values in parenthesis are depth of the bore in metres.

Electrical conductivity of groundwater showed some temporal and spatial variation. Prior to the lake filling in 1999, groundwater conductivity varied from 26 700–62 900 µS/cm. During flooding in 2000, groundwater appeared to become fresher, as a result of either leakage of fresh water through lake-bed recharge or infiltration of bores, before returning to pre-flooding salinities. Groundwater was substantially more saline than lake water, however, and there is a high risk of Fraser Lake becoming secondarily saline if groundwater rises further. At the same time groundwater is clearly interacting with a deeper paleochannel of the East Mortlock River (CD Walker unpublished data), a structure also underlying the adjacent 'Occurrence 2' wetland (Hamilton-Brown and Blyth 2000) and Lake Walyormouring, and frequent lake-bed recharge may prove to protect the lake from groundwater salinity by forcing discharge elsewhere.

Waterbirds

Waterbirds were monitored in 1998, 1999 and 2000 (Table 35, Fig. 98). In 1998, with water in the dam only, the waterbird fauna was restricted to Grey Teal, Australian Shelduck, Black-tailed Native Hen and White-faced Heron which were present in low abundance. These data were not included in the monitoring analysis. Species richness was greater after the lake re-flooded in 1999 and after further flooding in March 2000. Waterbird abundance increased toward the end of both the 1999 and 2000 sampling year, although this probably reflects particular patterns of water levels rather than a consistent trend at the lake. Grey Teal, Eurasian Coot and Pacific Black Duck were consistently abundant and Pink-eared Duck (212 individuals) and Australian Wood Duck (95 individuals) were numerous in March 2000. The Black-tailed Native-Hen occurred regularly until spring 1999, after which this irruptive species was not recorded.

The waterbird assemblage at Fraser Lake was a mix of species typically found in fresh and brackish wetlands. Both 1999 and 2000 surveys occupied similar positions in the ordination (Fig. 99) and represented a different community from any of those at the marker wetlands, although most similar to Toolibin and Pinjarrega.

Invertebrates

A total of 73 invertebrate species were collected in October 1999, of which 41 species (56% of the fauna) were insects, 12 (16%) were crustaceans and 13 (18%) were rotifers (Table 36). Both the water column and benthos of the wetland appeared to be species-rich. Planktonic crustaceans, particularly the cladocerans *Simocephalus* sp. and *Macrothrix* sp. and the copepods *Boeckella triarticulata* and *Australocyclops australis* had densities in excess of 10 000 individuals/sample. Of the insects, only some chironomid species and the pelagic hemipteran *Anisops thienemanni* were numerous (>1 000 individuals/sample). The more species-rich insect groups were Chironomidae with 14 species, and Hemiptera and Odonata with six species each.

The invertebrate community at Fraser Lake was very similar to that at Yaalup Lagoon (Fig. 100) and also showed similarities with Paperbark Swamp (Fig. 106) reflecting the similar water quality and filling regime of these wetlands. It was a species-rich community but the individual species present are mostly widespread in fresh and brackish waters of south-western Australia.

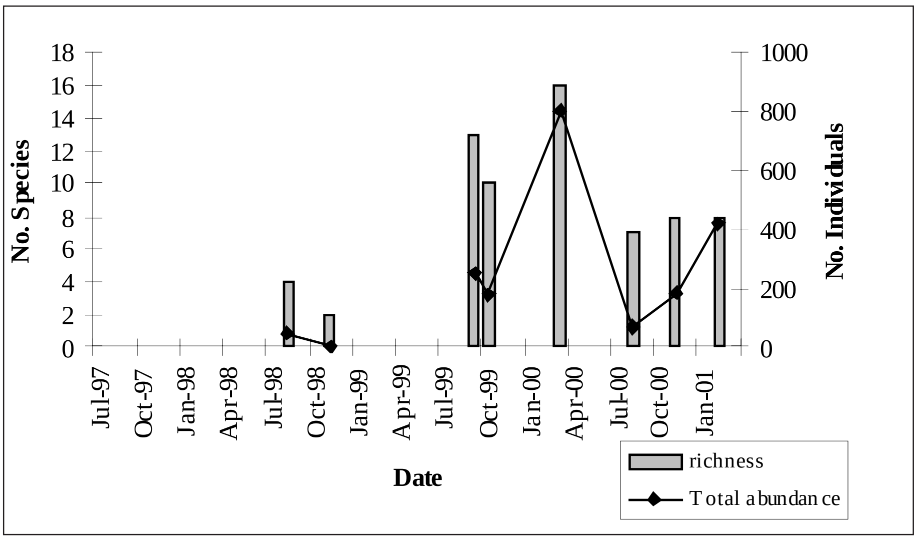

Figure 98. Waterbird species richness and abundance at Fraser Lake.

TABLE 35
Waterbird Species and their abundance on eight sampling occasions at Fraser Lake.

	SAMPLING DATE							
	AUG-98	NOV-98	SEP-99	OCT-99	MAR-00	AUG-00	NOV-00	FEB-01
Australasian Grebe	0	0	1	0	40	3	7	19
Australasian Shoveler	0	0	9	0	8	0	0	0
Australian Shelduck	2	0	2	0	13	0	0	0
Australian Wood Duck	0	0	0	15	95	0	2	0
Baillon's Crake	0	0	0	2	0	0	0	0
Black-tailed Native-hen	6	1	20	30	0	0	0	0
Black-winged Stilt	0	0	0	0	0	0	0	22
Blue-billed Duck	0	0	0	0	2	0	0	0
Eurasian Coot	0	0	69	28	57	38	14	50
Grey Teal	38	0	103	78	235	5	120	308
Hardhead	0	0	22	5	17	0	2	0
Hoary-headed Grebe	0	0	0	0	9	0	0	0
Little Black Cormorant	0	0	0	0	1	0	0	0
Little Grassbird	0	0	0	5	0	0	1	4
Little Pied Cormorant	0	0	0	0	1	1	0	0
Musk Duck	0	0	2	1	1	0	0	0
Pacific Black Duck	0	0	1	7	109	13	29	9
Pink-eared Duck	0	0	11	8	212	0	0	0
Swamp Harrier	0	0	1	0	2	1	0	1
White-faced Heron	1	1	1	0	3	5	6	9
Yellow-billed Spoonbill	0	0	7	0	0	0	0	0

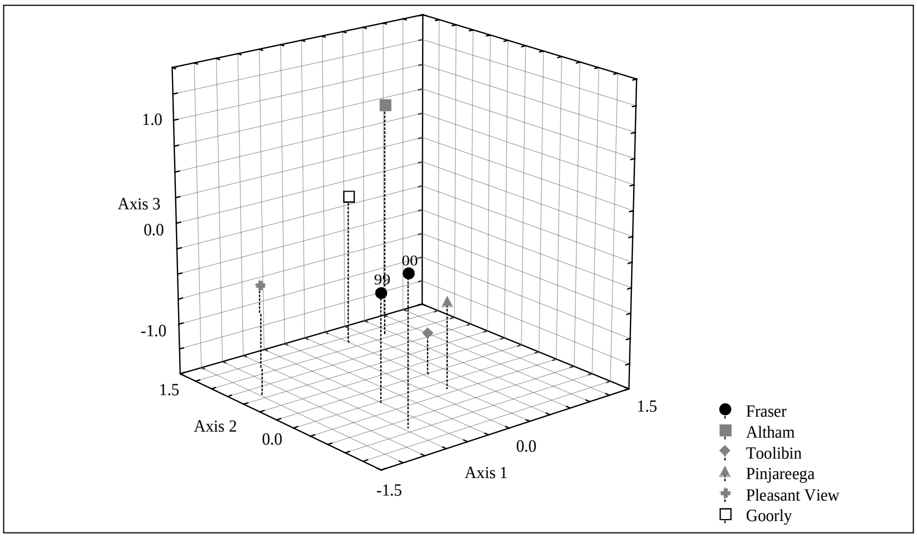

Figure 99. Ordination (SSH) of waterbird species data, showing Fraser Lake from 1999 and 2000 and the five marker wetlands.

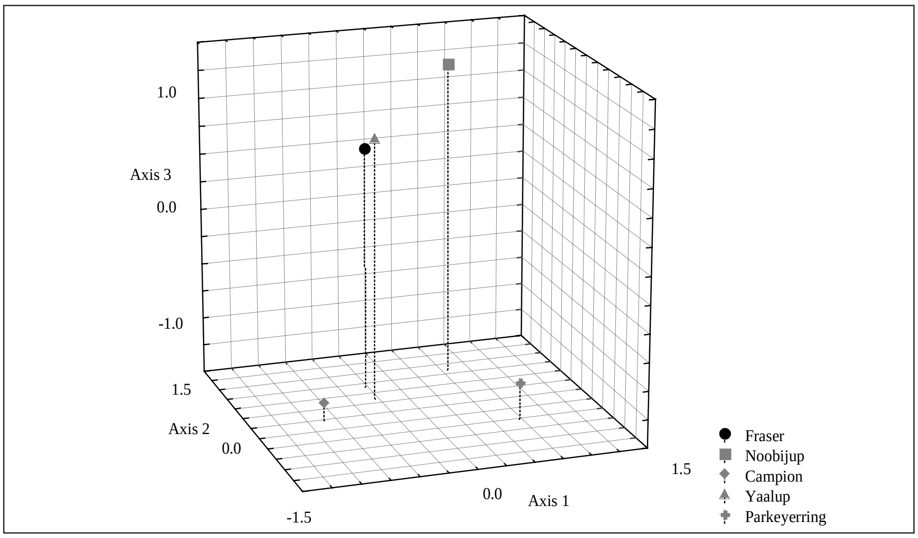

Figure 100. Ordination (SSH) of invertebrate data, showing Fraser Lake in 1999 and four marker wetlands.

TABLE 36
Invertebrate species collected from Fraser lake in the 1998 sampling year.

TAXA	1998	TAXA	1998
Spongillidae	✓	COLEOPTERA	
Turbellaria	✓	*Allodessus bistrigatus*	✓
Nematoda	✓	*Antiporus gilberti*	✓
HYDRAZOA		*Sternopriscus multimaculatus*	✓
Sinantherina cf. (colony)	✓	*Megaporus howitti*	✓
ROTIFERA		*Rhantus* sp.	✓
Flosculariidae	✓	*Berosus macumbensis*	✓
Brachionus quadridentatus	✓	*Enochrus maculiceps*	✓
Euchlanis sp.	✓	*Limnoxenus zelandicus*	✓
Lecane bulla	✓	Hydrophilidae	✓
Lecane ludwigii	✓	DIPTERA	
Lecane luna	✓	*Anopheles annulipes*	✓
Lecane sp.	✓	*Culex* (*Culex*) *australicus*	✓
Cephalodella gibba	✓	Stratiomyidae	✓
Trichocerca rattus	✓	*Procladius paludicola*	✓
Trichocerca weberi	✓	*Ablabesmyia notabilis*	✓
Trichocerca sp.	✓	*Paramerina levidensis*	✓
Trichocercidae	✓	*Corynoneura* sp.	✓
GASTROPODA		*Cricotopus 'parbicinctus'*	✓
Glyptophysa cf. *gibbosa*	✓	*Tanytarsus* nr *bispinosus*	✓
OLIGOCHAETA		*Paratanytarsus* sp.	✓
Aphanoneura	✓	*Chironomus tepperi*	✓
Naididae	✓	*Chironomus* aff. *alternans*	✓
ACARINA		*Dicrotendipes conjunctus*	✓
Acercella falcipes	✓	*Kiefferulus intertinctus*	✓
CLADOCERA		*Kiefferulus martini*	✓
Alona rigidicaudis s.l.	✓	*Polypedilum nubifer*	✓
Pleuroxus sp.	✓	*Parachironomus* sp. 1	✓
Simocephalus sp.	✓	HEMIPTERA	
Macrothrix sp.	✓	*Microvelia* sp.	✓
OSTRACODA		*Saldula brevicornis*	✓
Bennelongia barangaroo	✓	*Sigara* sp.	✓
Cypretta baylyi	✓	*Agraptocorixa parvipunctata*	✓
Cypericercus salinus	✓	*Micronecta* sp.	✓
Sarscypridopsis sp. 165 (Bennetts)	✓	*Anisops thienemanni*	✓
COPEPODA		*Anisops baylii*	✓
Boeckella triarticulata	✓	ODONATA	
Metacyclops sp. 434 (*arnaudi* sensu Sars)	✓	*Ischnura aurora aurora*	✓
Australocyclops australis	✓	*Austrolestes annulosus*	✓
AMPHIPODA		*Austrolestes aridus*	✓
Austrochiltonia subtenuis	✓	*Hemianax papuensis*	✓
		Diplacodes bipunctata	✓
		Hemicordulia tau	✓
		TRICHOPTERA	
		Oecetis sp.	✓
		Triplectides australis	✓

Paperbark Swamp

Paperbark Swamp (Fig. 101) lies within Paperbark Nature Reserve (Res. No.12900) south-east of Corrigin (32° 24'S 118° 06'E). This ephemeral fresh wetland comprises a number of small irregular basins (1–1.5 m deep when full) that are interconnected by slightly shallower broad channels. Water is frequently turbid because of the clay substrate. Surface inflow enters at the south end of the wetland from undefined channels that drain farmland to the south and south-west. Outflow, if it occurs, empties into a saline chain of lakes known collectively as the Bendering Lakes, which lie 2–3 km north of the swamp.

There is a dam on the lakebed at the north end where surface water persists for several months after the rest of the swamp has dried. Vegetation on the southern boundary of the reserve shows symptoms of waterlogging and salinity stress (Gurner *et al.* 1999). Vegetation of the swamp is in better condition with mature *Melaleuca strobophylla* and *M. phoidophylla* dominating the overstorey and forming a sparse seasonally inundated understorey through the centre and southern part of the wetland. At the northern end, *M. lateriflora* and *M phoidophylla* grow over an understorey that includes *Enchylaena tomentosa*, *Atriplex semibaccata*, *Maireana brevifolia*, *Grevillea acuaria*, *Lomandra effusa* and *Chenopodium* spp.

Paperbark Swamp has a history of salinity and depth measurements, and was included in the monitoring program because it is fresh and was known to support an intact and diverse invertebrate community.

Water chemistry and physico-chemical parameters

Paperbark Swamp was monitored in 1999. Winter rainfall caused inflow and further flooding occurred as a result of cyclonic rains in January 2000 (Fig. 102). When full, conductivity ranged from 447 to 588 µS/cm and cation concentrations exhibited a pattern of Na>Ca>Mg=K. The dominant anion was HCO_3, which is unusual in the Wheatbelt. Turbidity was high (1400 NTU) in spring 1999, the only occasion it was measured. Total phosphorus concentrations in the lake were also high (range 110–615 µg/l). Although samples were passed through a 0.45 µm filter prior to analysis, it is possible that high values are the result of some contamination by phosphorus adsorbed to clay particles. Total nitrogen concentrations were moderate (range 1600–2650 µg/l). Chlorophyll concentrations were relatively low despite high phosphorus levels, either because most of the phosphorus was unavailable or because high turbidity limited the availability of light.

Groundwater

Monitoring bores were installed on the three vegetation transects in 1999. Maximum depth to groundwater was recorded in January 2000 and varied between 3.1 and 5.7 m depending on location (Fig. 103). After the heavy rain in January 2000, groundwater levels rose 13 m but had returned to near pre-flooding levels by spring of that year. Electrical conductivity of groundwater showed enormous temporal and spatial variation (1730–77 000 µS/cm) depending on whether bores were sampling regional groundwater, perched freshwater lenses or a combination of both. Groundwater was always more saline than surface water.

Waterbirds

A total of nine species were recorded in 1999, with species richness being greatest in autumn after the lake flooded extensively (Table 37, Fig. 104). The most abundant species was the Grey Teal (13–32 individuals), which was present on all sampling occasions. In October 1999, White-necked Heron were breeding and 14 Nankeen Night Heron were recorded in March 2000. Jaensch *et al.* (1988) recorded one species from a single survey.

The waterbird community at Paperbark during the 1999 sampling year was a depauperate one with a mix of species, several of which are more-or-less restricted to fresh water. It did not show affinity with any of the marker wetlands (Fig. 105).

Invertebrates

Invertebrates were monitored in spring 1999 and 74 species were collected (Table 38). Species composition was dominated by insects with a total of 39 species (52% of the fauna). There were 11 species of beetle, including *Hyderodes* sp., which is typically collected from vegetated swamps with turbid or coloured water. Hemipterans were also well represented (7 species) but the most abundant insect species were the dipterans *Chironomus tepperi*, *Chironomus* aff. *alternans* and Stratiomyidae. A total of

Figure 101. Paperbark Swamp is an ephemeral freshwater wetland in the Paperbark Nature Reserve.

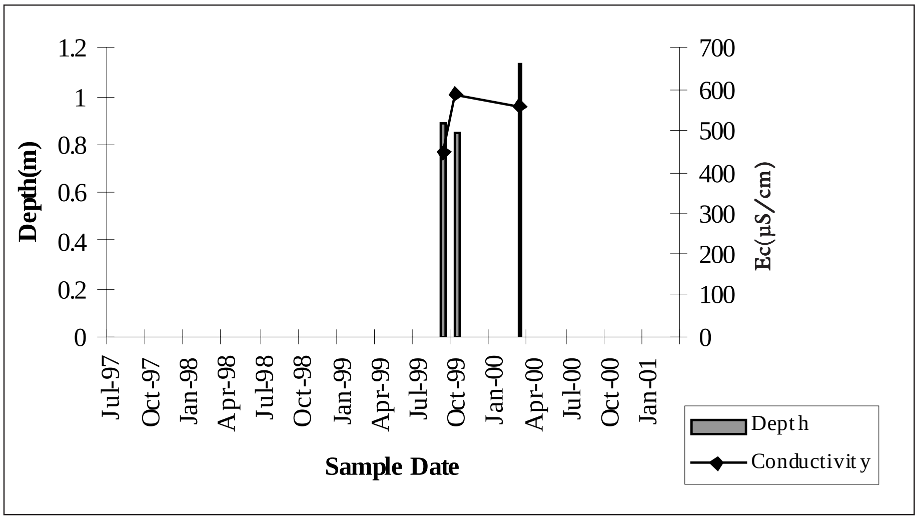

Figure 102. Gauged depth and electrical conductivity at Paperbark Swamp.

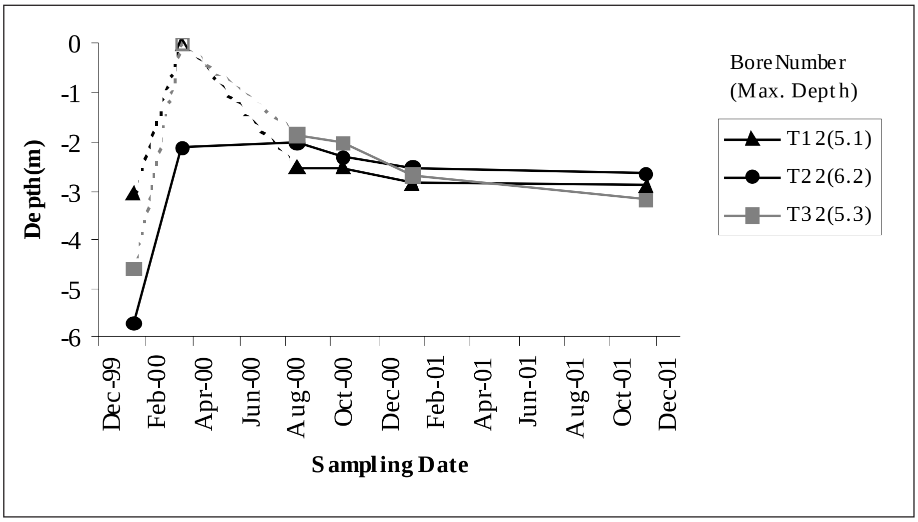

Figure 103. Groundwater level on the lowest bore on each vegetation transect at Paperbark Swamp. Legend values in parentheses are total depth of bores in metres. Open symbols represent sample period where bore was dry or underwater.

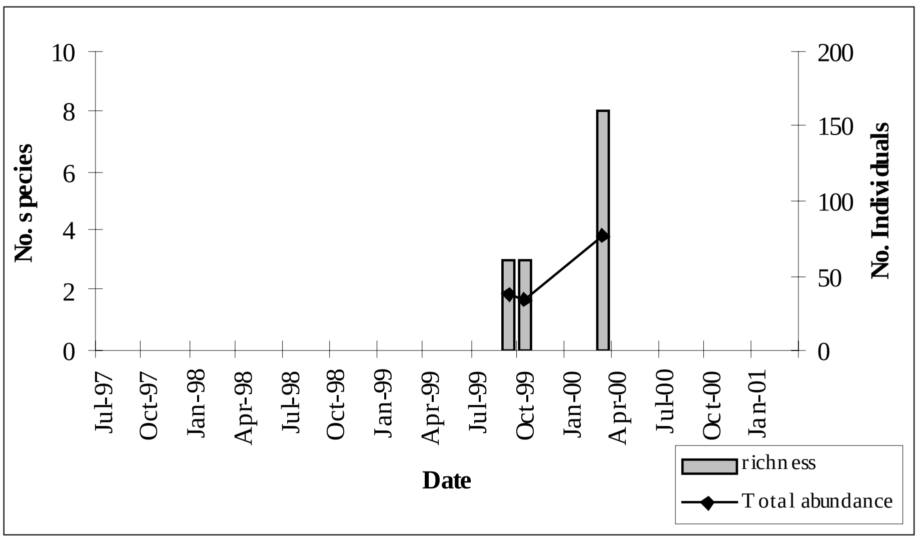

Figure 104. Waterbird species richness and abundance at Paperbark Swamp.

TABLE 37
Waterbird species and their abundance on three sampling occasions at Paperbark Swamp.

	SAMPLING DATE SEP-99	OCT-99	MAR-00
Australian Wood Duck	4	0	5
Eurasian Coot	0	0	14
Grey Teal	32	28	13
Hoary-headed Grebe	0	0	6
Nankeen Night Heron	0	0	14
Pacific Black Duck	1	3	8
Pink-eared Duck	0	0	12
White-faced Heron	0	0	4
White-necked Heron	0	2	0

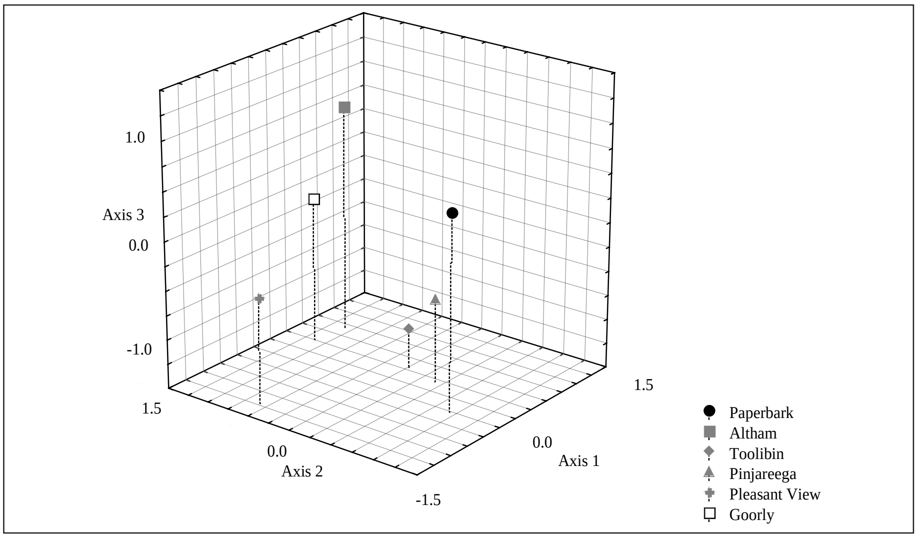

Figure 105. Ordination (SSH) of waterbird species data, showing Paperbark Swamp from 1999 and the five marker wetlands.

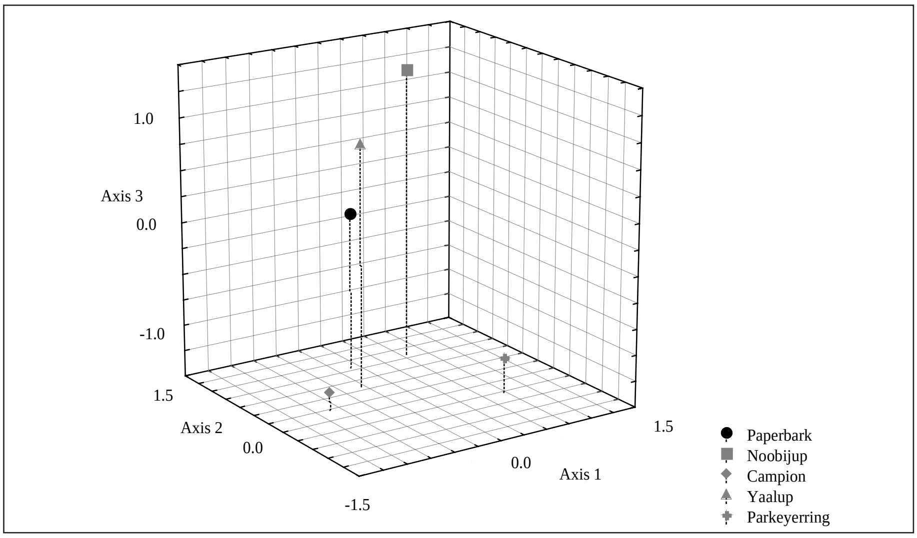

Figure 106. Ordination (SSH) of invertebrate data, showing Paperbark Swamp in 1999 and four marker wetlands.

22 species of crustaceans (29% of the fauna) were collected and, while not as species-rich as the insects, they were numerically dominant with the anostracan *Branchinella lyrifera* and the ostracod *Bennelongia barangaroo* both recorded at densities in excess of 10 000 individuals/ sample. Two species of conchostracans, *Lynceus* sp. and *Caenestheriella* sp., were also collected in large numbers.

The invertebrate community at Paperbark Swamp had similarities to that at Yaalup Lagoon, although there was a stronger freshwater element in the fauna (Fig. 106). Paperbark has considerable conservation importance for aquatic invertebrates. While many of the species recorded are capable of dispersing widely as the wetland dries or becomes unsuitable, others such as conchostracans and anostracans rely on a dessication-resistant stage to persist at Paperbark between filling cycles. These latter species would be compromised by changes in the hydrological cycle or water quality.

TABLE 38
Invertebrate species collected from Paperbark Swamp in the 1999 sampling year.

TAXA	1999	TAXA	1999
Turbellaria	✓	ISOPODA	
Nematoda	✓	*Haloniscus searlei*	✓
ROTIFERA		*Styloniscus* sp.	✓
Lepadella sp.	✓	COLEOPTERA	
Lecane sp.	✓	*Hyphydrus elegans*	✓
Notommatidae	✓	*Allodessus bistrigatus*	✓
Trichocerca sp.	✓	*Antiporus gilberti*	✓
GASTROPODA		*Sternopriscus multimaculatus*	✓
Isidorella sp.	✓	*Lancetes lanceolatus*	✓
OLIGOCHAETA		*Hyderodes* sp.	✓
Ainudrilus nharna	✓	*Eretes australis*	✓
Opisthopora	✓	*Berosus approximans*	✓
ACARINA		*Enochrus maculiceps*	✓
Eylais sp.	✓	*Limnoxenus zelandicus*	✓
Limnesia dentifera	✓	Hydrophilidae	✓
Oribatida	✓	Staphylinidae	✓
Trombidioidea	✓	Scirtidae sp.	✓
ANOSTRACA		DIPTERA	
Branchinella lyrifera	✓	Tipulidae group A	✓
CONCHOSTRACA		*Bezzia* sp. 2	✓
Caenestheriella sp.	✓	*Culicoides* sp.	✓
Lynceus sp.	✓	Forcypomyia sp.	✓
CLADOCERA		Tabanidae	✓
Diaphanosoma sp.	✓	Stratiomyidae	✓
Pleuroxus sp.	✓	Dolichopodidae sp. A	✓
Daphnia carinata	✓	Ephydridae	✓
Daphnia cf. *cephalata*	✓	*Procladius paludicola*	✓
Simocephalus sp.	✓	*Paramerina levidensis*	✓
OSTRACODA		*Paralimnophyes pullulus*	✓
Ilyocypris australiensis	✓	*Cricotopus brevicornis*	✓
Alboa worooa	✓	*Tanytarsus* sp. A (nr. K10)	✓
Bennelongia barangaroo	✓	*Chironomus tepperi*	✓
Candonocypris novaezelandiae	✓	*Chironomus* aff. *alternans*	✓
Heterocypris tatei	✓	*Cryptochironomus griseidorsum*	✓
Cypericercus salinus	✓	HEMIPTERA	
Sarscypridopsis aculeata	✓	Mesoveliidae	✓
COPEPODA		*Saldula brevicornis*	✓
Boeckella triarticulata	✓	*Agraptocorixa parvipunctata*	✓
Boeckella robusta	✓	*Micronecta robusta*	✓
Calamoecia sp. 342 (*ampulla* variant)	✓	*Anisops thienemanni*	✓
Metacyclops sp. 442 (*salinarum* in Morton)	✓	*Anisops hyperion*	✓
Australocyclops australis	✓	Anisops gratus	✓
		ODONATA	
		Austrolestes analis	✓
		Austrolestes aridus	✓
		TRICHOPTERA	
		Triplectides australis	✓

Coomalbidgup Swamp

Coomalbidgup Swamp (Fig. 107) lies within Coomalbidgup Nature Reserve 45 km west of Esperance on the South Coast Highway (33° 24'S 121° 21'E). Once an ephemeral wetland with live trees growing across the lake-bed, the swamp has been substantially wetter since 1986 owing to run-off from the extensively cleared catchment of 97 km^2 to the north-east (Froend and van der Moezel 1994). Large areas of the original lake vegetation have died, with 45% of the trees on the lake-bed dead by 1992 (Froend and van der Moezel 1994) and 100% by 1998 (Ogden and Froend 1998).

The lakebed now supports only dead stems of *Eucalyptus occidentalis*, *Melaleuca cuticularis* and *Banksia speciosa*. However, distinct thickets of *E. occidentalis* and *M. cuticularis* seedlings have established around the lake margin in recent years, reflecting strandlines from flood events. There is no evidence of regeneration by *B. speciosa*, perhaps because of the lack of fire since flooding occurred (Ogden and Froend 1998).

Coomalbidgup was included in the monitoring program because of the changes in catchment hydrology that are currently taking place and the opportunity to document changes in vegetation, invertebrates and waterfowl associated with the early stages of salinization.

Water chemistry and physico-chemical parameters

Coomalbidgup Swamp was monitored in late winter and spring 1999 but was inaccessible in autumn 2000 because of flooding after extensive rain in late summer. There was a surprisingly large (0.5 m) drop in water level between late winter and spring (Fig. 108) while conductivity showed little variation (5240–5615 µS/cm). This suggested considerable leakage through parts of the lake-bed when lake levels are high. The pattern of cation concentrations was Na>Mg>Ca>K, while Cl was the dominant anion. Total nitrogen concentration was moderately low (1200 µg/l) but Total phosphorus was high (160–190 µg/l). Coomalbidgup contains moderately dark water (100 TCU) and high phosphorus concentrations are common in such wetlands (Wrigley *et al.* 1988). Chlorophyll levels were low.

Groundwater

Monitoring bores were not installed until 2001 because, prior to this, vegetation transects were underwater. In some areas the groundwater level was close to the lakebed when lake levels were high, suggesting some lateral recharge flows out of the lake (Fig. 109). Other bores nearby have remained dry even when inside the inundated part of the lake. The vegetation transects and monitoring bores are located on the south-eastern and north-western sides of the swamp and do not give clear information about groundwater behaviour. Study of the lake structure indicates that groundwater (and surface water) flows through the lake in a north-east to south-west direction.

Groundwater salinity appears variable, ranging from 794 to 19 540 µS/cm in samples taken during 2001. This again suggests localised recharge of fresher lake water into portions of the surrounding profile, while salt accumulation around vegetation root systems has occurred elsewhere.

Waterbirds

A total of 17 species of waterbird were recorded at Coomalbidgup Swamp in 1999. Total abundance was greatest in spring (319 individuals) but most species were represented by fewer than 10 birds (Table 39, Fig. 110). There appears to have been an increase in waterbird use of the swamp since 1988-92, when twice-yearly counts of ducks, swans and coots recorded a maximum count of 84 birds (compared with 248 in spring 1999) and a maximum species count of six compared with nine (see Halse *et al.* 1994).

The waterbird community was similar to that recorded at Lake Pinjerrega in the early 1980s (Fig 111), reflecting the dominance of duck species. There is also some similarity between the community composition at Coomalbidgup and Fraser Lake (Fig. 99) which is of interest given that Coomalbidgup had a relatively constant salinity (*ca.* 5000 µS/cm) at the top end of that observed at Fraser Lake.

Figure 107. Lake Coomalbidgup was an ephemeral wetland but changing hydrology has increased the period of inundation and killed the once dominant overstorey of Eucalyptus occidentalis.

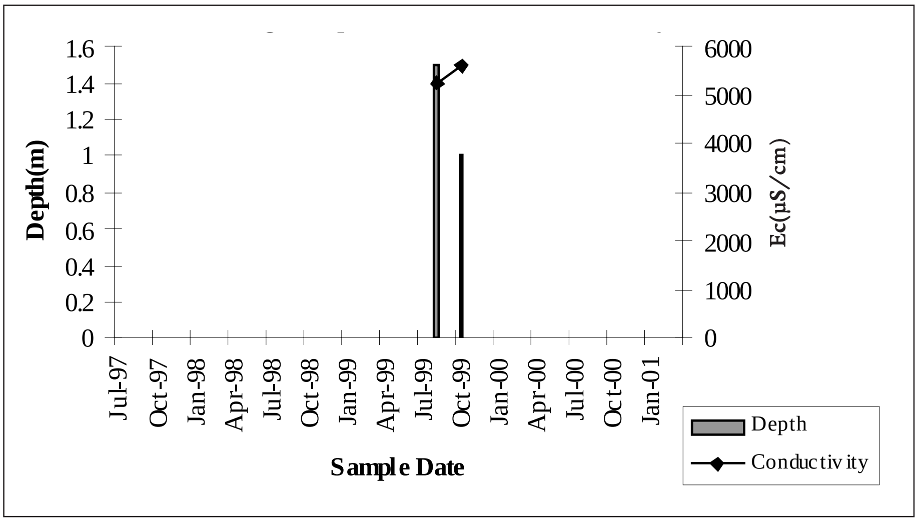

Figure 108. Gauged depth and electrical conductivity at Lake Coomalbidgup.

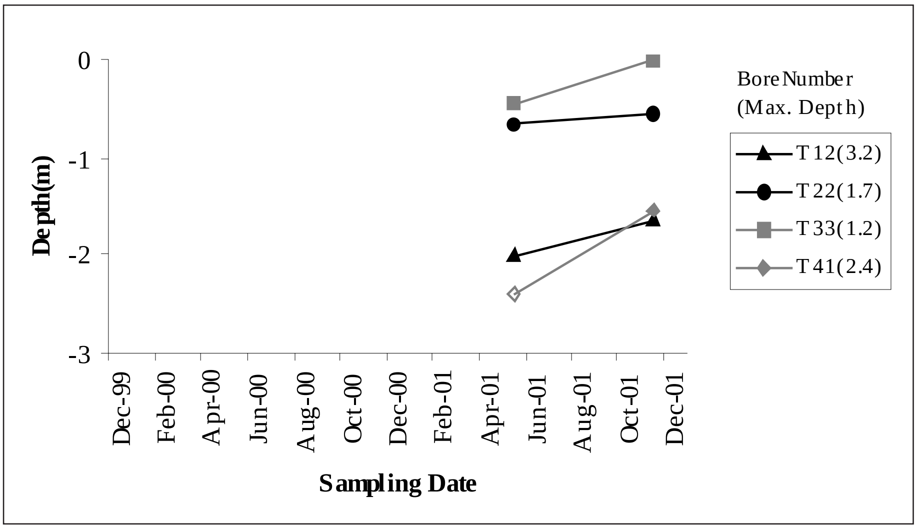

Figure 109. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Coomalbidgup. Open symbols represent dry bores. Legend values in parenthesis are depth of the bore in metres.

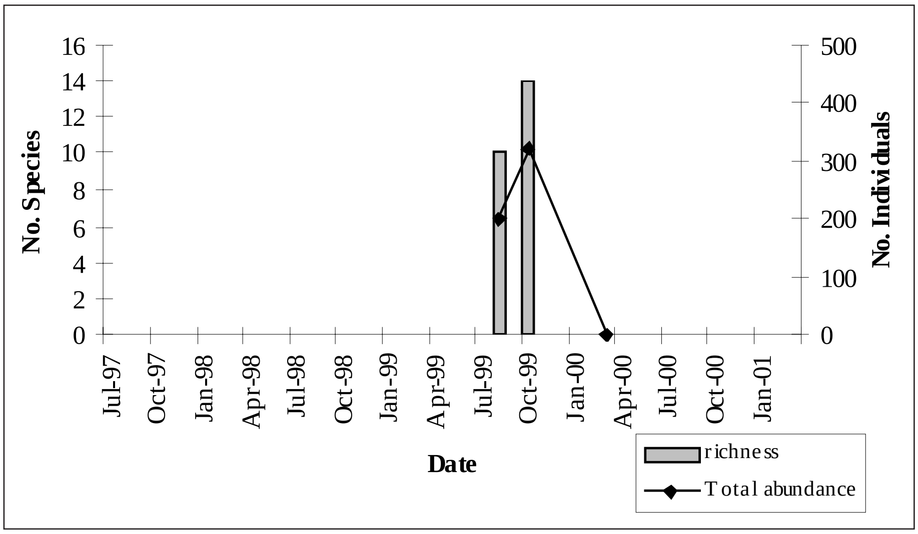

Figure 110. Waterbird species richness and abundance at Lake Coomalbidgup.

TABLE 39
Waterbird species and their abundance on three sampling occasions at Lake Coomalbidgup.

	SAMPLING DATE		
	AUG-99	OCT-99	MAR-00
Australasian Grebe	4	0	0
Australasian Shoveler	0	2	0
Black Swan	0	2	0
Blue-billed Duck	0	1	0
Chestnut Teal	4	3	0
Clamorous Reed-Warbler	0	2	0
Eurasian Coot	119	80	0
Grey Teal	12	109	0
Hardhead	2	0	0
Hoary-headed Grebe	29	56	0
Little Pied Cormorant	0	8	0
Musk Duck	7	9	0
Nankeen Night Heron	0	2	0
Pacific Black Duck	16	24	0
Pink-eared Duck	5	18	0
White-faced Heron	0	3	0
Yellow-billed Spoonbill	1	0	0

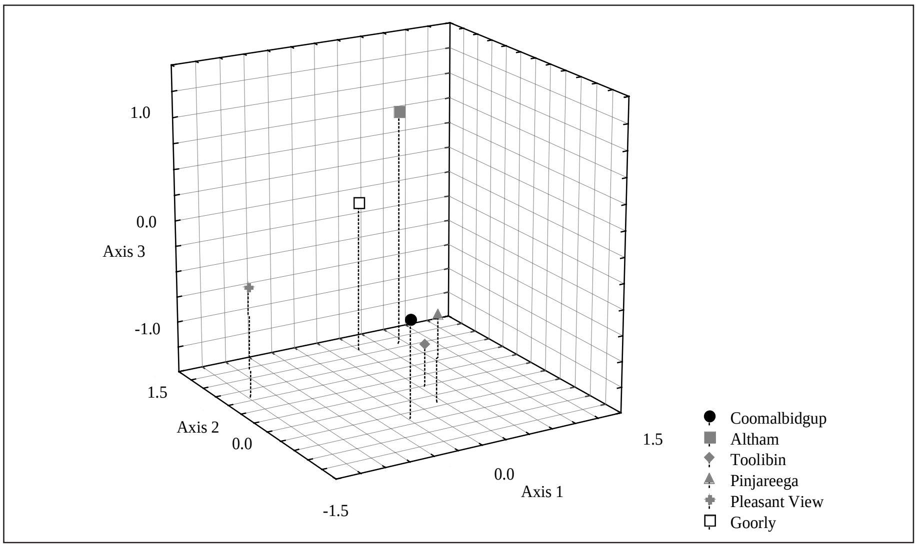

Figure 111. Ordination (SSH) of waterbird species data, showing Lake Coomalbidgup from 1999 and the five marker wetlands.

Invertebrates

A total of 67 species were collected in spring 1999 (Table 40). Insects dominated the fauna with 36 species (53% of the fauna) compared with 15 species of crustacean (22%). Rotifera were also significant in terms of richness with 10 species (14%), but were collected in low abundance. The most abundant species were crustaceans (two chydorids, two ostracods and the amphipod *Austrochiltonia subtenuis*), collected at densities in excess of 10 000 individuals/sample and suggesting some eutrophication of the wetland. Insect species were generally collected at low abundance except for the chironomids *Chironomus* aff. *alternans*, *Kiefferulus intertinctus*, *Polypedilum nubifer* and the hemipteran *Anisops thienemanni*, which were abundant. Eight species of odonates were collected, representing the most diverse odonate assemblage in any monitored wetland.

Invertebrate community structure resembled that of other freshwater wetlands in the monitoring program, lying closest to Yaalup in ordination space (Fig. 112).

TABLE 40
Invertebrate species collected from Lake Coomalbidgup in the 1999 sampling year.

TAXA	1999
Hydra sp.	✓
Turbellaria	✓
Nematoda	✓
ROTIFERA	
Rotaria sp.	✓
Brachionus angularis	✓
Keratella procurva	✓
Keratella quadrata	✓
Euchlanis dilatata	✓
Euchlanis sp.	✓
Lecane ludwigii	✓
Lecane sp.	✓
Lecanidae	✓
Cephalodella sp.	✓
OLIGOCHAETA	
Dero digitata	✓
Enchytraeidae	✓
ACARINA	
Hydrachna nr. *approximata*	✓
CLADOCERA	
Leydigia sp.	✓
Pleuroxus sp.	✓
Simocephalus sp.	✓
OSTRACODA	
Ilyocypris australiensis	✓
Alboa worooa	✓
Candonocypris novaezelandiae	✓
Cypretta baylyi	✓
Sarscypridopsis sp. 165 (Bennetts)	✓
COPEPODA	
Boeckella triarticulata	✓
Calamoecia sp. 342 (*ampulla* variant)	✓
Mesocyclops brooksi	✓
Eucyclops australiensis	✓
Paracyclops ?chiltoni	✓
Nitocra reducta	✓
AMPHIPODA	
Austrochiltonia subtenuis	✓
COLEOPTERA	
Hyphydrus elegans	✓
Sternopriscus multimaculatus	✓
Megaporus howitti	✓
Lancetes lanceolatus	✓
Onychohydrus scutellaris	✓
Berosus australiae	✓
Hydrophilidae	✓
DIPTERA	
Anopheles annulipes	✓
Culicoides sp.	✓
Nilobezzia sp. 1	✓
Stratiomyidae	✓
Procladius villosimanus	✓
Paramerina levidensis	✓
Paralimnophyes pullulus	✓
Tanytarsus sp. A (nr. K10)	✓
Chironomus aff. *alternans*	✓
Dicrotendipes pseudoconjunctus	✓
Kiefferulus intertinctus	✓
Polypedilum nubifer	✓
Cladopelma curtivalva	✓
HEMIPTERA	
Microvelia sp.	✓
Agraptocorixa eurynome	✓
Micronecta robusta	✓
Anisops thienemanni	✓
Anisops hyperion	✓
ODONATA	
Ischnura aurora aurora	✓
Ischnura heterosticta heterosticta	✓
Xanthagrion erythroneurum	✓
Austrolestes analis	✓
Austrolestes annulosus	✓
Austrolestes io	✓
Hemianax papuensis	✓
Hemicordulia tau	✓
TRICHOPTERA	
Notalina spira	✓
Oecetis sp.	✓
Triplectides australis	✓

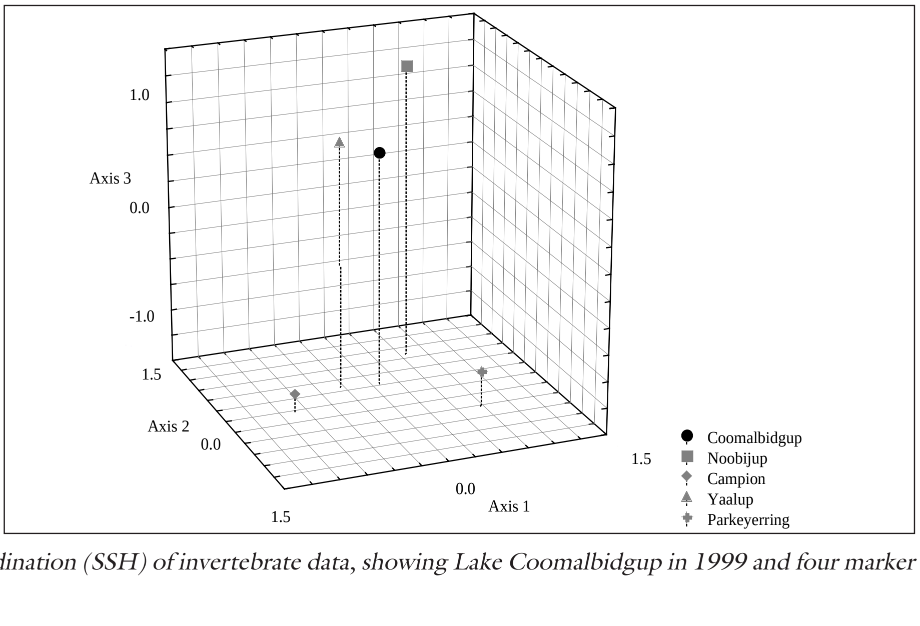

Figure 112. Ordination (SSH) of invertebrate data, showing Lake Coomalbidgup in 1999 and four marker wetlands.

Yaalup Lagoon

Situated in an un-named Nature Reserve (Res. No. 36967) 25 km north-east of Ongerup (33° 45'S 118° 34'E), Yaalup Lagoon is small (15.7 ha), fresh and semi-permanent (Halse *et al.* 1993b). The wetland basin (Fig. 113) is shallow with an undulating bed of sandy clays and, after heavy rain, floods beyond the wetland boundary into surrounding *Eucalytpus occidentalis* woodland. Water is frequently turbid because of the clay substrate. The surrounding catchment is cleared for farming except within the Reserve 36967 and a large adjacent nature reserve to the south-west, where the vegetation is in good condition (though see comments in groundwater section). The lake fills from a poorly defined channel that enters the lagoon from the south-west.

Less than one third of the lake area is open water. The remainder comprises a closed woodland dominated by *E. occidentalis* with scattered dense thickets of *Melaleuca strobophylla* (Gurner *et al.* 2000). The understorey is sparse and includes *Atriplex* sp. and *Centipeda minima*. Yaalup Lagoon has been depth-gauged since 1982 (Lane and Munro 1983), providing a long history of depth records. Similarly, there are some historical records of waterbirds that suggest the lake supports a moderate number of species at low abundance (Jaensch *et al.* 1988). The lake was included in the monitoring program as an example of a fresh wetland in which ecological condition is likely to decline in the short term.

Water chemistry and physico-chemical parameters

Yaalup Lagoon was monitored in 1999. Water level dropped only 10 cm between late winter and spring 1999 and then increased as a result of autumn rains to reach a maximum depth of 1.62 m in March 2000 (Fig. 114). Electrical conductivity indicated fresh conditions throughout the year (range 683–1192 µS/cm). Cation concentrations exhibited the common pattern Na>Ca>Mg>K and HCO_3 was the dominant anion. In spring 1999, the water was both turbid (850 NTU) and coloured (390 TCU). Chlorophyll levels were moderately low in both winter and spring of 1999 but in autumn 2000 they increased to 79 µg/l indicating high levels of algal production. Total phosphorus concentrations were consistently high (range 140–540 µg/l), but Total nitrogen concentrations were moderate (range 3100–3200 µg/l).

Groundwater

Monitoring bores were installed on both vegetation transects in 1999 and monitoring commenced in April 2000 when the lagoon was recently flooded and groundwater was shallow (range 1.28–2.60 m) compared with April 2001 (2.67–2.99 m) (Fig. 115). Groundwater was saline but showed some spatial and temporal variation (33 400–63 300 µS/cm), with lowest values recorded in September 2000. Groundwater was always substantially more saline than surface water and the lagoon would be threatened by rising groundwater. Some recent tree deaths on the eastern margin of the reserve and in adjacent farmland are probably a fore-warning of broader-scale deaths in the reserve and wetland.

Waterbirds

Seven species of waterbird were recorded from Yaalup Lagoon during monitoring (Table 41, Fig. 116) with a maximum abundance of 60 birds in March 2000. This is a substantially smaller fauna than the 18 species recorded in 24 surveys between 1981 and 1985 (Jaensch *et al.* 1988). The discrepancy is probably partly the result of fewer surveys during the monitoring program, but higher water levels during 1984 would have contributed to more species in the early 1980s .

Figure 113. Yaalup Lagoon is a semi-permenant freshwater wetland surrounded by Eucalyptus occidentalis.

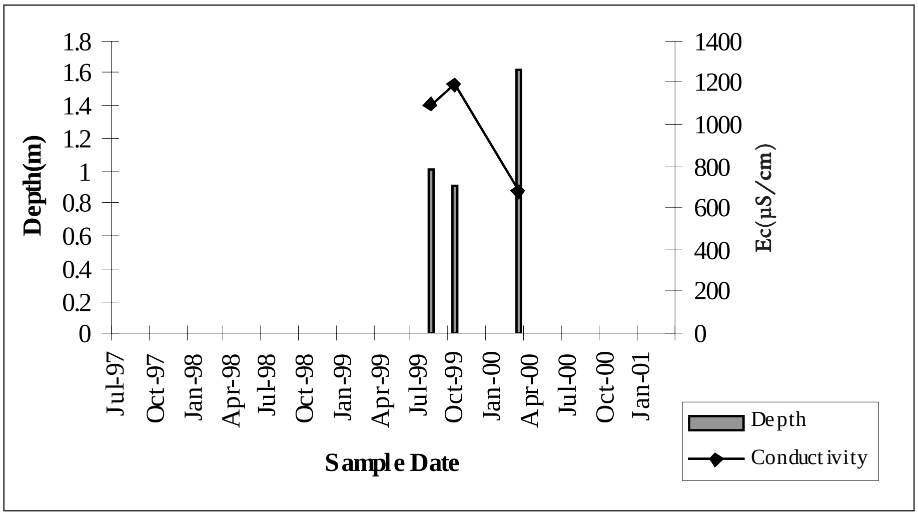

Figure 114. Gauged depth and electrical conductivity at Yaalup Lagoon.

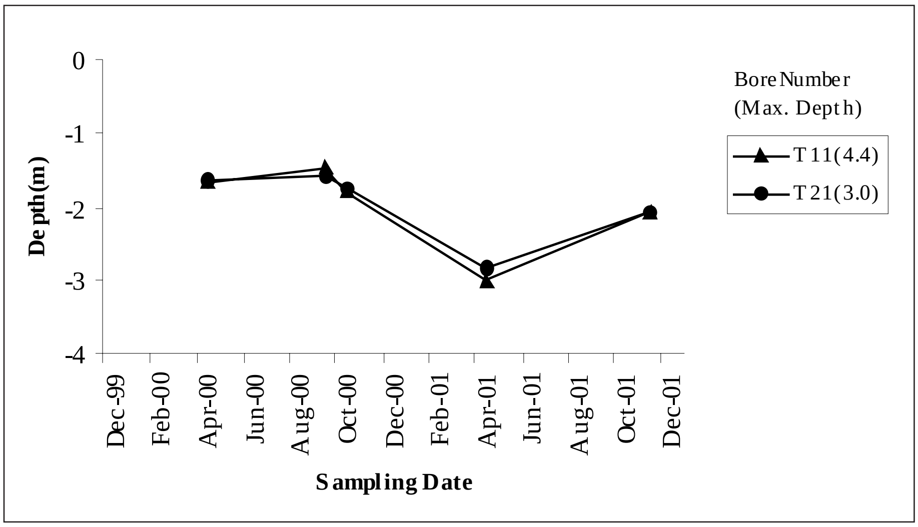

Figure 115. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Yaalup Lagoon. Legend values in parenthesis are depth of the bore in metres.

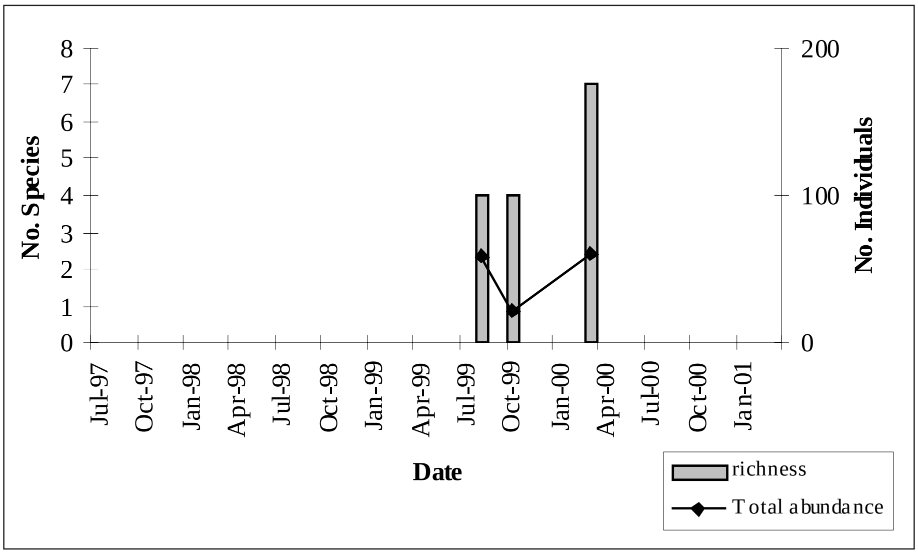

Figure 116. Waterbird species richness and abundance at Yaalup Lagoon.

TABLE 41
Waterbird species and their abundance on three sampling occasions at Yaalup Lagoon.

	SAMPLING DATE AUG-99	OCT-99	MAR-00
Australian Shelduck	0	1	6
Australian Wood Duck	2	3	2
Chestnut Teal	11	0	6
Eurasian Coot	0	0	2
Grey Teal	43	16	35
Pacific Black Duck	2	2	8
White-faced Heron	0	0	1

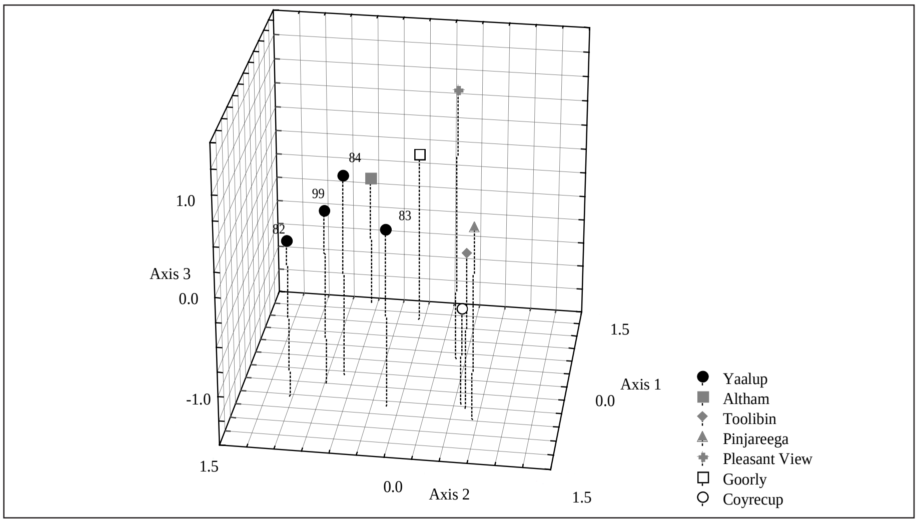

Figure 117. Ordination (PCR) of waterbird species data from Yaalup Lagoon, showing historical and monitoring data for Yaalup Lagoon and data for six marker wetlands.

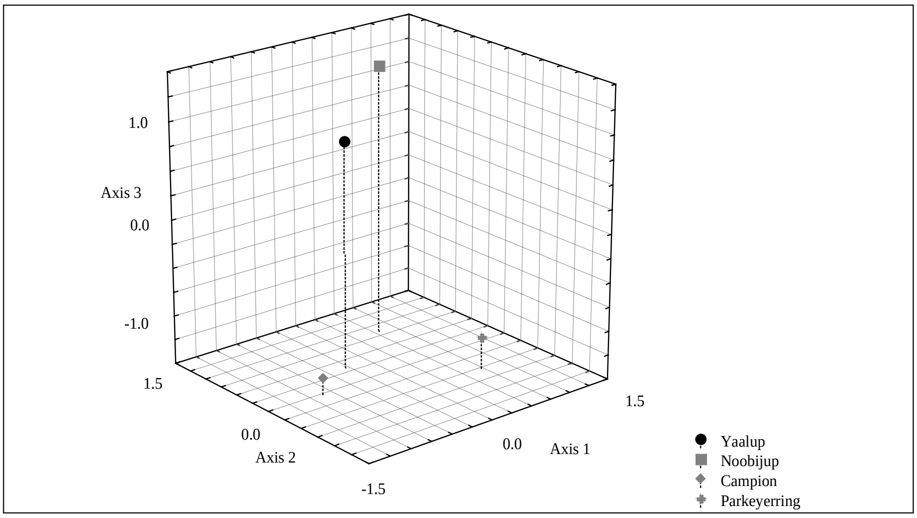

Figure 118. Ordination (SSH) of invertebrate data, showing Yaalup Lagoon in 1999 and three marker wetlands.

The waterbird community recorded at Yaalup was an unusual one. Species richness was low and all species were ubiquitous (i.e. found at most sites). Yaalup was quite distinct from the marker wetlands, both in 1999 and historical surveys (Fig. 117). The waterbird community recorded in 1999 fitted within historical variation, which was considerable.

Invertebrates

A total of 93 invertebrate species were collected when Yaalup was monitored in October 1999 (Table 42). Species richness was dominated by insects (48 species, 51% of fauna). Diptera were particularly rich with 15 species of Chironomidae and six other Diptera. Coleoptera were also diverse with 11 species from the families Hydrophilidae and Dytiscidae. There were 13 species of Rotifera and 24 species of crustaceans. The occurrence of the rotifer *Trichocerca tigris* was the first time the species has been recorded in Western Australia.

The invertebrate community of Yaalup was distinct from other marker wetlands (Fig. 118), although similar to that in other small fresh or brackish basin wetlands, such as Blue Gum Swamp (Fig. 61), Fraser Lake (Fig. 100) and Lake Coomalbidgup (Fig. 112).

TABLE 42
Invertebrate species collected from Yaalup Lagoon in the 1999 sampling year.

TAXA	1999
Spongillidae	✓
Temnosewellia minor	✓
Nematoda	✓
ROTIFERA	
Testudinella patina	✓
Brachionus quadridentatus	✓
Keratella quadrata	✓
Lepadella cf. *patella*	✓
Euchlanis dilatata	✓
Ascomorpha saltans	✓
Lecane ludwigii	✓
Lecane sp.	✓
Cephalodella gibba	✓
Polyarthra dolichoptera	✓
Trichocerca rattus	✓
Trichocerca similis	✓
Trichocerca tigris	✓
GASTROPODA	
Isidorella sp.	✓
OLIGOCHAETA	
Dero digitata	✓
ACARINA	
Acercella falcipes	✓
Oribatida	✓
Mesostigmata	✓
ANOSTRACA	
Branchinella lyrifera	✓
CLADOCERA	
Alona rigidicaudis s.l.	✓
Alona sp.	✓
Alona nr. *affinis*	✓
Leydigia sp.	✓
Pleuroxus sp.	✓
Rak sp. nov. b (Venemores)	✓
Simocephalus sp.	✓
Macrothrix sp.	✓
Neothrix sp.	✓
OSTRACODA	
Limnocythere mowbrayensis	✓
Ilyocypris australiensis	✓
Alboa worooa	✓
Cypretta baylyi	✓
Ilyodromus sp.	✓
Sarscypridopsis aculeata	✓
COPEPODA	
Boeckella triarticulata	✓
Calamoecia sp. 342 (*ampulla* variant)	✓
Microcyclops varicans	✓
Mesocyclops brooksi	✓
Canthocamptidae sp. 4	✓
Nitocra reducta	✓
AMPHIPODA	
Austrochiltonia subtenuis	✓
DECAPODA	
Cherax destructor	✓
COLEOPTERA	
Hyphydrus elegans	✓
Allodessus bistrigatus	✓
Antiporus gilberti	✓
Sternopriscus multimaculatus	✓
Megaporus howitti	✓
Lancetes lanceolatus	✓
Onychohydrus scutellaris	✓
Berosus macumbensis	✓
Paranacaena littoralis	✓
Enochrus maculiceps	✓
Limnoxenus zelandicus	✓
DIPTERA	
Monohelea sp. 1	✓
Nilobezzia sp. 2	✓
Psychodinae sp. 2	✓
Psychodinae sp. 3	✓
Tabanidae	✓
Stratiomyidae	✓
Coelopynia pruinosa	✓
Procladius paludicola	✓
Procladius villosimanus	✓
Ablabesmyia notabilis	✓
Paramerina levidensis	✓
Paralimnophyes pullulus	✓
Tanytarsus nr *bispinosus*	✓
Chironomus aff. *alternans*	✓
Dicrotendipes conjunctus	✓
Dicrotendipes jobetus	✓
Kiefferulus martini	✓
Polypedilum nubifer	✓
Cryptochironomus griseidorsum	✓
Cladopelma curtivalva	✓
Parachironomus sp. 1	✓
Tasmanocoenis tillyardi	✓
HEMIPTERA	
Sigara sp.	✓
Agraptocorixa parvipunctata	✓
Micronecta sp.	✓
Anisops thienemanni	✓
Anisops hyperion	✓
Anisops gratus	✓
NEUROPTERA	
Sisyra sp.	✓
ODONATA	
Xanthagrion erythroneurum	✓
Austrolestes annulosus	✓
Austrolestes aridus	✓
Hemianax papuensis	✓
Hemicordulia tau	✓
TRICHOPTERA	
Ecnomus pansus/turgidus	✓
Oecetis sp.	✓
Triplectides australis	✓

Lake Parkeyerring

Lake Parkeyerring (Fig. 119) is a large (322 ha) semi-permanent, secondarily saline wetland located 7 km south of Wagin in the Parkeyerring Nature Reserve (33º 22'S 117º 20'E). It is part of a chain of salt lakes forming the headwaters of the Coblinine River. The lake fills from inflow channels on the southern (Little Lake Parkeyerring) and south-western (draining a western sub-catchment) sides of the lake. There is shore seepage directly into the wetland from shallow soils and rocky outcrops to the west of the lake. The major outflow is through a channel on the north-east shore which empties into the Coblinine River. The majority of the Parkeyerring catchment is cleared for agriculture and the lake has been secondarily saline since the 1950s or earlier.

A narrow belt of terrestrial vegetation, comprising *Eucalyptus loxophleba* over *Acacia acuminata*, occurs on the eastern side of Lake Parkeyerring. *Casuarina obesa* grows as a narrow band around the perimeter of the lake and forms a healthy woodland on the western bank and occurs over *Melaleuca halmaturorum* on the northern bank, above the high water mark (Gurner *et al.* 2000). Samphire, mostly *Halosarcia lepidosperma* and *Sarcornia* sp., grows on the low-lying margins of the lake.

Waterbird surveys between 1981 and 1985 showed the lake supported a high abundance of birds, although species richness was only moderate and few species bred (Jaensch *et al.* 1988). The lake was selected for monitoring because it has a long record of depth and salinity data, has significant value for some waterbird species, and was regarded as a secondarily saline wetland where biological changes had stabilised.

Water chemistry and physico-chemical parameters

Lake Parkeyerring was monitored in late winter and spring 1999 but was dry in March 2000. Lake depth was greatest in spring (0.86 m) and at this time, conductivity was 102 500 µS/cm (Fig. 120). Lake pH was neutral-alkaline, Total nitrogen and phosphorus concentrations were moderate (4800–5450 µg/l and 40 µg/l, respectively) and chlorophyll concentrations were relatively low.

Parkeyerring was relatively shallow during 1999 and it is difficult to compare salinities (and salt loads) across time using data derived from partial inflow events. Nevertheless, there does appear to have been an increase in salinities since 1981 when a similar volume of inflow resulted in a salinity of about 35 000 µS/cm (see Fig. 29 in Lane and Munro 1983). The increase may be principally a reflection of the lack of large floods, and subsequent flushing, in recent years.

Groundwater

Monitoring bores were established on both vegetation transects and monitored from early 2000. The watertable is shallow and intersects with the bed of the lake in winter (even in summer the watertable is in contact with the lake-bed) (Fig. 121). Groundwater was substantially less saline than water in the lake (20 870–60 900 *vs* 101 600–102 500 µS/cm), which suggests salt has been accumulating in the lake sediments. Groundwater was generally more saline at the northern end of the lake than on the western side. An isolated low conductivity reading (5900 µS/cm) in the upper part of vegetation transect 1 in

Figure 119. Lake Parkeyerring is a large, secondarily saline wetland with a fringing band of vegetation.

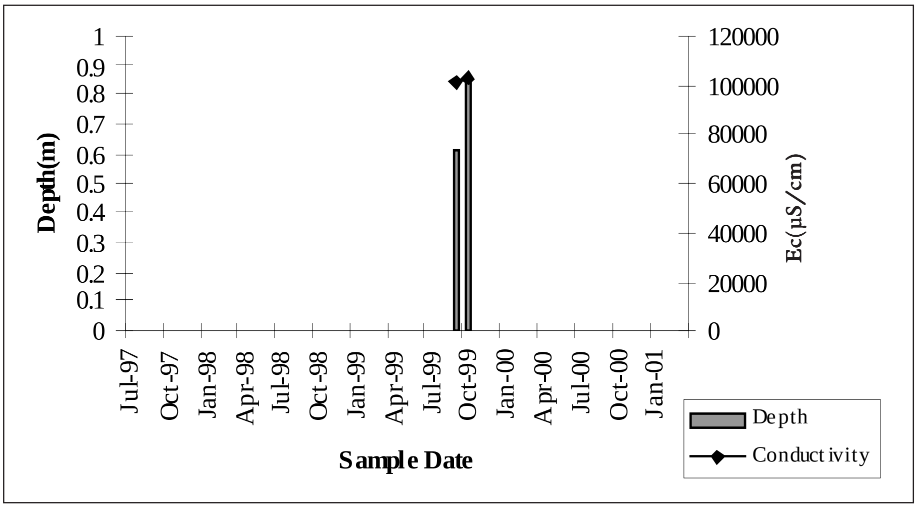

Figure 120. Gauged depth and electrical conductivity at Lake Parkeyerring.

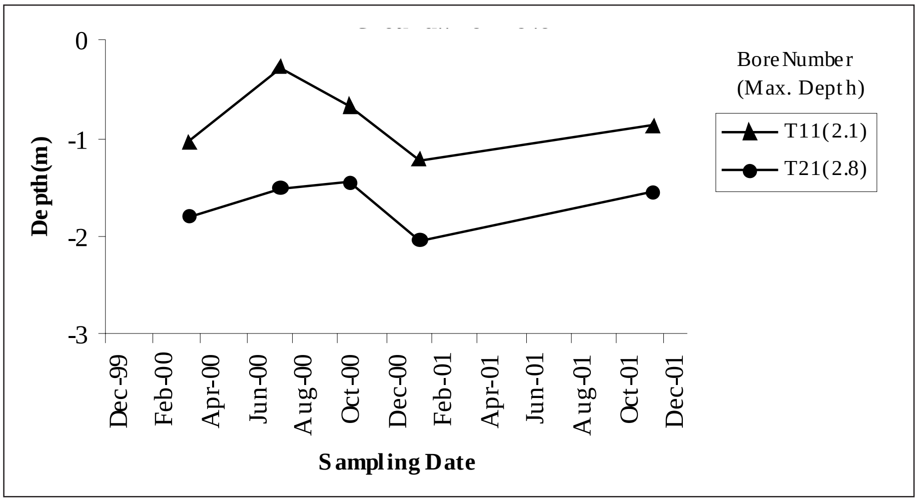

Figure 121. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Parkeyerring. Open symbols represent dry bores. Legend values in parenthesis are depth of the bore in metres.

July 2000 suggests the existence of localised perched aquifers around the western flank of the lake that form as a result of recharge of run-off after rainfall. Discharge from these aquifers may provide a source of fresh water for breeding waterbirds.

Waterbirds

Ten species of waterbirds were recorded in 1999. The community was dominated by salt-tolerant species such as the Australian Shelduck and Banded Stilt (Table 43, Fig. 122). Abundances of these species were high. The lake supported a comparatively large population of Silver Gulls (given its salinity), which was likely a reflection of its proximity to the Wagin waste disposal site.

Jaensch *et al.* (1988) recorded 17 species during 10 surveys between 1981 and 1985, when the lake contained substantially more water and was less saline. Silver Gulls were common during the earlier surveys. Comparison of the 1999 count with waterfowl counts between 1988 and 1992 (Halse *et al.* 1994) revealed no obvious changes, other than attributable to annual rainfall. Parkeyerring has a waterbird community typical of that of a secondarily saline lake with high salt levels (Fig.123).

Invertebrates

The invertebrate fauna of Lake Parkeyerring was monitored in October 1999. Only 10 species were collected, six of which were crustaceans (Table 44). The ostracods *Australocypris insularis*, *Diacypris compacta* and *Platycypris baueri* were numerically dominant. Three species of insects were collected, with the beetle *Necterosoma penicillatus* and midge *Tanytarsus* sp. being typical of saline waters while the beetle *Paroster* sp. 2 appears to be undescribed (CHS Watts[4], personal communication).

The invertebrate community in Parkeyerring was distinct from other marker wetlands and was judged to be that of a very saline wetland with secondary salinisation (Fig. 124). It was used as a marker wetland in the study for this reason.

4. C.H.S. Watts, South Australian Museum, Adelaide,S.A.

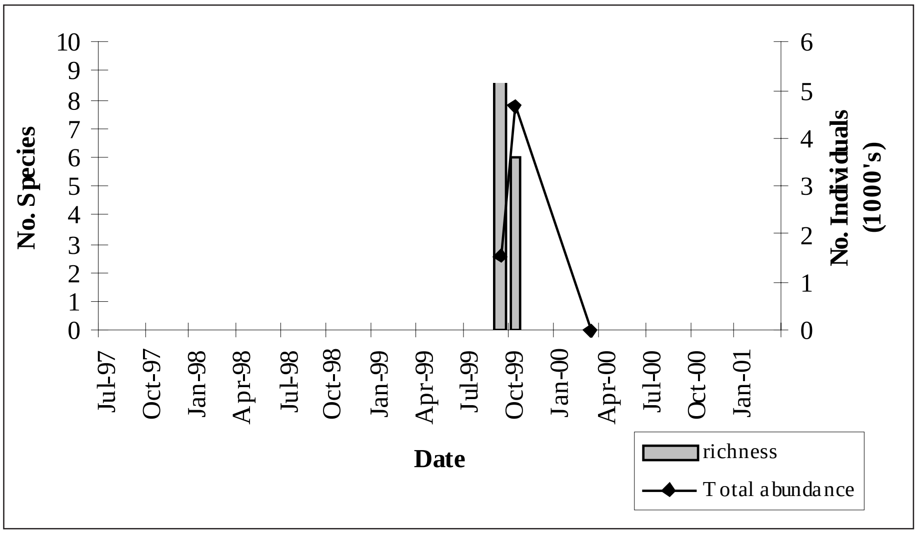

Figure 122. Waterbird species richness and abundance at Lake Parkeyerring.

TABLE 43
Waterbird species and their abundance on three sampling occasions at Lake Parkeyerring.

	SAMPLING DATE SEP-99	OCT-99	MAR-00
Australian Shelduck	1295	944	0
Banded Stilt	0	3608	0
Black Swan	159	53	0
Black-winged Stilt	40	2	0
Curlew Sandpiper	0	0	0
Eurasian Coot	1	0	0
Grey Teal	8	9	0
Hooded Plover	2	0	0
Pacific Black Duck	2	0	0
Pink-eared Duck	4	0	0
Red-capped Plover	0	0	0
Red-necked Stint	0	0	0
Silver Gull	40	41	0

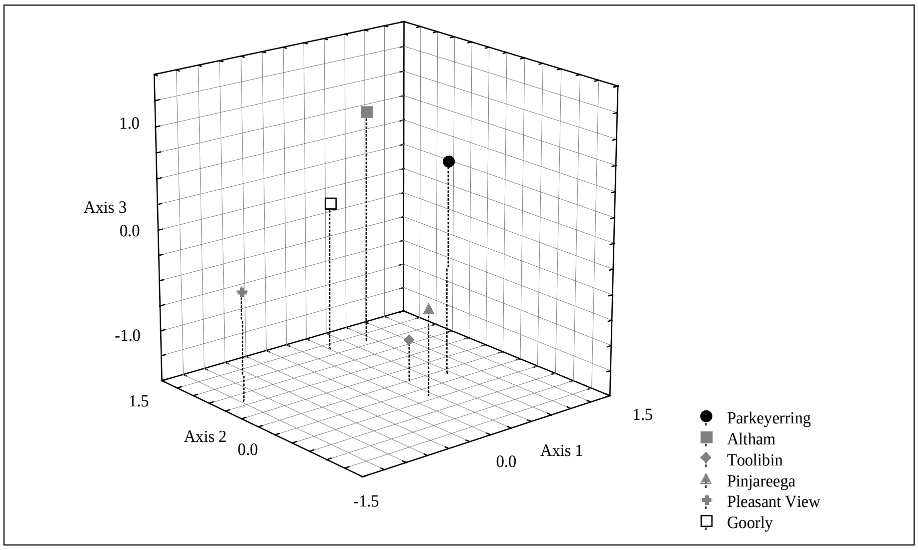

Figure 123. Ordination (SSH) of waterbird species data, showing Lake Parkeyerring from 1999 and the five marker wetlands.

TABLE 44
Invertebrate species collected from Lake Parkeyerring in the 1999 sampling year.

TAXA	1999	TAXA	1999
GASTROPODA		ISOPODA	
Coxiella sp.	✓	*Haloniscus searlei*	✓
OSTRACODA		COLEOPTERA	
Australocypris insularis	✓	*Paroster* sp. 2 (Parkeyerring)	✓
Diacypris compacta	✓	*Necterosoma penicillatus*	✓
Platycypris baueri	✓	DIPTERA	
COPEPODA		*Tanytarsus* sp.	✓
Calamoecia clitellata	✓		
Metacyclops arnaudi (sensu Kieffer)	✓		

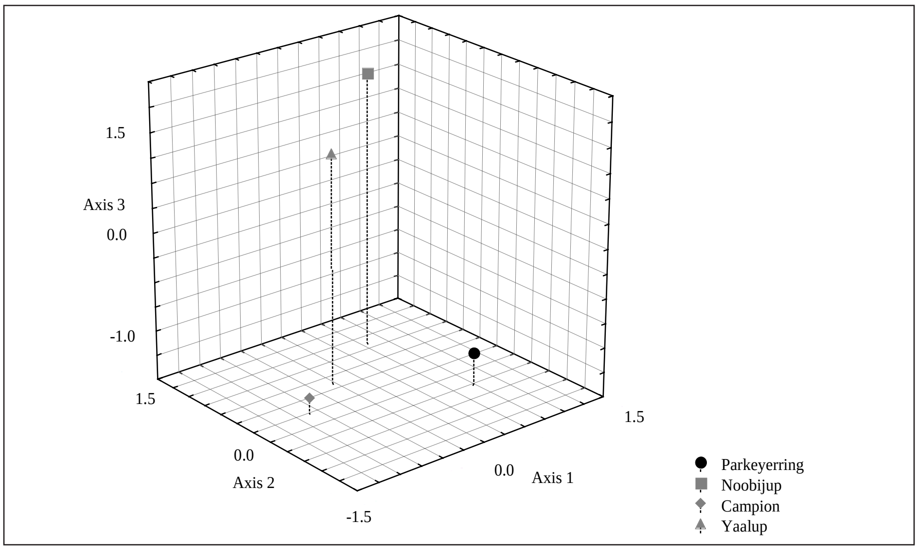

Figure 124. Ordination (SSH) of invertebrate data, showing Lake Parkeyerring in 1999 and three marker wetlands.

Lake Pleasant View

Lake Pleasant View (Fig. 125) is a moderately large, freshwater sedge lake 35 km north east of Albany (34º 50'S 118º 11'E). Most of the lake supports dense stands of various sedge species. The amount of open water is variable: Halse *et al.*(1993b) reported < 0.1% of the lake's 201 ha area being open water whereas 75% was estimated to be open water in 1985–86 (D Cale personal observation). During the monitoring period open water was estimated to comprise 5% of the lakes area (wetted area). Halse *et al.*(1993b) listed the lake as seasonal based on long-term data collected by JAK Lane but depth remained >0.75 m between 1979 and 1983 (Lane and Munro 1983). The lake lies within the 600–700 mm rainfall region and most lake water would appear to be derived from direct precipitation and groundwater, additional inflows occur from winter-wet flats to the north and a gneiss outcrop to the south. The lake has been depth-gauged since 1979.

Gurner *et al.* (2000) described the sedge communities of the lake, which are dominated by *Gahnia* sp. and, particularly in the centre, include stands of *Baumea articulata* and *B. rubiginosa*. At the edge of the wetland *Restio* sp., *Lepidosperma tenue*, *Shoenus* sp., *Baumea juncea* and *Lyginia barbata* occur in a mosaic. Above high water, they are replaced by a *Melaleuca cuticularis* shrubland or jarrah/marri woodland.

Jaensch *et al.* (1988) recorded 24 waterbird species during 29 surveys between 1981 and 1985. Both Australasian Bitterns and Little Bitterns were recorded breeding. The lake was selected for monitoring because of its extensive and diverse sedge communities, importance to bitterns, a perceived hydrological threat to the lake from surrounding farmland, and the availability of long-term waterbird and depth data.

Water chemistry and physico-chemical parameters

Water depth remained relatively constant through the 1999 sampling year, ranging from 0.92 m in August to 0.6 m in March (Fig. 126). Lake water was fresh (1210–1668 µS/cm) with cation ratios showing that calcium concentrations were comparatively low Na>Mg>Ca=K. Chloride was the dominant anion.

Nutrient levels were low with Total phosphorous at the limit of detection (5 µg/l) and Total nitrogen 1200 µg/l on all sampling occasions. Lake water pH was circum-neutral and algal production (as measured by concentration of chlorophyll) was low throughout 1999. Oxygen saturation was low (*ca.* 60%) in October and March as a result of the high oxygen demand of senescent and decaying sedge material.

Groundwater

Monitoring bores were established on each of the four vegetation transects and monitoring began in early 2000 (Fig. 127). Depth to groundwater in the bores closest to the lake (transect 4) suggested that groundwater and the wetland are interacting throughout most years. Conductivity measurements indicated that the shallow groundwater under the lake is slightly more saline than lake water (940–3040 µS/cm) and that lake water represents a mix of groundwater and rainfall. However, the upslope bore on transect 2 on the north side of the wetland contained substantially more saline water (18 140–28 000 µS/cm). At this stage, the more saline groundwater is possibly best characterised as an accumulation of salts around the root system of local vegetation. Future observations of growth of this pocket of groundwater may indicate a more saline aquifer fringing the lake with some potential for salinisation at Lake Pleasant View.

Waterbirds

A total of 14 species were recorded during the 1999 monitoring year (Table 45, Fig. 128). Five species were recorded in all surveys: Purple Swamphen, Swamp Harrier, Little Grassbird, Musk Duck and Australasian Bittern. The Purple Swamphen was the most abundant bird in the winter and spring surveys but ranked second behind the Australian White Ibis (61 birds) in autumn. The highest count for a single species recorded by Jaensch *et al.* (1988) in 29 surveys between 1981 and 1985 was a count of 60 Straw-necked Ibis. Jaensch *et al.* (1988) recorded 24 species, but annual species richness in the 1980s was similar (range 11–17 species) to 1999 and all species recorded in larger numbers in the 1980s were present in 1999.

The waterbird community at Lake Pleasant View had a strong sedge-wetland element (although many such wetlands support fewer species) and was distinct from other marker wetlands (Fig. 129). Waterbird community structure was similar in the 1980s and 1999.

Invertebrates

The invertebrate fauna of Lake Pleasant View was monitored in spring 1999 and was the richest collected from any monitoring wetland with 136 species (Table 46).

Figure 125. Lake Pleasant View is a freshwater sedge swamp near the south coast of Western Australia.

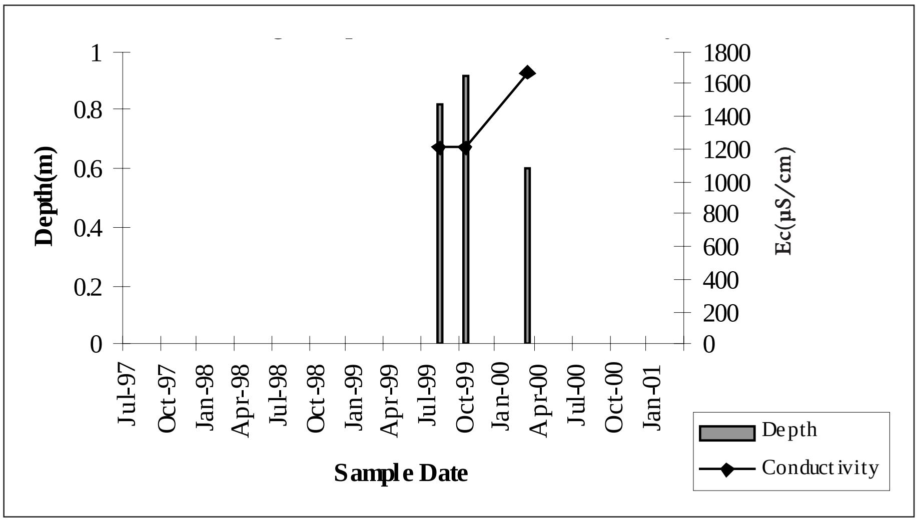

Figure 126. Gauged depth and electrical conductivity at Lake Pleasant View.

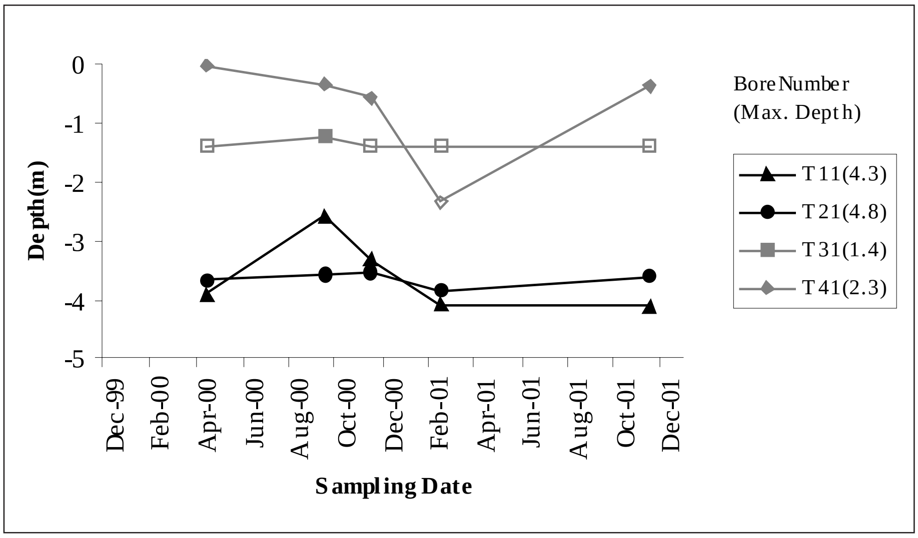

Figure 127. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Pleasant View. Legend values in parenthesis are depth of the bore in metres.

Insects accounted for 40% of the fauna (55 species), crustaceans 27% (37 species) and rotifers 20% (27 species). Abundances were very low with < 100 individuals for most species. This low abundance partly explains why only 57 species (42% of the fauna) occurred in samples from both sub-sites, although the number of species collected at each sub-site was similar (96 and 103 species). Ostracods were the most numerous animals and, with 19 species, represented a significant proportion of the total biodiversity. Cladocerans were represented by eight species with a general south-western distribution (see Storey *et al.* 1993). All insect orders were represented by a diverse array of species, including six species of Trichoptera, which is an unusually high richness for a Western Australian wetland. Dipterans were represented by 18 species, including 11 species of chironomids.

The invertebrate community at Pleasant View exhibited a similar composition to that of Noobijup Swamp, another sedge wetland (Fig. 130).

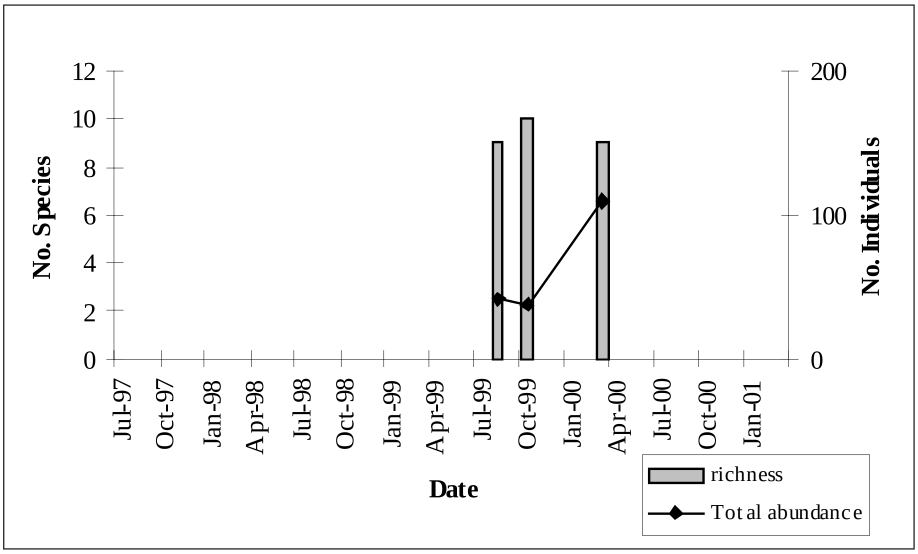

Figure 128. Waterbird species richness and abundance at Lake Pleasant View.

TABLE 45
Waterbird species and their abundance on three sampling occasions at Lake Pleasant View.

	SAMPLING DATE		
	AUG-99	OCT-99	MAR-00
Australasian Bittern	1	2	2
Australian Shelduck	4	2	0
Australian White Ibis	0	0	61
Baillon's Crake	0	1	0
Clamorous Reed-Warbler	2	4	0
Dusky Moorhen	1	0	0
Little Grassbird	2	7	10
Musk Duck	9	3	1
Pacific Black Duck	7	0	2
Purple Swamphen	13	14	27
Spotless Crake	0	0	5
Swamp Harrier	2	1	1
White-faced Heron	0	2	1
Yellow-billed Spoonbill	0	1	0

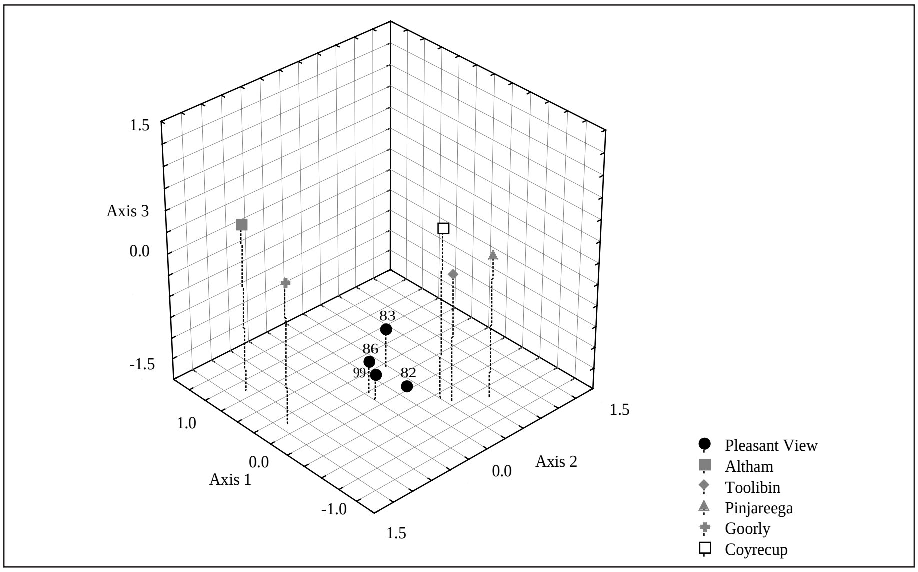

Figure 129. Ordination (PCR) of waterbird species data from Lake Pleasant View, showing historical and monitoring data for Lake Pleasant View and data for six marker wetlands.

TABLE 46
Invertebrate species collected from Lake Pleasant View in the 1999 sampling year.

TAXA	1999
Spongillidae	✓
Turbellaria	✓
Nemertini	✓
Nematoda	✓
ROTIFERA	
Rotaria sp.	✓
Testudinella cf. *amphora*	✓
Testudinellidae	✓
Asplanchna sp.	✓
Asplanchnopus multiceps	✓
Brachionus sp.	✓
Keratella javana	✓
Keratella procurva	✓
Platyias quadricornis	✓
Euchlanis dilatata	✓
Euchlanis sp.	✓
Lecane bulla	✓
Lecane ludwigii	✓
Lecane lunaris	✓
Lecane quadridentata	✓
Lecane signifera	✓
Lecane sp.	✓
Mytilinidae	✓
Monommata sp.	✓
Monommata sp. A	✓
Notommatidae	✓
Trichocerca bicristata	✓
Trichocerca rattus	✓
Trichocerca sp.	✓
Trichocercidae	✓
Trichotriidae	✓
Scaridium bostjani	✓
GASTROPODA	
Ferrissia petterdi	✓
Glyptophysa cf. *gibbosa*	✓
HIRUDINEA	
Placobdelloides sp.	✓
OLIGOCHAETA	
Insulodrilus bifidus	✓
Tubificidae	✓
Dero furcata	✓
Pristina longiseta	✓
Chaetogaster diaphanus	✓
ACARINA	
Limnochares australica	✓
Oxus australicus	✓
Pezidae	✓
Oribatida	✓
Mesostigmata	✓
CLADOCERA	
Alona sp.	✓
Alona nr. *affinis*	✓
Alonella sp.	✓
Chydorus sp.	✓
Graptoleberis sp.	✓
Scapholeberis cf. *kingi*	✓
Simocephalus sp.	✓
Macrothrix sp.	✓
OSTRACODA	
Gomphodella aff. *maia*	✓
Limnocythere sp. 447	✓
Candonopsis tenuis	✓
Alboa sp.	✓
Australocypris sp.	✓
Bennelongia australis	✓
Bennelongia barangaroo	✓
Cypretta sp. 587	✓
Cyprinotus edwardi	✓
Diacypris compacta	✓
Heterocypris sp.	✓
Mytilocypris tasmanica chapmani	✓
Reticy*prus walbu*	✓
Reticypris sp.	✓
Cypericercus sp.	✓
Lacrimicypris kumpar	✓
Platycypris baueri	✓
Newnhamia sp. 295	✓
Kennethia sp. 670	✓
COPEPODA	
Calamoecia attenuata	✓
Calamoecia tasmanica subattenuata	✓
Microcyclops varicans	✓
Macrocyclops albidus	✓
Mesocyclops brooksi	✓
Canthocamptus australicus	✓
Harpacticoida sp. 2	✓
AMPHIPODA	
Austrochiltonia subtenuis	✓
Perthia branchialis	✓
DECAPODA	
Cherax quinquecarinatus	✓
COLEOPTERA	
Haliplus sp.	✓
Hygrobia sp.	✓
Uvarus pictipes	✓
Allodessus bistrigatus	✓
Sternopriscus browni	✓
Megaporus howitti	✓
Megaporus solidus	✓
Rhantus suturalis	✓
Lancetes lanceolatus	✓
Spencerhydrus pulchellus	✓
Enochrus eyrensis	✓
Limnoxenus zelandicus	✓
Paracymus pygmaeus	✓
Hydrophilidae	✓
Scirtidae sp.	✓
DIPTERA	
Aedes sp.	✓
Culex latus	✓
Culex (*Neoculex*) sp. 1	✓
Coquillettidia linealis	✓
Bezzia sp. 1	✓
Clinohelea sp.	✓
Tabanidae	✓
Procladius paludicola	✓
Ablabesmyia notabilis	✓
Paramerina levidensis	✓
Corynoneura sp.	✓
Compterosmittia? sp. A	✓
Limnophyes sp. A	✓
Tanytarsus nr *bispinosus*	✓
Chironomus occidentalis	✓
Dicrotendipes conjunctus	✓
Cladopelma curtivalva	✓
Parachironomus sp. 1	✓
EPHEMEROPTERA	
Cloeon sp.	✓

TABLE 46 (continued)
Invertebrate species collected from Lake Pleasant View in the 1999 sampling year.

TAXA	1999	TAXA	1999
HEMIPTERA		*Austrolestes annulosus*	✓
Hydrometra sp.	✓	*Austrolestes psyche*	✓
Microvelia sp.	✓	*Aeshna brevistyla*	✓
Saldula sp.	✓	*Agrionoptera insignis allogenes*	✓
Diaprepocoris sp.	✓	*Procordulia affinis*	✓
Anisops hyperion	✓	TRICHOPTERA	
Anisops elstoni	✓	*Hellyethira litua*	✓
Paranisops endymion	✓	*Ecnomina* F group sp. AV18	✓
Paraplea brunni	✓	*Ecnomina* F group sp. AV16	✓
ODONATA		*Ecnomina* F group sp. AV20	✓
Austroagrion coeruleum	✓	*Notoperata tenax*	✓
Austrolestes analis	✓	*Oecetis* sp.	✓

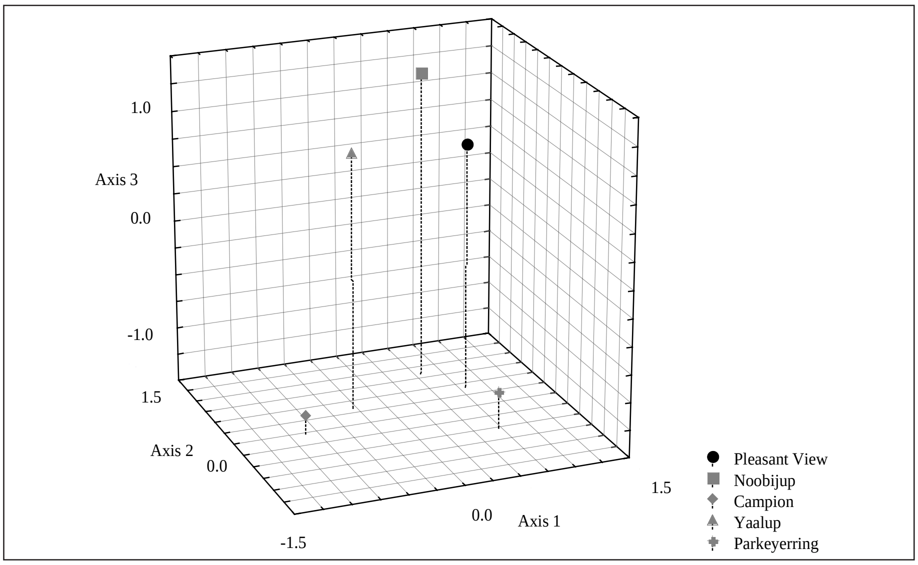

Figure 130. Ordination (SSH) of invertebrate data, showing Lake Pleasant View in 1999 and four marker wetlands.

Lake Ronnerup

Lying within the Dunn Rock Nature Reserve (No 36445; 33° 15'S 119° 37'E), Lake Ronnerup is an ephemeral, naturally saline wetland (Fig. 131). The lake is flat-bottomed with a relatively steep shoreline. On the south-eastern shore, there is a series of dunes and swales associated with the lake and these flood during major inflow events. Gurner *et al.* (2000) stated that water enters the lake from ephemeral channels originating near Lake King to the north-west. However, it is more commonly accepted that flow comes from the south-west through a channel connected to Bennett's Lake. Ronnerup and Bennett's lie very close to the South Coast Watershed, which divides drainage lines of the Yilgarn System from those of the south coast (Beard 1999), and there is confusion about whether they are at the top of the Camms River catchment or part of the Lake King catchment.

The vegetation of Lake Ronnerup is restricted to areas well above the usual highwater mark. Sparse low *Eucalyptus occidentalis* woodland, with an understorey of *Gahnia trifida*, *Atriplex vesicaria* and *Chenopodium* sp., interspersed with shrublands comprising *Santalum murrayanum*, *Acacia saligna*, *Olearia axillaris*, *Rhagodia drummondi* and *Lomandra effusa*. *Melaleuca cuticularis* forms low thickets in some low-lying areas (Gurner *et al.* 2000).

Water chemistry and physico-chemical parameters

Lake Ronnerup was monitored in the 1999 sampling year and in late winter and spring contained very little water (0.12 and 0.05 m, respectively) (Fig. 132). In March 2000, however, the lake filled to a depth of approximately 2 m (gauge was not yet installed), flooding into the surrounding dune swales and greatly increasing the area of inundated wetland. In October 1999, the lake had a conductivity of 220 000 µS/cm, but this fell to 73 500 µS/cm after filling. Calcium levels were relatively low with the cationic pattern being Na>Mg>K>Ca while Cl was the dominant anion. Lake water was neutral-alkaline with relatively low nutrient levels (Total nitrogen 2800 µg/l and Total phosphorus 50 µg/l). Chlorophyll concentrations were low.

Groundwater

Monitoring bores were not established until 2001 because of extensive flooding of the vegetation transects in 2000. Groundwater was close to the surface (Fig. 133) and intersected with the floor of the lake. Lake water was more saline than groundwater, even when the lake was fully flooded (73 500 *vs* 16 190–48 800 µS/cm), because of the accumulation of salt in lake sediments.

Waterbirds

Only four waterbird species were recorded in late winter and spring 1999, but there was a dramatic change in the community by March 2000, after the lake had flooded. At this time 16 species were recorded including Blue-billed Ducks, Baillon's Crake and Australian Spotted Crakes (Table 47, Fig. 134). Grey Teal were breeding prolifically. The mixed hydrological condition at Ronnerup (and resulting unusual combination of species) meant that the community occupied a central position in ordination space relative to marker wetlands (Fig. 135). Usually the community would be expected to be more like that of Lake Altham.

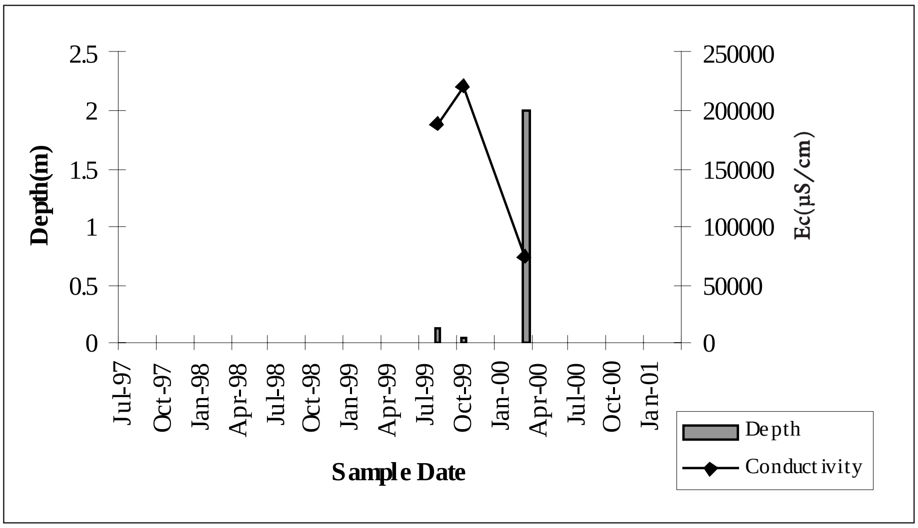

Figure 132. Gauged depth and electrical conductivity at Lake Ronnerup.

Figure 131. Lake Ronnerup is a large saline lake. Depicted here in a drying phase the lake is less than 5cm deep.

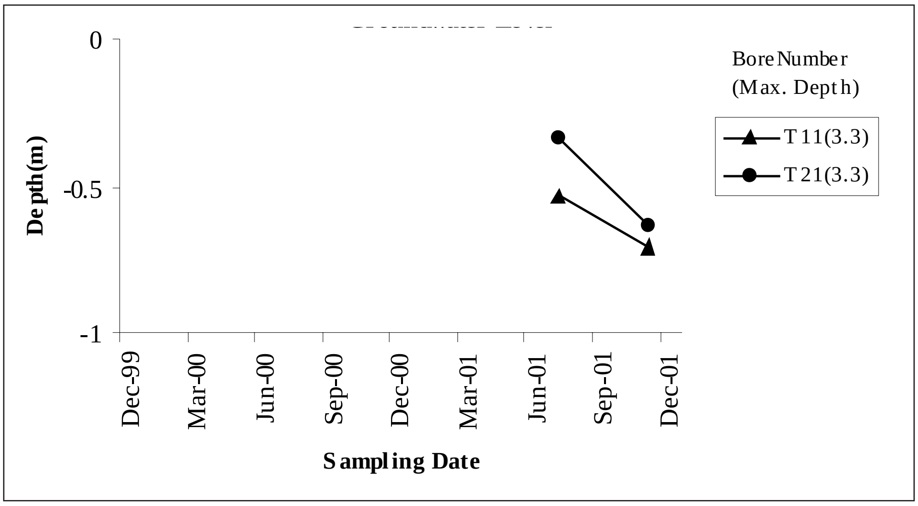

Figure 133. Depth below local ground level of groundwater in one bore (not necessarily closest to lake) on each vegetation transect at Lake Ronnerup. Legend values in parenthesis are depth of the bore in metres.

TABLE 47
Waterbird species and their abundance on three sampling occasions at Lake Ronnerup.

	DATE		
	AUG-99	OCT-99	MAR-00
Australasian Shoveler	0	0	32
Australian Shelduck	116	0	16
Australian Spotted Crake	0	0	1
Australian Wood Duck	0	0	48
Baillon's Crake	0	0	2
Banded Stilt	2	0	0
Blue-billed Duck	0	0	10
Chestnut Teal	0	0	6
Eurasian Coot	0	0	45
Grey Teal	0	0	215
Hoary-headed Grebe	0	0	26
Hooded Plover	19	5	0
Little Pied Cormorant	0	0	2
Musk Duck	0	0	15
Nankeen Night Heron	0	0	1
Pacific Black Duck	0	0	12
Pink-eared Duck	0	0	35
Red-capped Plover	0	2	0
White-faced Heron	0	0	14

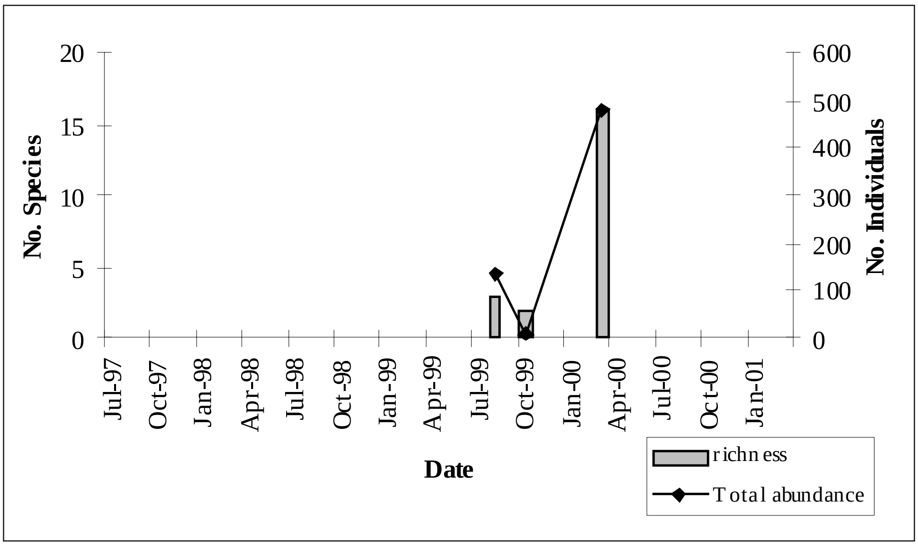

Figure 134. Waterbird species richness and abundance at Lake Ronnerup.

Invertebrates

Invertebrates were monitored in spring 1999 before the lake filled (Table 48). The invertebrate fauna was depauperate with only eight species collected from the hypersaline water. Of these, three were dipteran larvae typical of temporary waters (Ceratopogonidae, Muscidae and Stratiomyidae). The only crustacean present was *Parartemia longicaudata*, which is currently being treated as an undescribed sub-species (A Savage[5], personal communication). The ubiquitous and taxonomically unresolved groups Mesostigmata, Nematoda and Enchytraeidae (Oligochatea) were the only other taxa collected. The community exhibited affinities with Lake Campion (Fig. 136), principally because of low species richness rather than the identity of species.

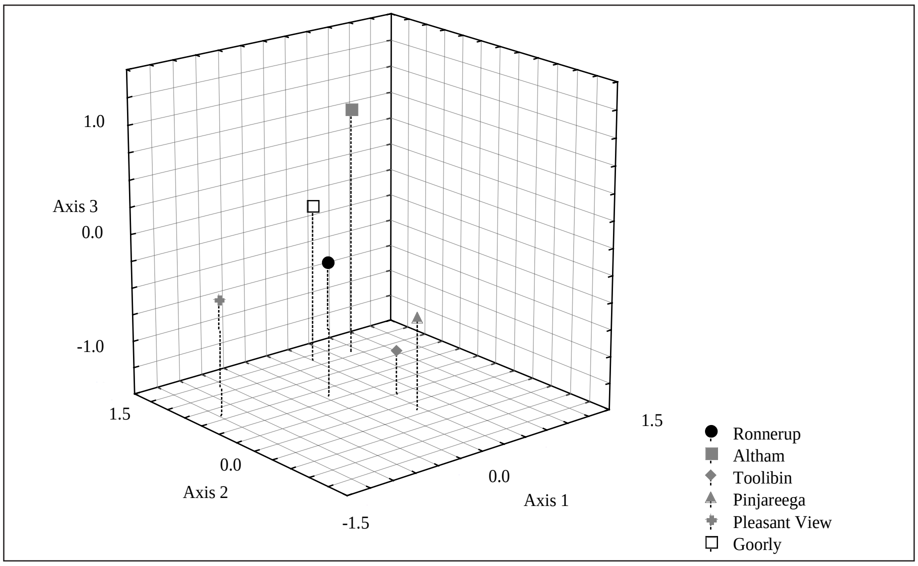

Figure 135. Ordination (SSH) of waterbird species presence/absence at Lake Ronnerup in 1999.

TABLE 48
Invertebrate species collected from Lake Ronnerup in the 1999 sampling year.

TAXA	1999	TAXA	1999
Nematoda	✓	COLEOPTERA	
OLIGOCHAETA		Carabidae	✓
Enchytraeidae	✓	DIPTERA	
ACARINA		*Culicoides* sp.	✓
Mesostigmata	✓	Stratiomyidae	✓
ANOSTRACA		Muscidae sp. A	✓
Parartemia longicaudata sbsp. A	✓		

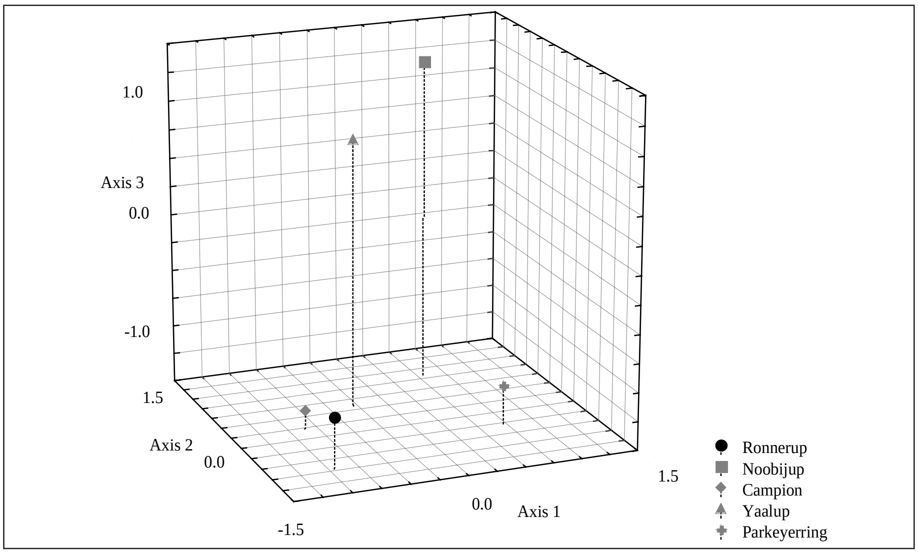

Figure 136. Ordination (SSH) of invertebrate data, showing Lake Ronnerup in 1999 and four marker wetlands.

5. A. Savage, The University of Western Australia, Nedlands, W.A.

DISCUSSION

The State Salinity Strategy Wetland Monitoring Program is designed to document long-term trends in the biodiversity of Wheatbelt wetlands. Data on waterbirds, invertebrates and aquatic vegetation represent a broad subset of the total biodiversity of a wetland and, hopefully, by sampling these biological groups, we have captured much of the biodiversity pattern in wheatbelt wetlands. It is important to sample a range of plants and animals because few wetlands will have synchronous conservation value for all biotic groups; rather they may be important for some groups and of little significance for others (Davis *et al.* 2001).

Table 49 shows the relative importance of each of the monitoring wetlands for waterbirds, aquatic invertebrates and vascular plants. Wetlands are arranged from most species-rich (across all biotic groups) to least. Only Lake Bryde is ranked highly for all elements of the biota. Other lakes generally are more important for one biotic group (12 lakes) or two biotic groups (10 lakes).

Lake Kulicup and Goonaping Swamp are clear examples of wetlands with diverse values for different elements of the biota. They have essentially no value for waterbirds but have intermediate or rich invertebrate faunas and rich plant communities (Gurner *et al.* 1999). Relative richness of invertebrate orders also varies among wetlands, with Kulicup having the single most diverse suite of cladocerans (16 species) recorded during monitoring. At the other extreme, only three species of plant were recorded from wetland transects at Lake Logue while the waterbird fauna comprised 44 species (up to 28 species per annum) and often several thousand individual birds.

Species richness as a measure of biodiversity

There is much debate about appropriate measures of biodiversity (Ferrier 2002; Sarkar and Margules 2002). However, species richness has been widely used and, provided several taxonomically unrelated groups are represented, should provide useful information about general trends in biodiversity (Margules and Redhead 1995; Martens and Hamer 1999). Species richness is known to respond to broad habitat changes such as large variations in salinity (Timms 1998), the presence or absence of submerged macrophytes (Cale and Edward 1990), eutrophication (Davis *et al.* 1993) and the presence of significant quantities of pesticide (Eisler 1992; Davies and Cook 1993).

Species richness is a particularly useful measure of biodiversity in situations where few or no species occur at one stage of the monitoring cycle because absence of species has an obvious meaning. Most indices, especially those based on community composition, cannot be used when no species are present. Two of the shortcomings of species richness, however, are that it takes no account of the importance of individual taxa and it discriminates against sites that are naturally depauperate, even though they may be in good ecological condition with high conservation value. This is particularly troublesome when assessing the waterbird and invertebrate richness of naturally saline lakes, such as Lake Ronnerup (Table 49). Natural salinity has less impact on plant richness (Halse *et al.* 1993ba).

TABLE 49
The relative rank for species richness of waterbirds, aquatic invertebrates and plants at the 23 monitored wetlands.

WETLAND	WATERBIRDS RICHNESS	WATERBIRDS RANK	INVERTEBRATES RICHNESS	INVERTEBRATES RANK	VEGETATION RICHNESS	VEGETATION RANK
Pleasant View	14	12	136	**1**	58	**2**
Noobijup	*13	13	102	**2**	69	**1**
Bryde	*24	**4.5**	*91	**5.5**	46	**4**
Wheatfield	*29	**3**	*91	**5.5**	25	9
Kulicup	*1	20.5	92	**4**	48	**3**
Logue	*44	**1**	*83	7	3	20.5
Coomalbidgup	17	9	67	13	40	**5**
Towerrining	*33	**2**	*74	10	7	18
Goonaping	*1	20.5	71	12	37	6
Blue Gum	*17	10	80	8	9	17
Yaalup	7	17	93	**3**	5	19
Fraser	*21	6.5	73	11	10	16.5
Paperbark	9	15	74	9	13	14
Coyrecup	*21	6.5	*26	16	30	7
Coomelberrup	*20	8	35	14	14	13
Bennett's	*24	**4.5**	19	17	12	15.5
Eganu	*16	11	26	15	12	15.5
Campion	*9	16	9	22	28	8
Altham	*6	18.5	15	20	23	10
Walyormouring	20	7	18	18	3	20.5
Ardath	*6	18.5	16	19	16	12
Ronnerup	4	19	8	23	20	11
Parkeyerring	10	14	10	21	10	16.5

** Richness recorded from multiple surveys over more than 1 year.*

Community structure as a measure of biodiversity

Species richness is a useful measure of wetland biodiversity but, often, community structure will be more sensitive because subtle habitat changes often leave species richness constant while species turnover occurs (Growns *et al.* 1992). Ordination is a useful method of presenting data on community structure (Streever 1998; Halse *et al.* 2002). One of the advantages of ordination is that it is more sensitive to turnover of species than loss of species (or them being missed through sampling error) (Halse *et al.* 2002). Use of historical waterbird data from some monitoring wetlands suggested community structure has been stable at several wetlands where salinity was stable (Lakes Walyormouring, Yaalup and Pleasant View) but had changed at others where secondary salinization and salt loads had increased (Coomelberrup, Coyrecup and Eganu).

In this report, we used marker wetlands to identify the community characteristics of different parts of ordination space and to calibrate shifts in wetland communities over time. The choice of markers affects the sensitivity of ordination (see Halse *et al.* 2002) and further efforts to select the most appropriate marker wetland are needed.

Hydrological cycles

Extent of lake-bed flooding, period of inundation and water depth often vary between years in Western Australian wetlands (Halse *et al.* 1998), including those of the Wheatbelt (Lane and Munro 1983). Community structure usually integrates conditions prior to, and during, the time of sampling. This principle is well established in river research (Smith *et al.* 1999) but has received less attention in wetlands, except for vegetation studies (Froend *et al.* 1993). In the case of aquatic invertebrates, integration occurs over the preceding month or so. Consequently, conditions prevailing at the time of sampling may not solely be those structuring the community. This introduces noise into monitoring results, just as the extent of rainfall in adjacent areas affects the number of waterbird species recorded (see Halse *et al.* 1992). At Lake Towerrining, the two sampling years presented similar conditions at the time of invertebrate sampling (Fig. 15) but in 1997 salinity was increasing while in 1999 it was decreasing. Although the salinity differences were not sufficient to result in vastly different species assemblages, some elements of the invertebrate community were surprisingly different, including Rotifera, Copepoda and Cladocera. Rotifera were present in 1999 only and, while the copepod and cladoceran faunas had similar richness, there were few species in common across years. Much larger changes in community composition and species richness occurred at wetlands where the hydrograph was markedly different between years. For example, the waterbird and invertebrate communities at Lake Logue showed considerable changes between 1997 and 1999 (Fig. 12,13), as did the invertebrate fauna at Bryde (Fig. 8).

On occasions, within year variation in the annual hydrological cycle caused a greater discrepancy in wetland values for waterbirds compared to invertebrates than was actually apparent. Combining the results of 3 waterbird surveys each year, from late winter, spring and autumn, meant that waterbird lists were sometimes compiled over a substantial range of wetland conditions. This was pronounced at Ronnerup, where summer flooding in 2000 significantly increased waterbird richness after invertebrates had been sampled. The conclusion that the wetland was of greater value to waterbird communities or that wetland value had declined for invertebrates would be erroneous since the two communities were formed under very different ambient conditions. A similar phenomenon occurred in Bryde in 2000.

Threats to Wheatbelt wetland biodiversity

The major threat to wetland biodiversity in the wheatbelt is secondary salinization (George *et al.* 1995; Williams 1999; Halse *et al.* 2003). Preliminary results of computer modelling exercises suggest water tables will continue to rise throughout the wheatbelt, with continued threat to wetland biodiversity a consequence (Clarke *et al.* 1999; see also Clarke *et al.* 2002). This process threatens the communities of naturally saline wetlands, as well as fresh water bodies (see Lyons *et al.* 2002; Halse *et al.* 2003; Pinder *et al.* 2003) because plants and animals that occur in naturally saline systems usually cannot tolerate the increased hydro-period and changed salinity regime associated with secondary salinity (Cramer and Hobbs 2002).

Groundwater monitoring bores have not been in place long enough to establish the extent of rising groundwater at any particular wetlands. With the exception of localised aquifers, groundwater beneath all the monitored wetlands was saline and in most wetlands was in close proximity to the lake-bed. Watertables were more than a few metres below the lake-bed at only a few wetlands (Kulicup, Campion, Goonaping, Fraser). Where groundwater intersects the lake-bed, lake water becomes more saline than groundwater as salts accumulate through successive years of evapo-concentration, as is the case in several monitoring wetlands (e.g. Coomelberrup, Walyormouring, Eganu, Parkeyerring and Ronnerup). Increasing salinization as a result of groundwater rise is likely to ocur at Coyrecup and Ardath which are already saline, and at Yaalup which is fresh. Several other wetlands are potentially threatened, including Noobijup, Towerrining and Bryde.

Groundwater may also interact with surface run-off into lakes and result in increased salt loads. The distinction between direct interaction between lake and groundwater and between groundwater and inflow is important as each has different management implications. Significant salt loads were imposed on some wetlands following flooding (Towerrining, Blue Gum, Fraser and Coomelberrup). It is also likely that major flood events purge some salinized wetlands and reduce salt loads. This appears to occur at Lakes Walyormouring and Towerrining, two wetlands where inflow and interaction with groundwater result in a significant salt load and yet lake salinity has remained relatively stable over the last 20 years.

Acidic groundwater has the potential to reduce the biodiversity of wetlands in the same manner as secondary salinization (see Halse *et al.* 2003). There are several pockets of naturally acidic groundwater in the Wheatbelt and rising groundwater often leads to further acidification. At present the process is not well documented and the buffering effect of carbonate soils has not been quantified. However, if rising watertables bring acidic groundwater into contact with surface water and pH within the wetland declines it is likely to affect wetland fauna (and surrounding plant communities) detrimentally. There are comparatively few salt-tolerant acidophiles. Acidic groundwater was observed at several monitoring wetlands (Campion, Ardath, in deep bores at Bryde and east of Coyrecup).

While disturbed hydrology is a major driver of threats to the biodiversity of Wheatbelt wetlands,it is not the only threatening factor. In particular, clearing of riparian vegetation, weed invasion, nutrients and pesticides frequently result in the degradation of wetland communities. Measures to control secondary salinization, including drainage and the disposal of drainage water, can also adversely affect wetland biodiversity.

Trends in salinity and faunal use of wetlands

Trends in salinity of Wheatbelt wetlands are currently being analysed by JAK Lane, using data collected over the past 20+ years (Lane and Munro 1983), and will not be considered in detail in this report. However, there is evidence of increased salinity in six of the 23 wetlands reported upon here, a further four exhibit secondary salinization but have been relatively stable over the past 20 years, and two others are likely to show increased salinity levels soon.

Monitoring data showed a strong negative relationship between invertebrate species richness and salinity (Fig. 137) and a significant, though less strong, relationship for waterbirds (Fig. 138). Williams (1998) argued that salinity was an important determinant of species richness only over wide ranges of salinity, with other factors such as micro-habitat being more important within narrow salinity ranges. The monitoring data suggest that salinity has a strong deterministic effect on overall richness of the invertebrate community but acts merely as a constraint on waterbird richness. Other factors, such as water depth and density of emergent vegetation often limit waterbird species richness in a dramatic fashion in freshwater wetlands, so salinity is not a good predictor of richness (Halse *et al.* 1993c).

Of the seven monitoring wetlands for which historical waterbird data are available, three have become more saline over the past 20 years and this has been accompanied by pronounced declines in the richness of waterbird communities at the two saline wetlands (Coyrecup, Coomelberrup). At Lake Bryde, salinity has increased but water is still brackish much of the time and waterbird use of the wetland has increased, in line with the findings of Halse *et al.* (1993c) that many waterbirds like brackish water.

Big shifts in waterbird community structure were apparent at particular wetlands in some years and appear to be related to salinity thresholds. For example, although average salinities at Lake Eganu appear to have changed little over the past 20 years, conditions were much more saline in 2000 than any other year for which waterbird data are available and the community was markedly different. Another important factor influencing waterbird use of salinized wetlands is the availability of freshwater, either within the lake itself as a result of discharge from perched freshwater aquifers or in nearby wetlands. Both Walyormouring and Parkeyerring have perched aquifers associated with throughflow from fringing gneiss outcrops

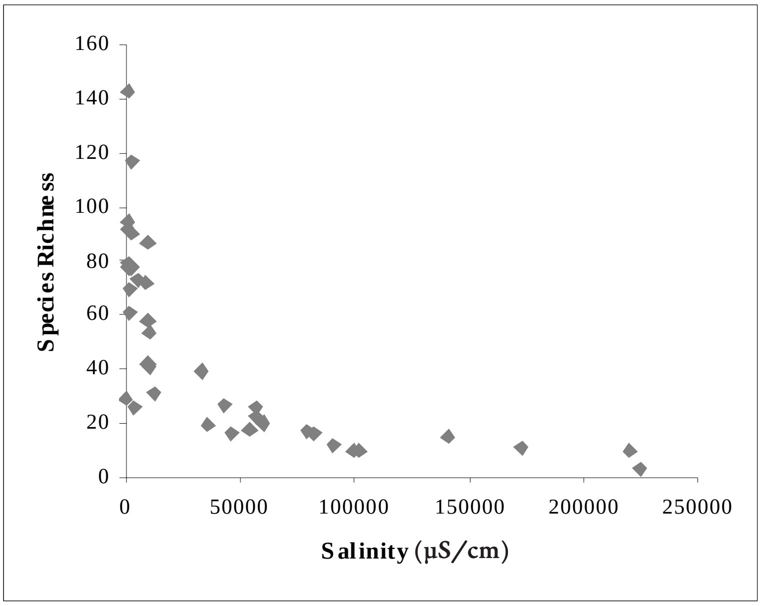

Figure 137. Relationship between salinity and species richness for aquatic invertebrates from 23 monitoring wetlands (Richness vs Log Salinity; ***r*** *= -0.78, p<0.01).*

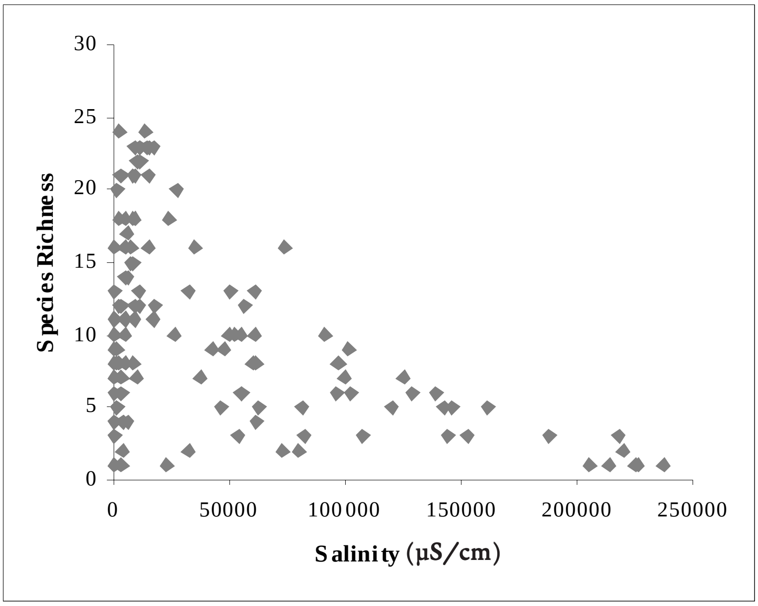

*Figure 138. Relationship between salinity and species richness for waterbirds from 23 monitoring wetlands (**r** = -0.45, p<0.01).*

and this may be true of other saline wetlands. Australian Shelduck and other waterbirds breed in salt lakes using this water source (Riggert 1977).

While the effect of secondary salinization on freshwater wetlands is widely recognised, the effect on naturally saline wetlands is often overlooked. Keighery *et al.* (1999) stressed the detrimental effect on wetland plants but there are few documented examples of the effect on invertebrate communities of these wetlands, although it can be inferred from distributional data that the effects are considerable. Recent broad scale survey of Wheatbelt wetlands (Pinder *et al.* 2003) has shown about 50 per cent of the invertebrate fauna is salt-adapted, with 23 per cent of these species occurring only in naturally saline wetlands with an undisturbed hydrological regime.

It should be re-iterated, however, that salinity is not the only cause of changes in the biodiversity values of Wheatbelt wetlands. Clearing of fringing vegetation, eutrophication and other factors have probably affected waterbird and invertebrate use of many Wheatbelt wetlands. Small changes appear to have occurred in the waterbird communities of Towerrining and Wheatfield over the past 20 years without significant changes in salinity, although these may be related to survey effort rather than altered wetland conditions. It is because many factors are likely to affect the composition of biological communities that biodiversity itself must be monitored, rather than environmental surrogates such as salinity or water depth, if trends in biodiversity are to be accurately documented. The lack of predictable monotonic response between biodiversity and disturbances such as salinity is another shortcoming of physical surrogates. Waterbirds and plants, in particular, appear to have complex relationships with salinity (Halse *et al.* 1993b,c).

Future monitoring

Changes in water quality and the physical conditions of Wheatbelt wetlands have been occurring over several decades. While it is likely that there are threshold values (in terms of salinity, vegetation structure, water depth etc.) to which biodiversity will show significant stepwise responses, the biological response is likely to occur over a similar time-scale (decades) to physical changes. Therefore, long-term monitoring will be required to show the extent of future change in wetland biodiversity. Data from wetlands such as Towerrining (Froend and McComb 1991) and Yarnup (Halse *et al.*1993b and subsequent monitoring by JAK Lane) suggest even dramatic changes across thresholds are expressed over periods of a decade or so. Variability in wetland biodiversity is not sufficiently characterised and will not be for many years to be able to define what an acceptable change in biodiversity of a particular wetland might be. The methodology does not attempt to enable the testing of acceptable change in biodiversity in each wetland; rather it is focused on trends in biodiversity. Future users of the data will be in a better position to determine hypotheses that should be tested from the data.

Some wetlands have filling and drying cycles that span several years. For example, Lakes Altham and Bryde may fill during extreme rainfall events and remain inundated for several years before returning to a seasonal drying cycle, which in turn may last several years. During Lake Bryde's seasonal phase, the lakebed is occupied by *Muelhenbeckia horrida*. During the flooded phase, this vegetation is inundated and senesces. The biodiversity values of Lake Bryde relate both to the periods when deeply flooded and when *M. horrida* is active. Thus, monitoring needs to encompass the range of conditions that occur at a wetland and provide data about their frequency as well as the biological attributes associated with each state.

This report provides only baseline data for the monitored wetlands and it is likely to be many years before strong trends in biodiversity become evident. In addition to the slow pace of wetland change, monitoring results can be confounded by climatic variability so that a long period of relatively frequent monitoring is often required. There are three kinds of climatic variability. Firstly, small-scale annual variability, principally in rainfall, causes annual variation in wetland depth and conditions that will affect waterbird and invertebrate communities and create some inter-annual noise in the monitoring data. A second, more significant kind of variability is caused by extreme rainfall years (either drought or flood) that cause pronounced short-term natural changes in the depth and ecology of a wetland that are greater than likely anthropogenic change. We recommend that extreme years are excluded from most analyses (Halse *et al.* 2002). The third kind of variability is long-term change in climate. This kind of variability is difficult to deal with when the purpose of monitoring is detecting the effect of anthropogenic changes, because appropriate reference conditions will change through time. However, given that the Wheatbelt is in that part of Australia most likely to be affected by Greenhouse-induced climate change (CSIRO 2001), monitoring the effect of climate change itself on biodiversity is important. In this context, results collected during the first few years of monitoring will be an important baseline.

In summary, the wetland monitoring program will express its full potential only if it continues over several decades. The analysis of historical waterbird data provided in this report (see also Halse *et al.* 2000a), and the space for time analysis of changes in invertebrate communities (Halse *et al.* 2002), suggest that biodiversity patterns in Wheatbelt wetlands are changing and that the monitoring program will be able to document these changes and provide a basis for the evaluation of remedial action in wetland catchments.

ACKNOWLEDGEMENTS

We are indebted to Melita Pennifold for sorting and identifying many of the invertebrate samples. The following identified particular invertebrate groups: Adrian Pinder (Oligochaeta), Russ Shiel (Cladocera, Rotifera), Jane McRae (Copepoda). Voucher specimens were confirmed by Ivor Lansbury (Hemiptera) Chris Watts (Coleoptera), Alan Savage (Anostraca), Ros St Clair (Trichoptera), Don Edward (Chironomidae), Winston Ponder (Coxiella), Mark Harvey (Acarina), John Hawking (Odonata) and Brian Timms (Spinicaudata). Site photographs were by S Halse unless otherwise acknowledged.

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APPENDIX A

Selected water chemistry and physical parameters for study wetlands. ND = "no data available".

Site	Date	Depth (m)	Field Ec (µS/cm)	Field pH	TN (µg/l)	Nitrate (µg/l)	TP (µg/l)	Total Chloroph. (µg/l)	Phaeoph. (µg/l)	Temp. (°C)	Dissolved Oxygen (%)	Turbidity (NTU)	Colour (TCU)	TDS (g/l)	Alkalinity (mg/l)	Hardness (mg/l)	Silica (mg/l)
Bryde	06-08-97	1.30	1250	8.22	ND	ND	ND	ND	ND	ND	87.3	ND	ND	ND	ND	ND	ND
Bryde	03-10-97	1.74	2540	8.08	1400	0.480	30	0.0	3.0	20.0	98.0	19.0	100.0	1.40	110	360	5.0
Bryde	11-03-98	0.70	5660	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bryde	28-08-99	0.10	22800	9.39	1700	0.010	10	3.5	2.0	23.6	188.0	ND	ND	ND	ND	ND	ND
Bryde	21-10-99	0.00	53700	9.44	6600	0.010	40	13	2.0	28.0	185.0	31.0	33.0	40.00	135	9200	2.0
Bryde	21-03-00	1.82	1197	7.56	3100	1.200	110	2.0	4.0	20.7	34.0	ND	ND	ND	ND	ND	ND
Logue	15-08-97	0.44	3730	8.59	ND	0.050	ND	ND	ND	20.4	ND	1.3	29.0	21.00	330	3000	2.7
Logue	01-10-97	0.36	12040	9.06	2500	1.300	20	8.0	22.0	18.0	105.0	210.0	17.0	7.30	300	1000	7.0
Logue	05-09-99	ND	1877	7.35	1800	0.270	140	3.5	2.0	16.1	81.0	ND	ND	ND	ND	ND	ND
Logue	27-10-99	3.65	1929	7.83	1500	0.260	140	4.0	0.5	21.1	76.3	70.0	280.0	1.10	80	200	11.0
Logue	13-03-00	2.84	2663	7.98	1400	0.010	70	1.5	6.0	23.9	81.0	ND	ND	ND	ND	ND	ND
Logue	21-08-00	2.64	2860	7.88	1100	0.010	40	7.0	0.5	15.4	78.4	ND	ND	ND	ND	ND	ND
Logue	14-11-00	2.52	3390	8.20	1400	0.010	40	3.0	2.0	26.6	104.3	58.0	33.0	2.00	145	340	13.0
Logue	13-02-01	1.80	4870	8.27	1200	0.010	5	5.5	18.0	24.9	83.3	ND	ND	ND	ND	ND	ND
Towerrining	07-08-97	2.80	8830	8.06	ND	ND	ND	ND	ND	ND	88.1	ND	ND	ND	ND	ND	ND
Towerrining	03-10-97	3.19	9560	8.30	3000	1.800	10	0.0	2.0	18.0	92.0	3.7	11.0	5.30	180	1700	19.0
Towerrining	11-03-98	2.30	13700	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Towerrining	21-08-99	3.28	10260	8.87	1300	0.010	5	13.0	3.0	14.3	109.0	ND	ND	ND	ND	ND	ND
Towerrining	22-10-99	3.34	9300	9.27	1300	0.010	10	9.0	140.0	18.9	126.8	3.6	22.0	5.50	148	1800	3.0
Towerrining	20-03-00	2.49	9330	8.97	1400	0.010	10	242.5	3.0	24.3	156.0	ND	ND	ND	ND	ND	ND
Coyrecup	06-08-97	0.86	51000	8.41	ND	ND	ND	ND	ND	ND	101.8	ND	ND	ND	ND	ND	ND
Coyrecup	25-10-97	0.90	52700	9.05	2700	0.050	20	0.0	0.0	26.0	136.0	6.1	24.0	40.90	130	9500	1.0
Coyrecup	11-03-98	0.10	61800	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Coyrecup	29-08-99	1.11	55300	9.15	2600	0.010	20	4.0	0.5	16.8	131.0	ND	ND	ND	ND	ND	ND
Coyrecup	21-10-99	1.09	56800	9.51	3000	0.010	20	1.5	4.0	24.3	188.6	16.0	20.0	42.00	113	11000	2.0
Coyrecup	18-03-00	0.42	144000	7.48	11000	0.010	110	4.5	8.0	18.6	81.0	ND	ND	ND	ND	ND	ND
Wheatfield	05-08-97	ND	14870	8.15	ND	ND	ND	ND	ND	ND	93.4	ND	ND	ND	ND	ND	ND
Wheatfield	17-11-97	2.00	10900	8.53	2200	0.210	20	56.0	21.0	22.0	159.0	5.5	130.0	6.70	220	1100	11.0
Wheatfield	10-03-98	0.70	24000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Wheatfield	26-08-99	2.50	8730	8.19	1600	0.020	30	36.0	5.0	14.5	104.0	ND	ND	ND	ND	ND	ND
Wheatfield	19-10-99	2.50	9010	8.69	1600	0.010	20	29.0	0.5	20.8	121.8	3.5	140.0	5.50	140	880	11.0
Wheatfield	23-03-00	2.00	5050	7.52	2300	0.070	50	21.0	11.0	19.7	41.0	ND	ND	ND	ND	ND	ND
Altham	18-08-98	0.15	152800	8.18	3100	ND	40	55.5	0.5	14.4	117.0	ND	ND	ND	ND	ND	ND
Altham	04-11-98	0.18	139300	7.87	5700	0.010	80	0.0	47.0	29.0	120.0	520.0	23.0	120.00	310	18000	2.0
Altham	20-04-99	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Altham	24-08-00	0.20	142300	8.33	7900	0.020	220	37.0	0.5	14.7	105.0	ND	ND	ND	ND	ND	ND
Altham	12-10-00	0.00	214000	6.62	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Noobijup	24-08-98	1.00	3910	7.29	1700	ND	5	1.5	5.0	14.6	350.0	ND	ND	ND	ND	ND	ND

APPENDIX A
Selected water chemistry and physical parameters for study wetlands. ND = "no data available" (continued).

Site	Date	Depth (m)	Field Ec (µS/cm)	Field pH	TN (µg/l)	Nitrate (µg/l)	TP (µg/l)	Total Chloroph. (µg/l)	Phaeoph. (µg/l)	Temp. (ºC)	Dissolved Oxygen (%)	Turbidity (NTU)	Colour (TCU)	TDS (g/l)	Alkalinity (mg/l)	Hardness (mg/l	Silica (mg/l)
Noobijup	06-11-98	0.70	1865	7.15	980	0.010	5	0.0	0.0	18.0	56.0	2.6	64.0	1.20	40	290	0.5
Noobijup	19-04-99	ND	5760	7.01	1500	0.010	5	2.0	4.0	17.6	ND	ND	ND	ND	ND	ND	ND
Noobijup	25-08-00	1.41	1699	6.25	1600	0.450	5	7.0	0.5	13.0	87.0	ND	ND	ND	ND	ND	ND
Noobijup	16-11-00	1.28	3810	7.63	810	0.010	10	1.5	1.0	24.8	89.2	1.2	61.0	1.20	45	290	0.5
Noobijup	16-02-01	0.85	3760	7.15	2400	0.010	5	11.0	0.5	20.4	40.0	ND	ND	ND	ND	ND	ND
Bennett's	19-08-98	0.70	48400	9.49	1800	ND	10	2.0	0.5	12.1	155.0	ND	ND	ND	ND	ND	ND
Bennett's	04-11-98	0.60	60700	9.80	1900	0.010	10	0.0	0.0	20.0	135.0	7.7	5.0	41.00	280	5200	0.5
Bennett's	21-04-99	0.09	216000	7.65	22000	0.020	440	45.0	0.0	21.8	27.3	ND	ND	ND	ND	ND	ND
Bennett's	31-08-00	2.60	8440	7.00	1300	0.080	30	3.0	0.5	11.7	85.6	ND	ND	ND	ND	ND	ND
Bennett's	15-11-00	2.43	10670	8.59	900	0.030	10	49.0	0.5	26.3	138.2	1.5	360.0	6.30	95	930	5.0
Bennett's	15-02-01	2.20	15670	7.95	1200	0.020	5	17.0	0.5	19.9	90.4	ND	ND	ND	ND	ND	ND
Ardath	27-08-98	1.50	63100	3.97	3000	ND	5	3.0	0.5	16.0	ND	ND	ND	ND	ND	ND	ND
Ardath	10-11-98	ND	79800	3.86	4100	0.035	5	7.0	0.0	23.0	96.0	11.0	2.5	60.00	1	11000	31.0
Ardath	21-04-99	ND	32300	4.08	2400	0.060	5	3.0	1.0	21.6	94.0	ND	ND	ND	ND	ND	ND
Ardath	30-08-00	1.27	73400	4.03	2300	0.030	5	6.0	0.5	13.2	110.4	ND	ND	ND	ND	ND	ND
Ardath	13-10-00	1.08	82500	3.66	2500	0.020	5	1.5	4.0	16.5	92.6	12.0	2.5	62.00	1	10000	21.0
Ardath	14-02-01	0.05	224000	2.58	9800	0.040	20	7.0	0.5	30.1	66.2	ND	ND	ND	ND	ND	ND
Blue Gum	28-08-98	0.90	5420	7.79	3400	ND	340	3.0	0.5	19.9	ND	ND	ND	ND	ND	ND	ND
Blue Gum	12-11-98	0.30	9330	8.23	4500	0.020	160	1.0	3.0	24.0	70.0	2.3	230.0	6.00	240	1000	7.0
Blue Gum	10-05-99	ND	2590	7.58	2500	0.100	360	1.0	4.0	18.6	ND	ND	ND	ND	ND	ND	ND
Blue Gum	22-08-00	0.79	38200	9.70	1900	0.010	10	6.5	0.5	16.6	193.0	ND	ND	ND	ND	ND	ND
Blue Gum	17-10-00	ND	46000	9.93	5700	0.010	5	9.0	0.5	23.0	197.0	4.5	21.0	33.00	135	4800	2.0
Blue Gum	13-02-01	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kulicup	26-08-98	0.09	ND	ND	760	ND	10	3.0	0.5	ND	ND	ND	ND	ND	ND	ND	ND
Kulicup	06-11-98	0.10	431	7.53	1400	0.010	20	0.0	5.0	18.0	88.0	76.0	210.0	0.42	130	80	48.0
Kulicup	20-04-99	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Kulicup	01-09-00	0.22	246	7.30	1000	0.010	20	1.5	0.5	9.7	62.1	ND	ND	ND	ND	ND	ND
Kulicup	11-10-00	0.20	329	7.64	950	0.010	20	1.5	0.5	18.2	66.9	150.0	250.0	0.42	105	53	26.0
Kulicup	16-02-01	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Campion	27-08-98	1.30	120300	4.29	6400	ND	5	1.5	0.5	17.6	ND	ND	ND	ND	ND	ND	ND
Campion	10-11-98	1.10	173900	3.85	6500	0.240	5	2.0	7.0	28.2	111.0	19.0	2.5	160.00	1	17000	12.0
Campion	22-04-99	1.84	96800	6.50	1300	0.070	10	8.0	0.0	22.9	104.0	ND	ND	ND	ND	ND	ND
Campion	23-08-00	0.83	205000	3.84	2500	0.210	5	2.0	0.5	15.8	96.0	ND	ND	ND	ND	ND	ND
Campion	19-10-00	0.65	225000	3.74	3200	0.240	5	4.0	0.5	ND	74.0	29.0	2.5	260.00	1	21000	9.0
Campion	14-02-01	0.20	218000	2.68	24000	1.300	5	8.0	0.5	20.5	86.1	ND	ND	ND	ND	ND	ND
Goonaping	26-08-98	0.10	150	6.85	1300	ND	5	2.0	6.0	19.4	ND	ND	ND	ND	ND	ND	ND
Goonaping	09-11-98	0.10	524	6.92	2400	0.010	30	1.0	0.0	36.6	61.4	10.0	180.0	0.40	28	26	10.0
Goonaping	20-04-99	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

APPENDIX A

Selected water chemistry and physical parameters for study wetlands. ND = "no data available" (continued).

Site	Date	Depth (m)	Field Ec (µS/cm)	Field pH	TN (µg/l)	Nitrate (µg/l)	TP (µg/l)	Total Chloroph. (µg/l)	Phaeoph. (µg/l)	Temp. (ºC)	Dissolved Oxygen (%)	Turbidity (NTU)	Colour (TCU)	TDS (g/l)	Alkalinity (mg/l)	Hardness (mg/l	Silica (mg/l)
Goonaping	29-08-00	ND	ND	ND	860	0.010	10	5.0	2.0	ND	ND	ND	ND	ND	ND	ND	ND
Goonaping	03-10-00	0.20	172	8.13	970	0.020	5	39.5	0.5	28.3	119.5	1.8	66.0	0.18	3	17	7.0
Goonaping	12-02-01	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Coomelberrup	18-08-98	0.78	60100	8.22	2300	ND	20	49.0	2.0	13.0	112.0	ND	ND	ND	ND	ND	ND
Coomelberrup	05-11-98	1.33	32800	9.65	1700	0.010	10	0.0	0.0	24.5	134.0	5.8	12.0	22.00	140	4200	1.0
Coomelberrup	20-04-99	0.57	96000	8.18	3600	0.010	20	8.0	0.0	22.1	4.6	ND	ND	ND	ND	ND	ND
Coomelberrup	24-08-00	0.93	81900	8.54	2800	0.010	5	12.5	0.5	13.9	99.0	ND	ND	ND	ND	ND	ND
Coomelberrup	12-10-00	0.89	91300	7.78	3400	0.010	5	1.5	0.5	17.6	66.0	2.5	6.0	73.00	285	14000	0.5
Coomelberrup	15-02-01	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Walyormouring	21-08-98	0.60	17790	9.42	2200	ND	20	4.5	0.5	15.8	124.0	ND	ND	ND	ND	ND	ND
Walyormouring	11-11-98	0.39	35300	9.97	3600	0.020	10	0.0	0.0	30.8	234.0	5.5	20.0	25.00	100	3700	1.0
Walyormouring	22-04-99	0.46	11320	10.35	1700	0.010	20	3.0	1.0	22.8	164.0	ND	ND	ND	ND	ND	ND
Walyormouring	23-08-00	0.44	60600	9.61	3500	0.010	5	1.5	2.0	14.3	177.0	ND	ND	ND	ND	ND	ND
Walyormouring	18-10-00	0.28	99700	8.31	6900	0.010	5	2.0	0.5	29.6	153.8	34.0	30.0	66.00	255	9000	2.0
Walyormouring	14-02-01	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Eganu	20-08-98	2.56	26800	8.12	1200	ND	10	2.0	0.5	16.9	105.0	ND	ND	ND	ND	ND	ND
Eganu	12-11-98	2.15	43300	9.01	1900	0.010	10	10.0	0.0	28.3	123.0	990.0	13.0	30.00	180	4600	8.0
Eganu	11-05-99	1.80	55700	8.25	2700	0.010	20	0.0	7.0	18.8	ND	ND	ND	ND	ND	ND	ND
Eganu	22-08-00	1.74	107800	8.04	3400	0.020	5	1.5	0.5	14.1	54.0	ND	ND	ND	ND	ND	ND
Eganu	09-11-00	1.58	128600	7.81	4400	0.020	5	2.0	0.5	29.0	76.4	2.4	33.0	110.00	210	15000	13.0
Eganu	13-02-01	0.00	226000	7.30	11000	0.010	10	26.0	0.5	34.1	42.5	ND	ND	ND	ND	ND	ND
Fraser	28-08-98	0.13	865	7.75	3000	ND	820	1.5	8.0	15.0	ND	ND	ND	ND	ND	ND	ND
Fraser	11-11-98	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fraser	03-09-99	0.65	508	7.17	1700	0.020	140	2.5	24.0	15.2	76.0	ND	ND	ND	ND	ND	ND
Fraser	26-10-99	0.80	629	7.63	1800	0.010	110	6.5	0.5	24.6	71.3	27.0	190.0	0.40	93	61	2.0
Fraser	16-03-00	1.50	826	7.02	1700	0.010	40	6.5	12.0	22.6	44.0	ND	ND	ND	ND	ND	ND
Fraser	29-08-00	1.28	1196	8.16	1000	0.010	20	3.0	1.0	15.2	124.7	ND	ND	ND	ND	ND	ND
Fraser	24-11-00	0.70	1710	8.77	2000	0.010	30	3.5	3.0	22.8	87.5	1.8	58.0	0.93	73	120	0.5
Fraser	12-02-01	0.30	4850	9.05	4600	0.010	30	20.0	0.5	27.6	183.0	ND	ND	ND	ND	ND	ND
Paperbark	02-09-99	0.88	447	7.43	2400	0.080	410	2.0	3.0	13.8	52.0	ND	ND	ND	ND	ND	ND
Paperbark	25-10-99	0.85	588	7.64	2700	0.110	640	2.5	8.0	25.6	67.7	1400.0	130.0	0.45	148	93	12.0
Paperbark	17-03-00	1.13	560	7.66	1600	0.010	110	5.0	11.0	24.8	93.0	ND	ND	ND	ND	ND	ND
Coomalbidgup	27-08-99	1.50	5240	7.96	1200	0.040	190	5.0	4.0	18.5	89.0	ND	ND	ND	ND	ND	ND
Coomalbidgup	19-10-99	1.00	5610	7.98	1100	0.010	140	1.5	6.0	20.8	70.4	2.4	110.0	3.30	208	520	2.0
Yaalup	28-08-99	1.01	1090	8.22	3200	0.080	540	12.5	0.5	16.4	86.0	ND	ND	ND	ND	ND	ND
Yaalup	23-10-99	0.90	1192	8.29	3100	0.010	520	19.0	18.0	18.9	81.0	850.0	390.0	1.10	263	130	5.0
Yaalup	21-03-00	1.62	683	7.36	3100	0.100	140	53.0	27.0	19.9	35.0	ND	ND	ND	ND	ND	ND
Parkeyerring	01-09-99	0.61	101600	7.84	4800	0.010	40	7.0	3.0	19.8	83.0	ND	ND	ND	ND	ND	ND

APPENDIX A

Selected water chemistry and physical parameters for study wetlands. ND = "no data available" (continued).

Site	Date	Depth (m)	Field Ec (µS/cm)	Field pH	TN (µg/l)	Nitrate (µg/l)	TP (µg/l)	Total Chloroph. (µg/l)	Phaeoph. (µg/l)	Temp. (ºC)	Dissolved Oxygen (%)	Turbidity (NTU)	Colour (TCU)	TDS (g/l)	Alkalinity (mg/l)	Hardness (mg/l	Silica (mg/l)
Parkeyerring	25-10-99	0.86	102500	8.94	5100	0.020	40	13.0	4.0	17.5	94.7	12.0	14.0	85.00	265	19000	1.0
Parkeyerring	18-03-00	0.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pleasant View	30-08-99	0.82	1210	6.89	1200	0.010	5	2.0	6.0	15.1	92.0	ND	ND	ND	ND	ND	ND
Pleasant View	24-10-99	0.92	1214	6.65	1100	0.010	5	4.5	2.0	17.8	64.3	1.7	71.0	0.71	35	110	3.0
Pleasant View	21-03-00	0.60	1668	7.16	1200	0.010	5	8.0	0.5	21.3	68.0	ND	ND	ND	ND	ND	ND
Ronnerup	28-08-99	0.12	188300	8.66	2200	0.020	50	14.0	0.5	17.1	100.0	ND	ND	ND	ND	ND	ND
Ronnerup	20-10-99	0.05	220000	7.55	2800	0.020	50	ND	ND	24.3	77.9	740.0	2.5	300.00	158	33000	4.0
Ronnerup	22-03-00	2.00	73500	7.43	1400	0.120	20	7.0	5.0	19.7	58.0	ND	ND	ND	ND	ND	ND

APPENDIX B
Ionic composition of water at site A for each study wetland.

Site	Date	Sodium (meq/l)	Calcium (meq/l)	Magnesium (meq/l)	Potassium (meq/l)	Chloride (meq/l)	Bicarbonate (meq/l)	Carbonate (meq/l)	Sulphate (meq/l)
Bryde	03-10-97	16.53	2.74	4.44	0.33	18.33	2.13	0.03	7.48
Bryde	21-10-99	487.20	51.39	132.50	6.78	592.20	2.50	0.19	191.36
Logue	15-08-97	324.07	6.23	59.09	3.14	377.88	6.60	0.03	62.4
Logue	01-10-97	100.05	4.99	15.63	1.35	112.80	6.06	0.03	20.80
Logue	27-10-99	14.22	1.19	2.79	0.35	14.94	1.60	0.03	4.16
Logue	14-11-00	24.96	2.09	4.60	0.56	25.66	2.90	0.03	7.07
Towerrining	03-10-97	60.90	5.98	27.15	0.28	84.60	3.44	0.03	35.36
Towerrining	22-10-99	62.20	6.13	29.13	0.23	90.24	2.75	0.19	37.44
Coyrecup	25-10-97	478.50	42.41	148.14	2.20	676.80	2.62	0.03	197.60
Coyrecup	21-10-99	513.30	53.89	160.48	2.73	648.60	1.44	0.79	228.80
Wheatfield	17-11-97	91.35	3.24	18.10	1.38	98.70	4.42	0.03	22.88
Wheatfield	19-10-99	73.95	2.59	14.89	1.07	81.78	2.80	0.03	18.30
Altham	04-11-98	1435.50	38.42	312.74	16.38	1833	6.23	0.03	374.40
Noobijup	06-11-98	14.35	0.99	4.85	0.10	17.20	0.80	0.03	6.03
Noobijup	16-11-00	12.78	0.99	4.77	0.07	16.35	0.90	0.03	6.03
Bennett's	04-11-98	522.00	4.24	98.76	6.91	620.40	0.70	4.66	108.16
Bennett's	15-11-00	86.13	2.34	16.21	1.35	98.70	1.90	0.03	19.34
Ardath	10-11-98	652.50	74.85	148.14	6.91	930.60	0.01	0.03	228.80
Ardath	13-10-00	756.90	43.56	166.24	7.80	874.20	0.01	0.03	208.00
Blue Gum	12-11-98	73.95	5.98	13.99	1.38	78.96	4.75	0.03	20.80
Blue Gum	17-10-00	425.43	17.46	77.85	5.76	507.60	2.29	0.03	99.84
Kulicup	06-11-98	3.26	0.44	1.15	0.17	1.57	2.62	0.03	1.66
Kulicup	11-10-00	3.26	0.29	0.74	0.10	1.46	2.09	0.03	1.10
Campion	10-11-98	2349.00	94.81	238.67	13.56	2679.00	0.01	0.03	353.60
Campion	19-10-00	3871.50	72.85	344.83	20.78	4230.00	0.01	0.03	436.80
Goonaping	09-11-98	4.35	0.19	0.32	0.20	4.23	0.55	0.03	0.54
Goonaping	03-10-00	2.47	0.09	0.24	0.07	4.51	0.04	0.03	0.35
Coomelberrup	05-11-98	274.05	15.96	68.30	1.33	282.00	1.24	1.59	87.36
Coomelberrup	12-10-00	856.95	44.66	232.90	5.19	1043.40	5.70	0.03	291.20
Walyormouring	11-11-98	313.20	21.45	52.67	5.37	310.20	0.01	1.79	76.96
Walyormouring	18-10-00	874.35	35.32	144.02	15.07	958.80	4.70	0.03	187.20
Eganu	12-11-98	369.75	17.46	72.42	5.12	479.40	2.62	0.99	95.68
Eganu	09-11-00	1487.70	77.34	226.32	15.20	1579.20	4.19	0.03	312.00
Fraser	26-10-99	4.74	0.64	0.57	0.30	3.94	1.85	0.03	1.26
Fraser	24-11-00	13.61	1.09	1.39	0.69	12.69	1.44	0.03	2.49
Paperbark	25-10-99	4.43	0.99	0.82	0.23	3.10	2.95	0.03	1.93
Coomalbidgup	19-10-99	44.80	2.99	7.40	0.92	47.94	4.14	0.03	10.81
Yaalup	23-10-99	9.35	1.19	1.48	0.40	6.20	5.24	0.03	2.70
Parkeyerring	25-10-99	1057.05	78.34	302.86	5.29	1297.20	5.29	0.03	395.20
Pleasant View	24-10-99	9.57	0.49	1.72	0.33	9.87	0.70	0.03	2.28
Ronnerup	20-10-99	4480.50	32.78	618.07	41.47	5076.00	3.14	0.03	686.40

Corrigenda

Abbott, I. (1999). The avifauna of the forests of southwest Western Australia: Changes in species composition, distribution and abundance following anthropogenic disturbance. *CALMScience Supplement* No. **5**, 1-175.

The following corrections should be noted:

TEXT

PAGE	COLUMN	LINE	ACTION
2	2	4-5*	Delete reference to Keartland collecting in forests in 1895 near King George Sound
6	1	31**	Change ?1905 to 1907
6	1	32**	Change ?1906 to 1907
31	1	18**	Change Figure 3 to Figure 4
44	2	20*	Change Storr 199 to Storr 1991
67	1	13*	Change 1829 to 1830
97	2	5*	Change *Zoologishe* to *Zoologische*

* counting from bottom of page, ** from top

TABLES

PAGE	ACTION
140	The rows *Leipoa ocellata, Coturnix novaezelandiae* and *Coturnix ypsilophora* are out of sequence. Place them after *Dromaius novaehollandiae*, as is the case elsewhere in Table 2.
148 (No. 41)	Change 102 to 10 and 500 to 2 500
149 (No. 45)	Change 201 to 20 and 750 to 1 750
152 *(Meliphaga virescens)*	'Brown' in column 1 belongs in column 3
156	The dots in rows *Merops ornatus* through to *Smicrornis brevirostris* should commence immediately from under the column headed W

List of Referees

The Science Publications Unit expresses grateful appreciation for the contributions made by the following reviewers (as well as a small number who preferred to remain anonymous) of manuscripts for publication in *Conservation Science Western Australia* Volume **4** 2001-2002

Ray Bird, Tourism Consultant, Perth.
Jonathan Brand, Forest Products Commission, Perth.
Dr Penny Butcher, CSIRO, Forestry and Forest Products.
Dr Stephen Davies, Consultant, Mount Helena WA.
John Dell, Department of Environmental Protection, Perth.
Mark Ellis, Primary Industries and Resources, South Australia.
Dr Stephen Forbes, Botanic Gardens, Adelaide.
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EA Griffin, Department of Agriculture, Perth.
Dr Chris Harwood, CSIRO, Forestry and Forest Products.
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Dr George Yen, Department of Agriculture, Perth.
Dr Andrew Young, CSIRO, Plant Industry.