Biodiversity and Conservation Science

Wheatbelt Wetland Biodiversity Monitoring

Fauna Monitoring at Lake Ronnerup 1999-2012

Report WWBM-FR07

David Cale
Wetlands Conservation Program
Science and Conservation
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GOVERNMENT OF WESTERN AUSTRALIA
Department of Biodiversity, Conservation and Attractions

Department of Biodiversity, Conservation and Attractions

Locked Bag 104

Bentley Delivery Centre WA 6983

Phone: (08) 9219 9000

Fax: (08) 9334 0498

www.dbca.wa.gov.au

This report was prepared by David Cale and Adrian Pinder

Questions regarding the use of this material should be directed to:

Program Leader
Ecosystem Science Program
Department of Parks and Wildlife
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 92199868
Email: adrian.pinder@dbca.wa.gov.au

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Cover photo: Lake Ronnerup, from the south-east shore looking north, in August 2009.

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Contents

1 Summary

Lake Ronnerup is a naturally saline wetland situated in Lake King Nature Reserve (R 39422) approximately 40 km south-east of Lake King township (33°15’S 119° 37’ E). The lake had an extended hydroperiod between 1999 and at least 2001, partly from an extensive fill event in early 2000, reaching a maximum depth of 2m and salinity as low as 49.5 mS/cm. Since then, the lake has had shallower fillings (to 0.2m) lasting < 12 months with salinity 175 to 236 mS/cm. The relationship between salinity and depth is complex, probably due to variable salt load and volumes of inflows and outflows. The greater depth and associated lower salinity during the extended hydroperiod supported much higher diversity and abundance of waterbirds (up to 16 species and 3115 individuals per survey), probably due to the deeper water, submerged macrophyte growth and more diverse aquatic invertebrates, than during the years with shallow depth (e.g. 2009 with 1 species with as few as 10 individuals per survey). Higher richness of invertebrates (up to 10 species) during extended hydroperiods would also be largely driven by lower salinity and richer macrophyte growth than at other times, when only 1 or 2 species were present. Maintaining connectivity with other wetlands in the system (such as Bennetts Lake) is important for communities present during large events, especially if microcrustacean egg banks decline during extended periods without large fills. Most recorded species are common and widespread in the Wheatbelt, except for the Hooded Plover which was present on 6 occasions with counts of 1 to 19.

2 Background to the Wheatbelt wetland biodiversity monitoring project

The loss of productive land and decline of natural diversity in Western Australia as a result of salinisation, triggered a series of escalating community and government responses through the 1980s and 1990s. The first thorough review of the consequences of salinisation across Western Australian government agencies was released in 1996 (Wallace, 2001). This review resulted in the publication of: *Salinity; a Situation Statement for Western Australia* (Government of Western Australia, 1996a) which provided the basis for a detailed action plan published as *Western Australian Salinity Action Plan* (Government of Western Australia, 1996b). The Salinity Action Plan was reviewed and revised several times between 1996 and 2000 (including Government of Western Australia, 2000) details of which are provided by (Wallace, 2001). Amongst the actions detailed in the Salinity Action Plan the Department of Biodiversity Conservation and Attractions (as its predecessor CALM) was tasked with the establishment of six Natural Diversity Recovery Catchments in which remedial actions targeted at salinisation would protect natural diversity. Additionally, the department was tasked to "... monitor a sample of wetlands and their associated flora and fauna, in the south-west, to determine long-term trends in natural diversity and provide a sound basis for corrective action" (Government of Western Australia, 1996b).

The department’s response to the latter task was two-fold. Firstly, re-expansion of a long-term monitoring program (later known as the South West Wetlands Monitoring Program or SWWMP). This program monitored depth, salinity and pH at wetlands across the south-west and was established in the late 1970s to provide data on waterbird habitats (Lane, Clarke & Winchcombe, 2017) for determining timing of the duck hunting season and bag limits. The second response was a new program to monitor flora and fauna at 25 representative wetlands, including some in the Natural Diversity Recovery Catchments. The addition of two further recovery catchments added three wetlands to the program in

2010 to 2011. The 28 monitored wetlands were chosen using a number of criteria (Cale, Halse & Walker, 2004) to ensure representativeness and to build on already available data.

For sampling of fauna, the wetlands were divided into two groups and each half sampled each alternate year. For monitoring of flora, three groups were established with each group sampled every third year (see Lyons *et al.*, 2007 for details). Detailed methods for the fauna component, including methods for analyses presented below, will be detailed in a separate report in this series.

Previous publications based on the monitoring data have included assessment of the sampling design (Halse *et al.*, 2002), waterbird composition by wetland (Cale & Halse, 2004, 2006) and wetland case studies (Cale, 2005; Lyons *et al.*, 2007; Cale *et al.*, 2010, 2011).

Lake Ronnerup was selected because it represented a naturally saline wetland in the eastern Wheatbelt with high conservation value that was expected to remain unchanged in the medium term. It was given the site code SPM025.

3 Wetland description

Lake Ronnerup is a naturally saline wetland situated in Lake King Nature Reserve (R 39422) approximately 40 km south-east of Lake King township (33^{o}15'S 119^{o} 37' E). With an area of approximately 145 ha (Watkins & McNee, 1987) the lake comprises a broad flat bed with moderately steep banks. When the wetland fills to near maximum depth adjacent swales are also inundated increasing the area of the wetland (Cale *et al.*, 2004).

As far as we are aware no direct analysis of surface drainage to Lake Ronnerup has been published. However, a generally northward drainage of the landscape is suggested by the position of Lake Ronnerup approximately 10 – 15 km north of the south coast watershed described by Beard (1999). This watershed divides the northward draining Yilgarn system from the southward draining south coast systems. The upper reaches of the Yilgarn system have very low topographical gradients (Beard, 1999) with up to half of the "Lakes sub-catchment" having a gradient between 0 and 1% (Leoni & Murphy-White, 2006). Gurner et al (2000) suggested inflow to Lake Ronnerup was from ephemeral drainage originating to the north west. This contrasts with the view of Watkins & McNee (1987) who, following high rainfall in 1986, stated "… surface drainage enters the lake from the southwest corner.". It is likely, given the low gradients, that surface drainage to Lake Ronnerup is essentially dependent on patterns of local rainfall and run off until high rainfall events raise water levels in the lake sufficiently to promote drainage in a northward direction. Such events would link Lake Ronnerup with Bennetts Lake upstream and Lake King downstream.

Water depth, salinity and pH were monitored twice annually at Lake Ronnerup since 2000 (Lane, Clarke & Winchcombe, 2015). These September and November recordings indicate that since November 2002 the lake has had a depth <0.3m and while water has always been present in September the lake has completely dried by November in several years. This shallow period contrasts with higher water levels recorded prior to 2002. The maximum recorded depth in excess of 2.0 m in September 2000 (Lane *et al.*, 2015 pg 152) followed filling of the lake and adjacent swales shortly before March 2000 (Cale *et al.*, 2004). The lake filled because of high rainfall across the region on the 21-22 of January 2000 in what has been described as a 1 in 20 year event (Leoni & Murphy-White, 2006). The inundation of the lake persisted into 2001, declining to *ca* 1m depth by September of that year, and probably into 2002 when 0.5m was recorded in September.

Most vegetation at Lake Ronnerup is restricted to elevated ridge tops well above high water. Species found at the lowest elevations included *Atriplex viscaria*, *Halosarchia indica*, *Lawrencia squamata*, *Frankenia aff pauciflora*, *Stipa juncifolia* and *Dishphyma crassifolium* (Watkins & McNee, 1987; Gurner *et al.*, 2000). The vegetation of ridge tops is characterised by sparse *Eucalyptus occidentalis* over a mixed shrub community (opp. cit.). The presence of recruit seedlings of *E. occidentalis* and *Melaleuca cuticularis* was observed on low elevations toward the lake bed in 1999 (Gurner *et al.*, 2000).

4 Sampling Program

Lake Ronnerup was visited on 21 occasions comprising 7 monitoring years between 1999 and 2012. On three occasions (autumn 2003 and spring and autumn 2007) the lake was dry and no samples were collected (Table 1). The drying of the lake by spring in 2007 prevented the sampling of invertebrates, resulting in only 6 inventories of the invertebrate community during the study period. In 2011, lake depth measured at the gauge plate was 0 m in spring and autumn, but a small quantity of surface water (<0.01m) was present on some parts of the lake bed, enabling some data collection.

Table 1. Site visits, collected datasets and depth for Lake Ronnerup, 1998 – 2013.

LW = late winter (Aug), Sp = spring (Oct), Au = autumn (Mar).

Sample	Monitoring Year	Date	Invertebrates sampled?	Waterbirds surveyed?	Depth
LW99	1999/2000	28/08/1999	×	✓	0.12
Sp99	1999/2000	20/10/1999	✓	✓	0.05
Au99	1999/2000	22/03/2000	×	✓	2
LW01	2001/2002	23/08/2001	×	✓	1.1
Sp01	2001/2002	21/10/2001	✓	✓	1.06
Au01	2001/2002	26/03/2002	×	✓	0.5
LW03	2003/2004	12/08/2003	×	✓	0.23
SP03	2003/2004	21/10/2003	✓	✓	0.18
Au03	2003/2004	29/03/2004	×	×	0
LW05	2005/2006	10/08/2005	×	✓	0.13
Sp05	2005/2006	25/10/2005	✓	✓	0.17
Au05	2005/2006	23/03/2006	×	✓	0.09
LW07	2007/2008	7/08/2007	×	✓	0.13
Sp07	2007/2008	24/10/2007	×	×	0
Au07	2007/2008	31/03/2008	×	×	0
LW09	2009/2010	25/08/2009	×	✓	0.1
Sp09	2009/2010	28/10/2009	✓	✓	0.14
Au09	2009/2010	24/03/2010	×	✓	0.06
LW11	2011/2012	30/08/2011	×	✓	0.09
Sp11	2011/2012	20/10/2011	✓	✓	0
Au11	2011/2012	27/03/2012	×	✓	0

5 Physical and chemical environment

Physico-chemical data is provided in Appendix 1.

Hydrology

The most frequently observed pattern of inundation (hydrocycle) had a maximum duration of less than 12 months. This involved shallow filling to a depth of 10-20 cm, commencing before late winter and peaking by either late winter or spring. This was followed by a period of drying until either dry (2003 and 2007) or very nearly dry (2005, 2009, 2011) by spring or autumn. It is possible that in some of these years water persisted, at very low depth, after autumn and into the next hydrocycle.

An extended hydrocycle spanning at least 34 months was observed during the monitoring period, coinciding with parts of the 1999/2000 and 2001/2002 sampling years (Table 1). This extended hydrocycle occurred when summer rainfall filled the lake to approximately 2 m by March 2000, superimposed on what would otherwise have been a short hydrocycle in 1999/2000. Peak depth was reached by September 2000 (7 months after filling), followed by a period of declining depth until the hydrocycle ended sometime between November 2002 (after 34 months) and September 2003 (Lane *et al.*, 2017). Depth declined by 1 m in the 19 months between March 2000 and October 2001 but fell a further 0.5 m in the next 5 months to March 2002. The increased rate of drying probably occurred because further inflows maintained depth in the first period while in the second period increased evaporation occurred due to the increased surface to volume ratio of the lake.

pH

The mean pH of lake water was 7.94 ± 0.64, and, except in 2001, pH was in the range 7.24 – 8.66. In 2001, with depths around 1m, late-winter and spring pH was > 9. This coincided with the occurrence of extensive macrophyte beds (principally charophytes) reproducing a pattern of linkage between charophytes and high pH already described in this study for Bennetts Lake immediately upstream (report in prep.). It is possible that increased pH was the result of photosynthesis (Falkowski & Raven, 2007) or the maintenance of tissue chemistry under saline conditions by charophytes which can use a hydrogen/sodium antiporter to actively pump Na from the plant at the expense of removing protons from the water (Kiegle & Bisson, 1996).

Salinity and ionic composition

The spring relationship between laboratory measured total dissolved solids (TDS) and electrical conductivity (ec) measured in the field was highly significant ($R^2_{adj} = 0.81$, $p < 0.000$, df= 4) and described by the equation TDS(mg.l)=1.5*ec(mS/cm)-46.35.

Salinity (as electrical conductivity) at Lake Ronnerup was in the broad range of 49.5 – 236 mS/cm, but can be more usefully separated into lower-salinity and very high salinity periods. The lake had lower-salinity in late winter and spring 2000/2001 during the second year of the extended hydrocycle, when salinity was 49.5 and 55.5 (mean of 2 sites) mS/cm respectively. During the very high salinity periods, which included all other sampling dates. salinities were above 140 mS/cm (mean 201.2 ± 24.2) with the exception of autumn 2000/2001 when salinity was 73.5 mS/cm.

Ionic composition was consistent across the monitoring period with a dominance hierarchy of Na > Mg > K >Ca and Cl > SO4 > HCO3 >CO3. While the dominance hierarchy for anions was consistent across all salinities, under lower salinity conditions in 2001 the proportion of HCO_3^- ion was 10 times higher than in very high salinity years.

Between spring 1999 and autumn 2000 depth increased to 2 metres following summer rains and salinity dropped from 220 mS/cm to 73.5 mS/cm. By winter 2001 depth had declined by nearly 50% to 1.1 m but salinity dropped further to 49.5 mS/cm. This decoupling of depth and salinity may have been due to a combination of two factors. Firstly, the export of salt if the wetland overflowed to the north-west, possibly as a result of even greater depths between autumn 2000 and winter 2001 (e.g. data in Lane et al. 2017 suggests depth reached 2.2 metres in spring 2000) and secondly, that depth is not linearly correlated with water volume because of the extensive flooding of adjacent swales when the main basin fills. Salinity did appear to return to pre-1999 levels (146 to 231 mS/cm) at similar depths (≤0.18 m) in 2003 but this does not negate the idea that salt was exported because at these shallow depths (especially in 1999 and after 2008) salts are frequently already at saturation and measured salinity while reflecting dissolved salts may not reflect the salt load present.

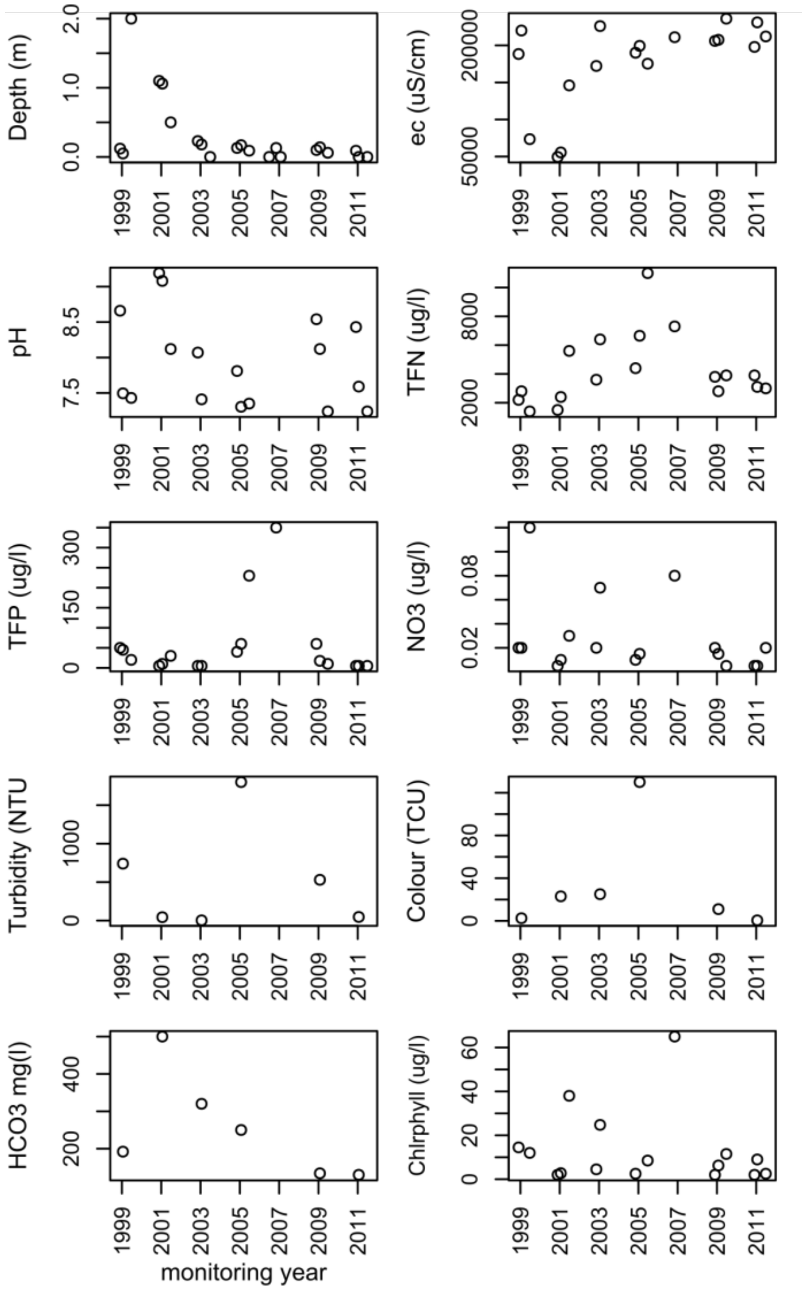

Figure 1. Water chemistry parameters at Lake Ronnerup for late-winter, spring and autumn sampling occasions between 1999 and 2012. Ec is electrical conductivity, TFP total filtered phosphorus, TFN total filtered nitrogen, NO3 nitrate, HCO3 bicarbonate ion and total chlorophyll is the sum of the photosynthetic pigments chlorophyll a, b and c and phaeophytin. Tick marks are positioned at spring sampling.

Nutrients and chlorophyll

Total filtered nitrogen (TFN) concentration was variable with mean 4208 ±2405 µg/l and range 1400 – 11000 µg/l. While TFN was not correlated with other chemical variables there was a tendency for the lowest concentrations to coincide with highest water levels and the highest concentrations to occur when the wetland was in the late stages of drying. There was no evidence of TFN accumulating throughout the monitoring period but Individual years such as 2005, with a range of 4000 -11000 mg/l, and 2007 expressed higher than average concentrations.

Total filtered phosphorus (TFP) was also variable with concentrations in the range 5 – 350 µg/l. High concentrations of phosphorus generally coincided with high TFN and could generally be explained by evapoconcentation as the wetland dried. This was not the case in late winter 2007 when TFP was 350 µg/l and more likely to be the result of a specific source of inflow.

Chlorophyll concentration was variable and not correlated with depth, salinity or nutrient concentrations. Chlorophyll concentration ranged from 2 – 65 µg/l, however only a single sample date (late winter 2007) with primary production driven by high concentrations of TFP had concentrations greater than 38.0 µg/l. The high concentrations found in 2007 included a high proportion of chlorophyll c (23%) which is typical of dinoflagellates, diatoms and brown algae (Strain, Manning & Hardin, 1943) and indicates a distinctive aquatic algal community at this time. During the extended hydroperiod submerged macrophytes were observed on the lake bed and, while not detected in the chlorophyll measurements, which are principally from the water column, they are likely to have played an important part in primary production within the wetland.

The Lake's sediments are very fine and readily suspended by wind action; consequently, the lake was frequently turbid with spring measurements indicating a mean turbidity of 527 ± 693 NTU and a maximum turbidity of 1800 in spring 2005. Turbidity was not correlated with the concentration of nutrients suggesting that neither release from nor adsorption to sediments was a significant factor.

Summary of physical and chemical conditions

Lake Ronnerup was a hypersaline (>140 mS/cm) wetland with hydroperiods < 12 months for most of the monitoring period. However, filling of the lake in 1999/2000 greatly reduced salinity and made samples from within an extended hydrocycle of up to 34 months distinct from other years. At lower salinities, pH was more alkaline, macrophyte growth was greater and chlorophyll proportions suggest a distinct algal community not present on more saline occasions. Nutrient concentrations were highest as the lake dried toward the end of each hydrocycle and there was no evidence of accumulation of nutrients across the monitoring period.

6 Fauna

Aquatic invertebrate diversity

The invertebrate fauna at Lake Ronnerup was of low diversity comprising just 17 taxa (Appendix 2). Annual species richness ranged from 1 to 10 with highest richness occurring in 2001 during the extended hydrocycle and at greatest depth and lowest salinity. This contrasted with low richness of 1 or 2 species each year after 2003 when both late-winter and spring sampling periods were shallow and hypersaline.

Despite a relationship at the extremes of depth and salinity, there was no correlation between invertebrate richness and these variables overall. In 1999, despite low water levels, richness was similar to that recorded in 2001 and 2003 at greater depths. At hatching, many Invertebrate species have lower salinity thresholds than adults (e.g. Timms, Pinder & Campagna (2009) and papers in Nielsen *et al.*, 2003)). In years when the wetland fills insufficiently to reduce salinity this would prevent species from establishing populations despite conditions in which adults could live. The higher richness in 1999 and 2003 suggests that salinity was reduced earlier in the hydrocycle enabling the establishment of more species; conditions not met in 2005 – 2011.

Most taxa were collected only once, however an endemic brine shrimp, *Parartemia longicaudata*, was collected in all years except 2001 when the lake was at the lowest recorded salinity. Despite the absence of this species in 2001 and presumably in 2000, when the wetland had even greater depth and lower salinity, it was again present in 2003, clearly indicating a continued capacity to be present in the wetland after at least two unsuitable years. Estimated abundance of *P. longicaudata* ranged from 10s to 1000s of individuals per sample. Highest abundance occurred in 2003 and 2011 when the wetland was both shallow and hypersaline, but, in contrast to other such years, had higher temperature (26 – 30 °C) and lower turbidity (4 – 47 NTU). Lower concentrations of HCO_3^- in other hypersaline years may have constrained the abundance of this species as this ion is important for the energetics of osmoregulation of species of *Parartemia* (Timms, 2009). With an average male body length of 25.4 mm (Timms, 2012) this species is potentially an important food source for waterbirds when the lake is hypersaline. In 2001 three much smaller crustaceans *Daphnia truncata*, *Calamoecia clitelata* and *Austrochiltonia subtenuis* were in abundances in excess of 10000 per sample. All three of these species have widespread distributions but are less salt tolerant than *P. longicaudata*.

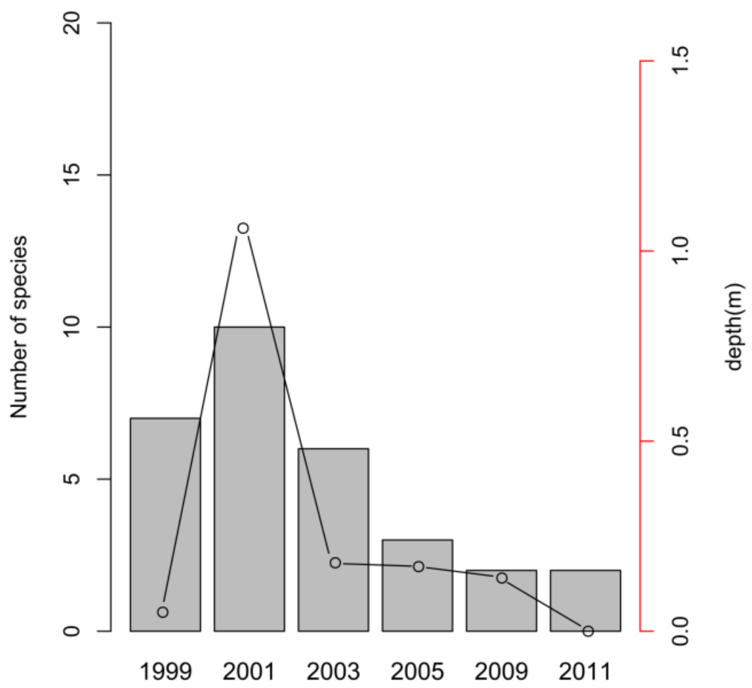

Figure 2. Invertebrate richness (columns) in spring of each monitoring year with depth (line) at the time of sampling.

Invertebrate community composition

An ordination (NMDS) of community composition across the monitoring period indicated three aspects of the community's composition (Fig. 3). Firstly, the largest axis of variation in composition (along NMDS1) is a product of a gradient in species richness. Low richness observed in 2005, 2009 and 2011, contrasts with relatively high richness in 2001 and more intermediate richness in 1999 and 2003. With very low richness (2005-2011), the Lake Ronnerup community is very dissimilar to all the marker wetlands simply because they have a low probability of sharing species.

Secondly, during 1999, 2001 and 2003 the wetland is most similar to naturally saline and naturally hypersaline, ephemeral wetlands (markers 11 and 12 respectively). The distinction between a hypersaline fauna in most years and the saline fauna in 2001 can be seen across the second major axis of variation (NMDS2) and is strongly influenced by several species of micro-crustacea which established populations in 2001 at lower salinity. Two salt tolerant species, *Austrochiltonia subtenuis* (Amphipoda) and *Culicoides sp.* (Ceratopogonidae) persisted in 2003, despite hypersaline conditions. Their presence, maintained richness and the similarity of the fauna to that of 2001. The absence of these species in subsequent years despite similar salinities suggests that the drying of the wetland interrupted their ability to recolonise. This might occur either by affecting the hatching or persistence of local propagules or by increasing the effective distance to sources of colonising individuals.

Thirdly, despite low richness being a feature exclusively of the most recent sampling events there is no evidence that this is a change in the character of the wetland. Rather this should be considered the modal condition in the wetland and the earlier high diversity the result of the establishment of a community of species taking advantage of a 1 in 20-year filling event. Microcrustacean species comprised the bulk of the community present during the filling event. These species have drought resistant propagules and are likely to be resident even when conditions are unsuitable, however the same species were collected in the adjacent Bennetts Lake and colonisation by adults and hatching from propagules in this more frequently filled wetland may be important.

Salinity (as total dissolved solids) and pH were the only environmental variables for which a correlation with community composition could be demonstrated. A redundancy analysis (RDA) identified that a model using pH significantly ($F = 2.64$, $df = 1,4$, $p < 0.05$) constrained 39.7% of the variation in composition (Fig. 4a). This variation is largely the difference between the relatively high richness at one extreme of pH and low richness of communities at the other extreme, consequently the constraining axis was not statistically significant. An almost identical model with TDS as the constraining term was just outside accepted levels of significance ($F = 2.57$, $df = 1,4$, $p < 0.06$), however when TDS is used to scale sample points (Fig.4b) it is apparent that it describes the separation of samples as well as pH. Further, the strong correlation between depth and salinity suggests that the constraining axis is describing a poorly defined gradient of high depth and pH and low salinity in 2001 compared to the opposite extreme in other years. Salinity is known to influence community composition (Pinder *et al.*, 2005) whereas the pH range across the monitoring period would be within the tolerances of most species. Variation on the first principal component (Fig 4) is principally through hypersaline communities and strongly reflects decreasing species richness toward the top of the axis. Unmeasured factors, such as the effect of antecedent salinity on hatching may have been more useful in describing this variation in composition.

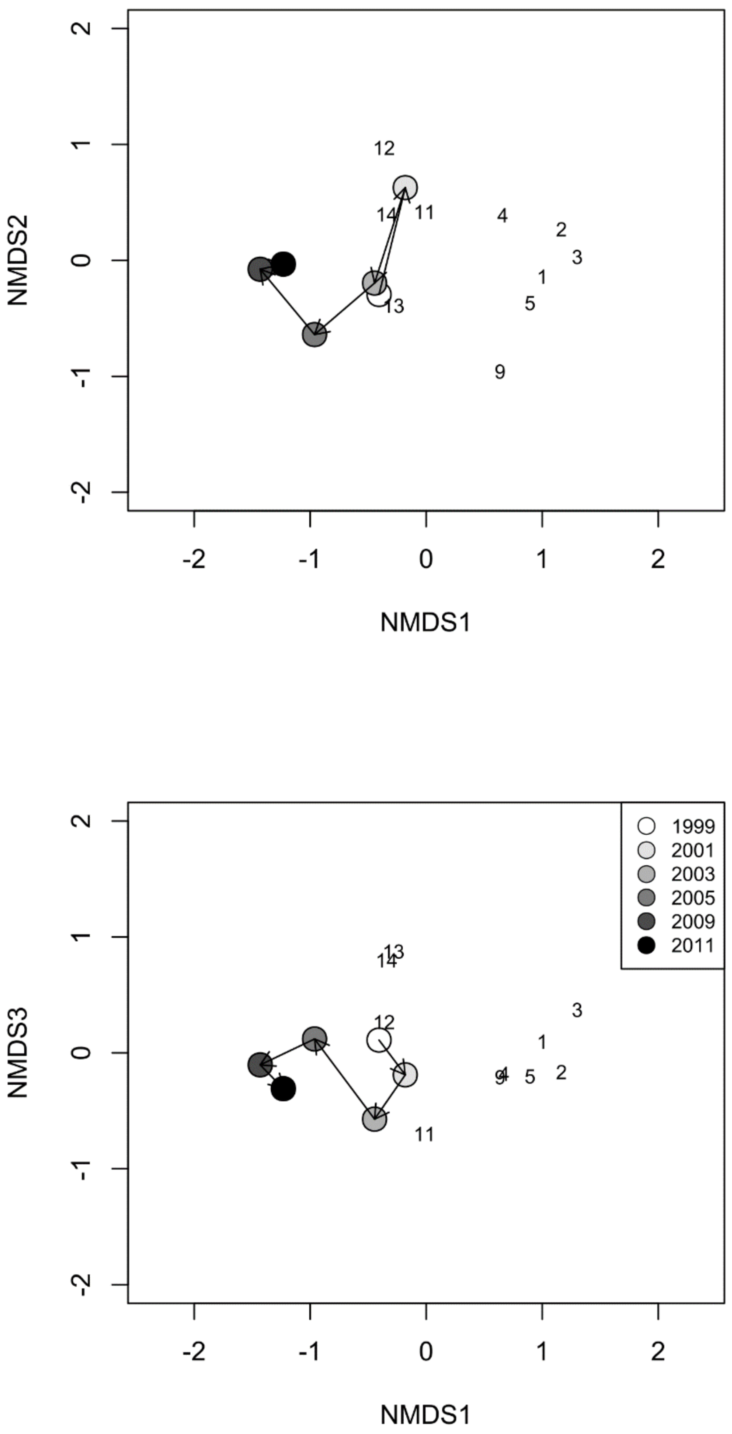

Figure 3. An ordination of spring invertebrate community composition (presence-absence) at Lake Ronnerup and 'marker' wetlands (see methods). This ordination had a low stress of 0.08. Marker wetland 1=fresh high richness, 2=subsaline sandy sump, 3=fresh, ephemeral wooded swamp, 4=naturally subsaline high richness, 5= secondary subsaline high richness, 9 = fresh sedge swamp, 11 =naturally saline in good condition, 12=naturally hypersaline ephemeral, 13=secondary hypersaline, 14=natural hypersaline basin.

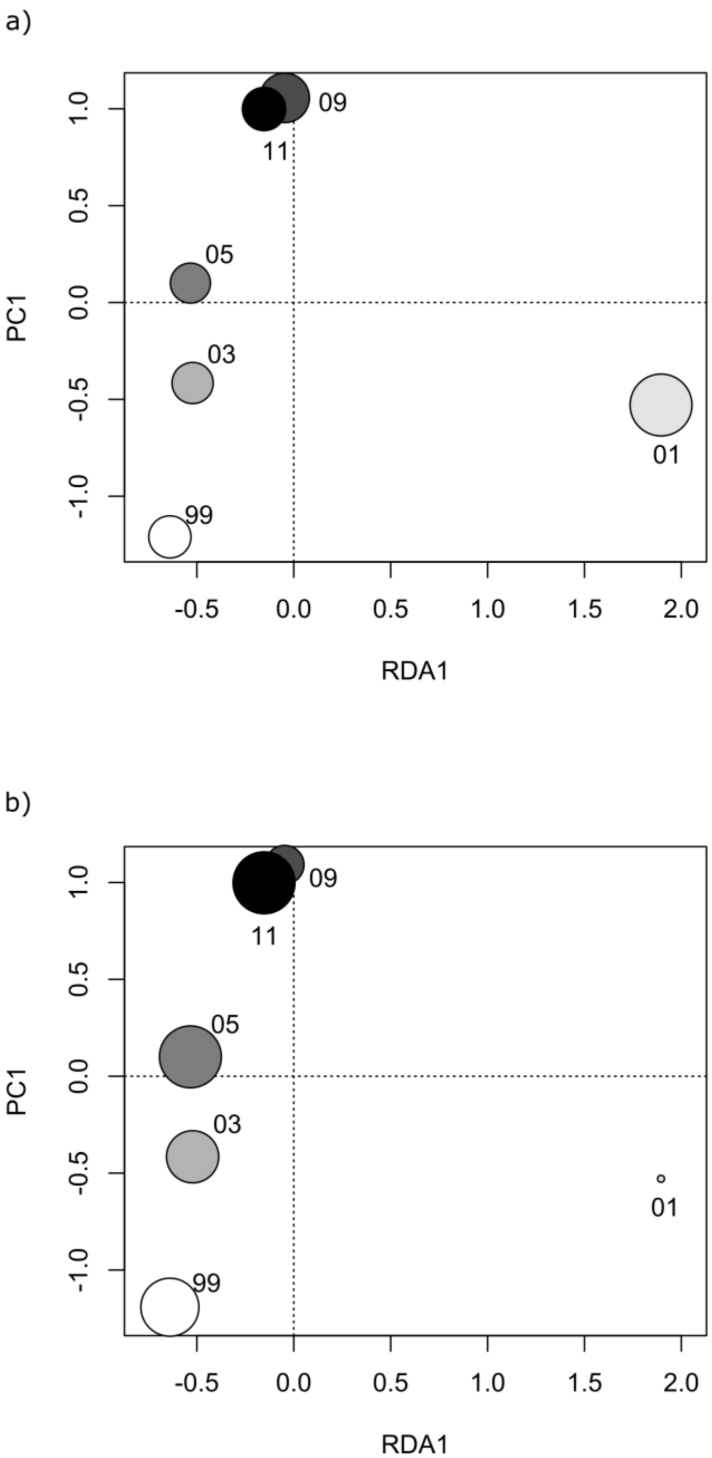

Fig 4 Redundancy Analysis for invertebrate community composition using pH as a constraining term. Sample points are scaled by a) pH and b) total dissolved solids.

In summary, the invertebrate community at Lake Ronnerup is adapted to hypersaline conditions and is generally species poor, but habitat changes (depth, salinity and pH) result in the addition of species from a species pool adapted to lower salinity and probably reliant on more frequently filled wetlands in the immediate region; such as Bennetts Lake. The occasional high abundance of *P. longicaudata* may be important to the wetlands ability to support waterbirds when shallow.

Waterbird Richness

Twenty-one species of waterbird were recorded at Lake Ronnerup (Appendix 3). Seventeen were only recorded during the extended hydrocycle, whereas no species were exclusively recorded when the wetland was shallow. Small shorebirds, including red-necked stint, red-capped plover and hooded plover, were present at depths up to 0.5 m indicating sufficient beach and shoreline were present up to this depth. Notable species included the hooded plover observed on 6 occasions across 1999 – 2005, chestnut teal present in winter and spring 2001 and Australian spotted crake and Baillon's crake which only occurred in March 2000. The hooded plover and chestnut teal are significant because of the small size of populations in south-west Western Australia. Hooded plover abundance ranged from 1 to 19 individuals (mean 7.6 ± 6.4). Chestnut teal were only present on 3 occasions all at depth > 1.0m and at relative low abundance (mean 3 ± 2.6 male birds[1]). Crakes are not typical of the fauna occupying hypersaline wetlands lacking emergent vegetation, their presence in March 2000 probably reflects dispersal of the species across the rain affected parts of the south-west and the use of a variety of wetlands as stepping stones in the search for suitable habitat. Lake Ronnerup was suitable habitat for at least long enough for the Australian spotted crake to breed.

[1] Female birds were not distinguished from grey teal, which were abundant

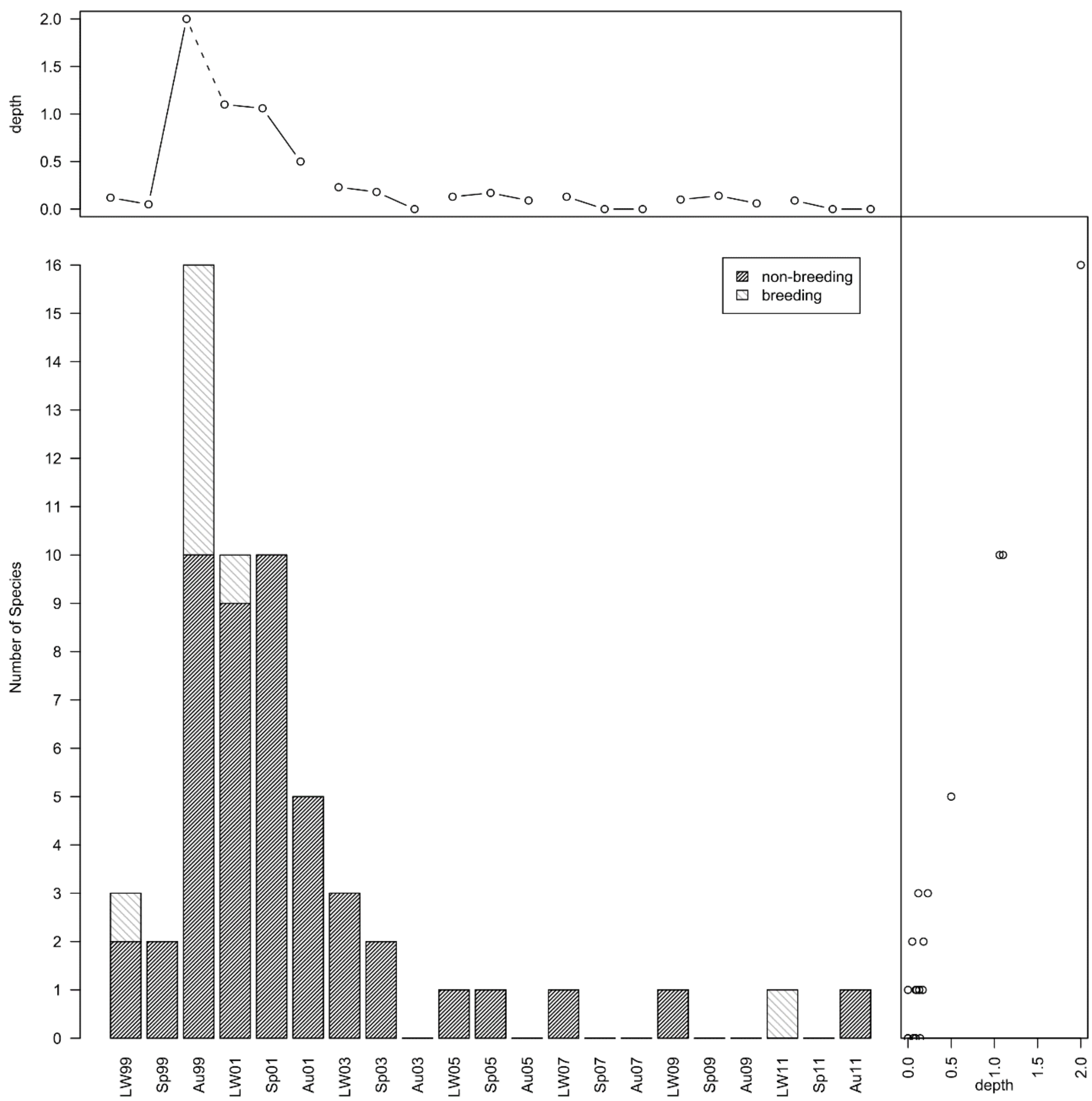

Figure 5 Waterbird species richness across the monitoring period.

Richness of the bird community was positively correlated (rho = 0.78, df = 19, $p < 0.01$) with lake depth (Fig. 5 right panel) and showed similar patterns to that of aquatic invertebrates, i.e., richness was high during the extended hydrocycle and reduced to very low levels after 2003. The highest single survey richness was 16 in March 2000 immediately after the lake filled. Increased richness during the extended hydrocycle also resulted in increased functional diversity of the waterbird community. The mean number of waterbird guilds present for surveys during the 2000 - 2002 hydrocycle was 3.75 ± 1.2 compared to 1.2 ± 0.4 for surveys conducted during other hydrocycles.

Highest abundances occurred throughout late-winter and spring 2001. The most abundant species were black swan, and Australian shelduck which reached maxima of 1032 and 1062 individuals respectively during 2001. Submerged macrophyte beds, on which both of these species are dependent for feeding (Riggert, 1977; Choney *et al.*, 2014), were present at this time.

It is recognised that some waterbirds breed immediately following rising water levels in recently flooded wetlands (Braithwaite & Frith, 1969; Briggs & Maher, 1985). At Lake Ronnerup, inundation of dry or almost dry sediments occurred in January 2000 and in March, 60 days later, broods of 6 species were present. Breeding species were grey teal (13 broods), hoary-headed grebe (7), pink-eared duck (2) Australian spotted crake (1), Pacific black duck (1) and blue-billed duck (1). These species were not recorded breeding later in this longer hydrocycle, but data were not collected again until late-winter 2001 and breeding may have continued throughout the remainder of 2000. The only breeding in other years was by Australian shelduck with broods recorded in late-winter 1999, 2001 and 2011 at a broad range of depths.

Waterbird community composition

An ordination (NMDS) of annual species occurrence adequately characterises the composition of the Lake Ronnerup waterbird fauna and marker wetlands on two axes (stress =0.04). This ordination shows a clear shift in community composition between the extended hydrocycle (2000-2002) and the dry phase in remaining years (Fig. 6). Large variations in composition between years during the period 2005 – 2011 are an artefact of very low species richness and the turnover of single species. During shallow, hypersaline hydrocycles the community is most like "species–poor, shallow, saline wetlands" represented by Lake Altham; sharing both low richness and individual species. In 1999/2000 and 2001/2002 the filling of the lake supported a community composition between that of the saline but higher richness Lake Goorly and the high richness and subsaline Toolibin/Pinjareega markers. At these higher water levels, the inter-annual variation in composition was much lower. There is no evidence of a directional change in community composition over the study period, other than that associated with the high water levels in the first two years of the program and very low water levels in later years.

Three environmental variables; depth, salinity and chlorophyll were correlated with waterbird community composition (Fig. 7). Using a constrained ordination (RDA) of waterbird presence-absence, a model based on square root transformed depth ($F=12.53$, $df = 1,7$, $p = 0.01$), electrical conductivity ($F=3.48$, $df = 1,7$, $p = 0.02$) and log chlorophyll ($F=3.21$, $df = 1,7$, $p < 0.06$) explained a total of 64% of the variance in composition on two significant axes (RDA1; $F=13.75$, $df = 1,7$, $p < 0.00$, RDA2; $F=3.09$, $df = 1,7$, $p < 0.05$). This analysis shows a strong dichotomy along RDA1 with a saline/deep fauna to the right and a hypersaline/shallow fauna to the left (Fig. 7a). This axis, which shows the dichotomy between the addition of species when the lake fills and the low occurrence of waders during the extended hydrocycle, represents 53% of the variance in composition. For either side of this dichotomy primary production, as represented by chlorophyll concentration, can be used to explain another 11% of the variation observed (axis RDA2). Because of missing chlorophyll data, surveys from spring 1999 and 2005 could not be included in the analysis and while their low species richness would place them to the left of RDA1 amongst other hypersaline/shallow communities it is unclear how they would be positioned on, or affect, the interpretation of the lesser gradient of primary production. Similarly, low chlorophyll in late-winter and spring 2001 probably did not reflect actual primary production at this time. This is because the well-developed macrophyte beds, which are not sampled by the water column chlorophyll method used, would have had greater biomass than phytoplankton.

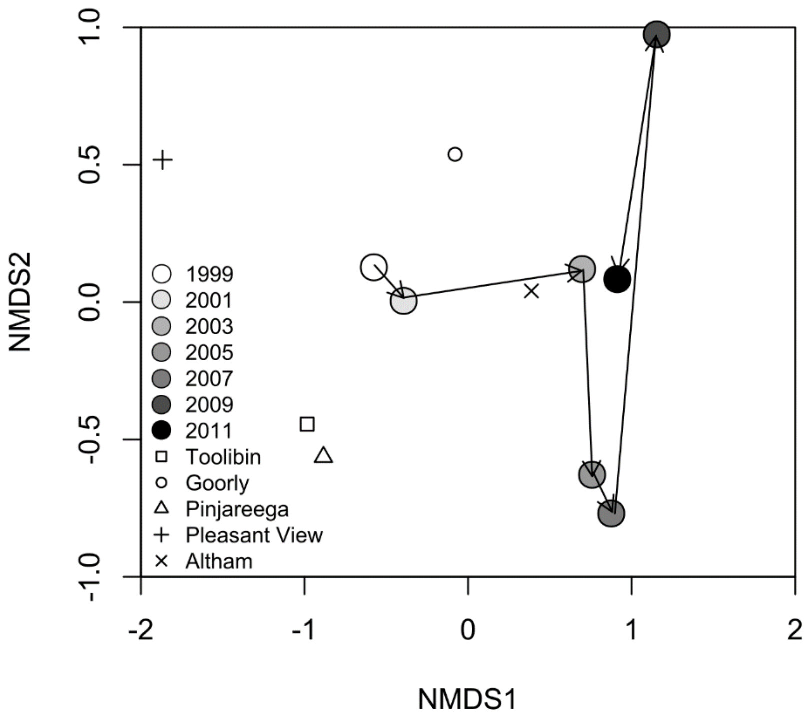

Figure 6. NMDS Ordination of waterbird species annual presence/absence compiled from late winter, spring and autumn surveys for each year. 1999 includes surveys from 1999/00, 2001 from 2001/02 etc.

In summary the diversity, abundance, extent of breeding and composition of the waterbird fauna was strongly dependent on elevated water levels and the resulting reduction of salinity during the extended hydrocycle. When filled the lake is an important waterbird habitat but during dryer years the wetland supports very few species or individuals and only the regular occurrence of hooded plover indicates the importance to waterbird communities of. The collected data do not provide evidence that the abundant brine shrimp population during more saline periods supports large numbers of birds.

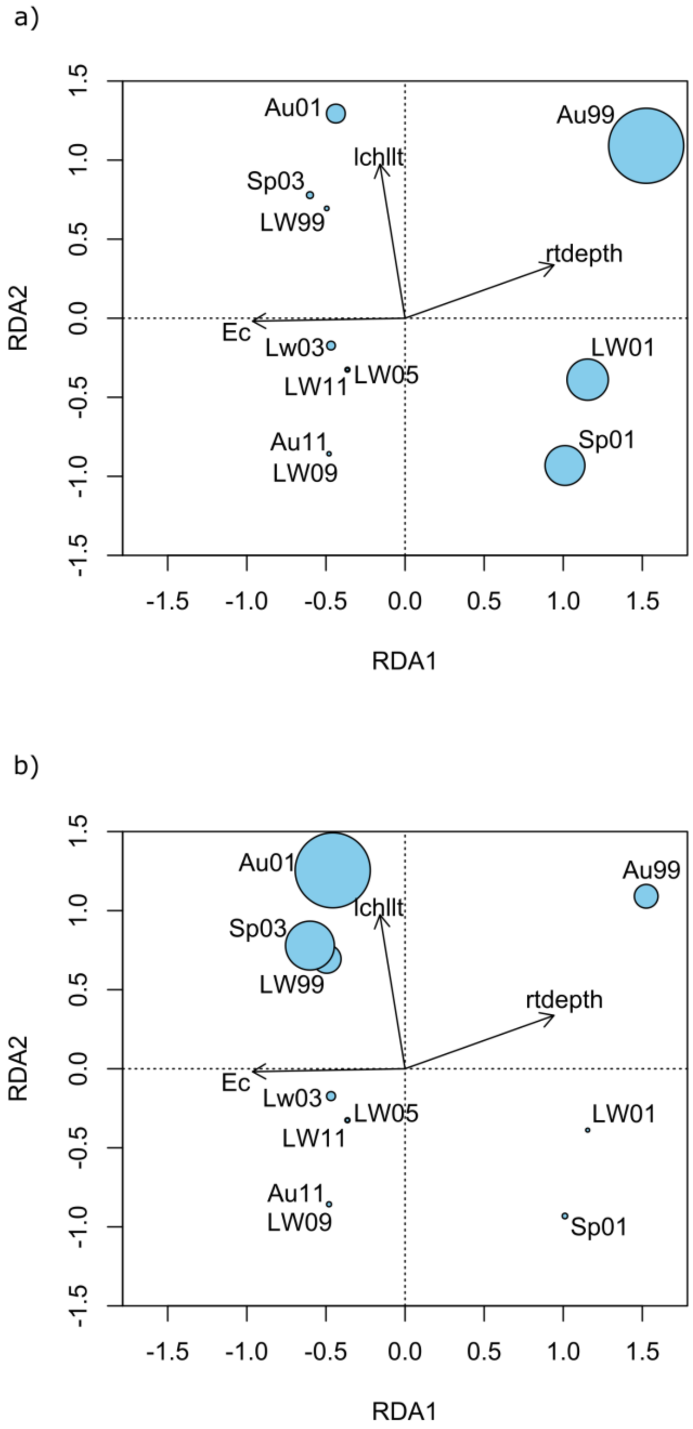

Figure 7. Constrained ordination of waterbird community composition for individual surveys at Lake Ronnerup. Seasonal surveys are labelled according to the monitoring year and the consecutive seasons LW =late-winter, Sp= spring, Au= autumn. Sample points are scaled by a) lake depth and b) chlorophyll. Arrows indicate the direction of the effect of significant environmental variables (electrical conductivity, log (chlorophyll +1) and Sqrt depth).

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Appendix 1. Depth and water chemistry data

Physico-chemical variables measured at Lake Ronnerup. In spring, values of pH, conductivity, temperature, oxygen, nutrients and photosynthetic pigments were measured at both site A and site B. The mean of these paired values was used in analyses. For other dates measurements were made at site A only. Depths before November 2000 were estimated from the lakebed.

Date	28/08/1999	20/10/1999	20/10/1999	22/03/2000	23/08/2001	21/10/2001	21/10/2001	26/03/2002	12/08/2003	21/10/2003	21/10/2003	29/03/2004	10/08/2005	25/10/2005	25/10/2005	23/03/2006	7/08/2007	30/10/2007	30/03/2008	25/08/2009	28/10/2009	28/10/2009	24/03/2010	30/08/2011	20/10/2011	20/10/2011	27/03/2012
season	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au
site	A	A	B	A	A	A	B	A	A	A	B	A	A	A	B	A	A	A	A	A	A	B	A	A	A	B	A
Depth (m)	0.12	0.05	0.05	2	1.1	1.06	1.06	0.5	0.23	0.18	0.18	0	0.13	0.17	0.17	0.09	0.13	0	0	0.1	0.14	0.14	0.06	0.09	0	0	0
Conductivity (μS/cm)	188300	220000	220000	73500	49500	55400	55700	146000	172200	226000	226000		190000	198700	199900	175300	211000			206000	203000	212000	236000	197900	231000		212000
pH	8.66	7.55	7.44	7.43	9.19	9.07	9.09	8.12	8.07	7.53	7.29		7.81	7.31	7.3	7.35				8.54	8.21	8.03	7.24	8.43	7.59		7.24
TFN (μg/L)	2200	2800	2800	1400	1500	2400	2400	5600	3600	6200	6600		4400	6200	7100	11000	7300			3800	3000	2600	3900	3900	3100		3000
TFP(μg/L)	50	50	40	20	5	10	10	30	5	5	5		40	60	60	230	350			60	30	5	10	5	5		5
Chlorophyll-a (μg/L)	6	-9999	-9999	2	0.5	0.5	0.5	10	1	5	0.5		0.5	-9999	-9999	2	24			0.5	0.5	9	5	0.5	6		1
Chlorophyll-b (μg/L)	6	-9999	-9999	2	0.5	0.5	0.5	25	1	3	1		0.5	-9999	-9999	3	10			0.5	0.5	0.5	3	0.5	0.5		0.5
Chlorophyll-c (μg/L)	2	-9999	-9999	3	0.5	0.5	0.5	2	0.5	2	2		0.5	-9999	-9999	3	15			0.5	0.5	0.5	3	0.5	2		0.5
Phaeophytin-a (μg/L)	0.5	-9999	-9999	5	0.5	0.5	2	1	2	3	33		1	-9999	-9999	0.5	16			0.5	0.5	0.5	0.5	0.5	0.5		0.5
Temperature (°C)	17.1	24.3	21	19.7	15.1	18.3	19.3	22.9	13.8	28.2	32.5		17	19.3	19.3	17.9				15.5	24.5	22.4	32	22.5	26.8		34.9
Dissolved Oxygen(%)	100	77.9	70.9	58	120	96.5	82.4	46.5	-9999	-9999	-9999		58.8	56.9	62.3	66.3											
NO3 (mg/L)	0.02	0.02	0.02	0.12	0.005	0.01	0.01	0.03	0.02	0.07	0.07		0.01	0.01	0.02		0.08			0.02	0.02	0.01	0.005	0.005	0.005		0.02
Turbidity (NTU)		740				44				3				1800							530				47		
Colour (TCU)		2.5				23				25				130							11				0.5		
TDS (g/L)		300				36				270				320							200				320		
Alkalinity (mg/L)		158				410				263				205							110				107		
Hardness (mg/L)		33000				4700				33000				41000							14000				21000		
Si (mg/L)		4				1.3				3				7.6							3.6				2.6		
Na (mg/L)		103000				12000				113000				110000							65400				106000		
Ca (mg/L)		657				132				416				468							363				490		
Mg (mg/L)		7510				1070				7800				9590							3080				4790		
K (mg/L)		1620				294				1550				2100							1270				1610		
Mn (mg/L)		0.2				0.01				0.09				0.17							0.005						
Cl (mg/L)		180000				20000				160000				176000							109000				183000		
HCO3 (mg/L)		192				500				320				250							134				130		
CO3 (mg/L)		1				1				1				1							0.5				0.5		
SO4 (mg/L)		14400				1530				14100				17700							6540				10600		
Iron(mg/L)		0.77				0.07				0.05				0.2													
Tot Chlorophyll(μg/L)																											

Appendix 2. Aquatic invertebrate data

Lake Ronnerup invertebrate species matrix. Species in this log-class abundance matrix have been combined to the lowest common taxonomic level across all samples, in order to analyse community composition across the monitoring period.

	TAXON	LowestIDNC	1999	2001	2003	2005	2009	2011	%occurrences
Nematoda (round worms)	Nematoda spp	II999999	2		1				33
Annelida (Segmented worms)	Enchytraeidae	LO089999	1						17
Acarina (water mites)	Mesostigmata	MM9999A2	1						17
Anostraca (fairy shrimps)	*Parartemia longicaudata* subspecies a	OD0201A1	1		3	1	1	3	83
Cladocera (waterfleas)	*Daphnia truncata*	OG040217		5					17
Ostracoda (seed shrimps)	*Diacypris* sp.	OH080799		3				1	33
	Mytilocypris mytiloides	OH081204		3					17
	Platycypris baueri	OH082601		3			1		33
Calanoida	*Calamoecia clitellata*	OJ110208		5					17
Harpacticoida	Harpacticoida sp	OJ699999		2					17
Anphipoda (shrimps)	*Austrochiltonia subtenuis*	OP020102		4	1				33
Diptera (larval flies	*Culicoides* sp.	QD090899	1	1	1	1			67
	Stratiomyidae	QD249999	1	1					33
	Muscidae sp. A	QD8999A0	1			1			33
Chironomidae (non biting midges)	*Procladius paludicola*	QDAE0803		2					17
	Tanytarsus barbitarsis	QDAH0402			1				17
Hemiptera (water striders)	*Mesovelia* sp.	QH520199			1				17

Appendix 3. Waterbird data

Abundance of species for each seasonal survey at Lake Ronnerup. Occurrence as a percentage of surveys where depth was > 0 m.

		28/08/1999	20/10/1999	22/03/2000	23/08/2001	21/10/2001	26/03/2002	12/08/2003	21/10/2003	29/03/2004	10/08/2005	25/10/2005	23/03/2006	7/08/2007	24/10/2007	31/03/2008	25/08/2009	28/10/2009	24/03/2010	30/08/2011	20/10/2011	27/03/2012	% Ocurrence
Australasian Shoveler	*Anas rhynchotis*			32	2	10																	18.8
Australian Shelduck	*Tadorna tadornoides*	116		16	19	1062	446	4			10			1						2			56.3
Australian Spotted Crake	Porzana fluminea			1																			6.3
Australian Wood Duck	*Chenonetta jubata*			48																			6.3
Baillon's Crake	Porzana pusilla			2																			6.3
Banded Stilt	*Cladorhynchus leucocephalus*	2					184																12.5
Black Swan	*Cygnus atratus*				602	1034	18																18.8
Blue-billed Duck	*Oxyura australis*			10																			6.3
Chestnut Teal	Anas castanea			6	2	1																	18.8
Eurasian Coot	*Fulica atra*			45	555	126																	18.8
Grey Teal	*Anas gracilis*			215	75	690																	18.8
Hoary-headed Grebe	*Poliocephalus poliocephalus*			26	115	133																	18.8
Hooded Plover	*Thinornis rubricollis*	19	5				8	1	10			3											37.5
Little Pied Cormorant	*Phalacrocorax melanoleucos*			2																			6.3
Musk Duck	*Biziura lobata*			15	6	11																	18.8
Nankeen Night Heron	*Nycticorax caledonicus*			1																			6.3
Pacific Black Duck	*Anas superciliosa*			12	2																		12.5
Pink-eared Duck	*Malacorhynchus membranaceus*			35	4	47																	18.8
Red-capped Plover	*Charadrius ruficapillus*		2			1		1									1					13	31.3
Red-necked Stint	*Calidris ruficollis*						56		2														12.5
White-faced Heron	*Ardea novaehollandiae*			14																			6.3