Wheatbelt Wetland Biodiversity Monitoring

Fauna monitoring at Coyrecup Lake 1997-2012

Report WWBM-FR02

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Wetland Conservation Program

Science and Conservation

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Cover photo: Coyrecup Lake from the west shore looking north east in October 2009.

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Contents

1 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 *et al.*, 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 five representative wetlands, including two in Natural Diversity Recovery Catchments. This program was extended to 25 wetlands across the inland agricultural region of the south-west by 1999. 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 *et al.*, 2004b) 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 assesment of the sampling design (Halse *et al.*, 2002), waterbird composition by wetland (Cale *et al.*, 2004a, 2006) and wetland case studies (Cale, 2005; Lyons *et al.*, 2007; Cale *et al.*, 2010, 2011).

Coyrecup Lake had a history of data collection (Lane *et al.*, 2017) and was included in the monitoring program as a representative of secondarily salinised wetlands which are expected to remain unchanged in the medium term . It was given the site code SPM004.

2 Summary

Coyrecup Lake is a well known secondarily saline wetland, with salinities that would be much higher than prior to clearing of the catchment and hydroperiods probably much longer. In most years Coyrecup Lake filled to less than 1m depth, had a hydroperiod approaching 12 months (although very shallow and hypersaline in autumn) and salinities from 47400 – 236000 µS/cm. This contrasted with less saline conditions during an extended hydrocycle of at least 24 months beginning in 2005. At this time, depth was as high as 2.3 m resulting in outflow from the lake and salinities as low as 5730 µS/cm. Salinities are regularly much higher than most aquatic invertebrates would tolerate, but the wetland has significant value for waterbirds. Elevated nutrient concentrations are probably also derived from catchment agriculture.

Aquatic invertebrate communities consisted entirely of very widespread and common species and most were capable of tolerating moderate salinity. The current fauna reflects the salinised nature of the lake and would be very different to its original fauna. The greater depth and lower salinity during the extended 2005-2007 hydrocycle enabled the establishment of more diverse invertebrate and waterbird communities than is usually now the case, including some with less tolerance to salinity. During this time, invertebrate richness was 48 species and community composition was comparable to other naturally sub-saline wetlands of the Wheatbelt. Otherwise, the invertebrate fauna was more depauperate (<23 species) but abundance, particularly of microcrustacea, was higher. Other than this contrast between average hydrocycles with higher salinity and longer hydrocycles with periods of lower salinity, there was no directional trend in invertebrate richness or composition during the monitoring period.

While Coyrecup Lake is not notable for its invertebrate fauna, it retains significant value for waterbirds. Waterbird communities reached greatest richness at moderate depths (around 1 m), declining when the lake was shallower or deeper. This pattern was largely due to a greater extent of habitat for wading and shore feeding species when depths were moderate, in contrast to reduced availability of habitats at greater depths and the effects of salinity on both birds and potential food items at lower depths. When maximum depths were recorded, the waterbird community was similar to that of Lake Toolibin in the 1980s; a recognised benchmark for diverse high conservation value waterbird communities. Historical data for Coyrecup Lake showed that during the 1980s the community was similar to that of Lake Toolibin over a broad range of water depths. The more recent data presented here indicates that only at the highest depths is this community now supported and at lower depths the community has greater similarity to communities occurring in other secondarily salinized wetlands.

3 Wetland description

Coyrecup Lake lies approximately 25 km east of Katanning (33° 42' S 117° 50' E); within Coyrecup Nature Reserve (Res. No. 28552) which was gazetted for the purpose of flora and fauna conservation and recreation. The lake is situated upstream of Lake Dumbleyung within the drainage line of the Coblinine River in the Blackwood River basin.

A comprehensive review of the lake's character can be found in Nowicki *et al.* (2009). This review indicates that the lake lies in the western subregion (zone of rejuvenated drainage) of the Avon Wheatbelt Region of the Interim Bioregionalisation of Australia (IBRA). Hydrology is strongly influenced by rainfall, the low topographical relief, deep soil profile and resultant low rates of surface runoff (Nowicki *et al.*, 2009). Probably once more seasonally inundated, extensive clearing of native vegetation in the catchment has resulted in increased inflow to the lake, so that it is now almost permanent, with water retained (although very shallow and hypersaline in autumn) throughout most years (Lane *et al.*, 1996; Nowicki *et al.*, 2009).

Coyrecup Lake has an area of 448 ha and is predominantly open water (Halse *et al.*, 1993a). Most inflow is via a creek channel, which enters the lake over an area of shallow deposited sediments along the middle of the eastern shore and may retain water when the rest of the lake is dry. Outflow from the lake occurred when it overflowed across Coyrecup Road in the south west corner in 1983 (Jaensch et al. 1988) and again in 2005 (pers. comm. Peter Muirden, Dept. of Environment 2005). Peak depths recorded in 1988 and 1992 suggest the lake may have overflowed in these years also (Lane *et al.*, 2017). Depth and salinity in the lake have been monitored in September and November since 1978 (Lane *et al.*, 2017) and data suggest peak depths of around 2.5 m, at which time salinity is low (ca 5 g/l or less), but the lake is hypersaline when depth is less than 1 m. There was no increasing trend for either depth or salinity at the lake up to 2000 (Lane *et al.*, 2004) but in the last 15 years depths in spring have tended to be lower and salinity higher (Lane *et al.*, 2017).

Groundwater in shallow root zone monitoring bores to the east of the lake (approx. 1.5 km upstream), had higher salinity than those close to the lake and were acidic with pH as low as 3 (Cale *et al.*, 2004b). Unpublished data (DBCA[1],) from monitoring bores close to the lake (on vegetation transects 1 and 2 of Franke *et al.*, 2001), suggest depth to shallow groundwater varied with rainfall but remained 2 – 3 m below ground level between 2000 and 2016. The salinity of these bores was between 499 and 8630 μS/m and pH ranged from 4.15 to 7.32.

Historically, the lake supported a fringing band of *Casuarina obesa* and *Melaleuca* sp. (Jaensch *et al.*, 1988; Lyons, 1988) but those trees on the lake bed were mostly dead by 1992 (Halse *et al.*, 1993a), remaining as a fringe of dead trees. Under this dead tree fringe and extending slightly into the lake is a samphire community including *Tecticornia pergranulata*., *Tecticornia lepidosperma* and *Sarcocornia quinqueflora* (Halse *et al.*, 1993a; Franke *et al.*, 2001). Submerged macrophytes (*Ruppia polycarpa* and *Chara* sp.) form dense beds around the inflow channel (Nowicki *et al.*, 2009). Above the high watermark there remains a band of live *C. obesa* along much of the shoreline. A low woodland of *Melaleuca* sp. still persists on depositional flats around the creek mouth but frequently suffers extensive tree death. A full description of the vegetation of the Coyrecup Nature Reserve is given by Lyons (1988).

At least 41 species of waterbird have been recorded at Coyrecup Lake including five species listed under international agreements for the protection of migratory species (Nowicki *et al.*, 2009 and references therein). During surveys conducted between 1981 and 1985 in the south-west of Western Australia (Jaensch *et al.*, 1988), Coyrecup Lake ranked 31 amongst 197 wetlands for waterbird species richness. At this time the lake was seen to be particularly important for 'maned duck' (= Australian wood duck, *Chenonetta jubata*) with one count recording 540 individuals (Jaensch *et al.*, 1988 pg 142). Across all species, a total abundance of about 1000 individuals was typical from January to May and maximum abundances of 6000 birds were recorded in single surveys in 1983 (Jaensch *et al.*, 1988) and 1989 (Halse *et al.*, 1992). On the basis of waterbird community composition Coyrecup Lake was shown (Halse *et al.*, 1993b) to fall within a group of wetlands (WL5)

[1]collected by Colin Walker (Geo and Hydro)

which included wetlands with high waterbird conservation value such as Toolibin (Halse *et al.*, 2000) amongst others (e.g. Towerrining, Dumbleyung, Taarblin, Coomelberup).

4 Sampling Program

For detailed sampling methods, including data analysis, refer to Cale et al. (2004) and the separate program summary document to be published as part of this series. Coyrecup Lake was sampled in each of three seasons every second year, i.e. 8 years and 24 occasions, between August 1997 and March 2012 (*Table 1*). A total of 8 invertebrate, 22 waterbird and 22 physico-chemical datasets were collected. Median annual rainfall at Badgebup (BOM station 1058), 8.5 km NE of Coyrecup Lake, is 402mm (1915-2011) and during the study period rainfall was above the median in 1998, 2005 and 2008. The lake was dry in autumn 2004 and 2008 at which times no species were present.

Table 1. Site visits, collected datasets and depth for Coyrecup Lake, 1997 – 2012.

Sample	Monitoring Year	Date	Invertebrates sampled?	Waterbirds surveyed?	Depth
LW97	1997/98	6/08/1997	×	✓	0.86
Sp97	1997/98	25/10/1997	✓	✓	0.9
Au97	1997/98	11/03/1998	×	✓	0.1
LW99	1999/00	29/08/1999	×	✓	1.11
Sp99	1999/00	21/10/1999	✓	✓	1.09
Au99	1999/00	18/03/2000	×	✓	0.42
LW01	2001/02	26/08/2001	×	✓	0.48
Sp01	2001/02	1/11/2001	✓	✓	0.35
Au01	2001/02	25/03/2002	×	✓	0
LW03	2003/04	8/08/2003	×	✓	0.38
Sp03	2003/04	31/10/2003	✓	✓	0.81
Au03	2003/04	26/03/2004	×	×	0
LW05	2005/06	12/08/2005	×	✓	2.3
Sp05	2005/06	28/10/2005	✓	✓	2.28
Au05	2005/06	25/03/2006	×	✓	1.52
LW07	2007/08	10/08/2007	×	✓	0.41
Sp07	2007/08	25/10/2007	✓	✓	0.52
Au07	2007/08	3/04/2008	×	×	0
LW09	2009/10	27/08/2009	×	✓	1.23
Sp09	2009/10	30/10/2009	✓	✓	1.1
Au09	2009/10	23/03/2010	×	✓	0.31
LW11	2011/12	2/09/2011	×	✓	0.68
Sp11	2011/12	22/10/2011	✓	✓	0.63
Au11	2011/12	30/03/2012	×	✓	1.37

5 Physical and chemical environment

Physico-chemical data is provided in Appendix 1.

5.1 Hydrology

Coyrecup Lake was strongly influenced by winter inflow during the study period. This winter inflow, sometimes with additional spring flows, was responsible for partially filling the lake in six of the eight sampled years. In 1999, the hydrocycle was in its second year having retained water from the previous year. In 2011, the lake did not fill until late spring (*Figure 1*, *Table 1*) and summer rain resulted in significant additional inflows.

Generally, the wetland had a hydroperiod of less than 12 months; filling to a moderate depth between 0.5 and 1 m on the strength of winter inflow then slowly drying until either dry or very nearly dry (with much reduced wetted area and very shallow surface water) in late autumn or early winter preceding the next winter inflow. Consequently, winter and spring depths (mean 0.93 ± 0.63 and 0.96 ± 0.59 m respectively) were substantially greater than in autumn (0.46 ± 0.62 m). Where depth was less than 0.8 m in October the lake was dry by the following March (e.g. 2001/02, 2003/04 and 2007/08); except in 2011 when summer rainfall continued to fill the wetland.

Longer hydroperiods, of at least 24 months, occurred in 1998/99 and 2005/06. In 2005, when high winter rainfall filled the lake to 2.3 m, water persisted throughout 2005 and 2006. With spring depth in excess of 1 m in 2006 (Lane et al. 2015) it is likely that water persisted until the lake had further inflow in late-winter 2007. However, the lake almost certainly dried before filling again in 2008 suggesting an upper limit for hydroperiod of around 36 months during the study. Similarly, water persisted in the lake through 1999, having filled by winter 1998 and dried by May 2000 (Huntley unpublished data[2]); a hydroperiod of approximately 23 months.

5.2 pH

Coyrecup Lake was consistently alkaline, with pH varying between 7.28 and 10.05 (Figure 1). Changes in pH occurred independently of water depth or season.

5.3 Salinity and ionic composition

The correlation between total dissolved solids (TDS) and electrical conductivity (ec) measured in spring was highly significant (R^2adj = 0.99, p <0.001, df= 6) and described by the equation TDS (mg/l) = 0.811 * ec(µS/cm) - 3490.701. Salinity is measured as electrical conductivity in the remaining discussion unless otherwise noted.

[2] Bart Huntley (DBCA) used an archive (1988 – 2016) of data from Landsat sensors 5, 7 and 8 to extract band 5 data for the wetland and equate these values with ground measured depths in order to determine when the wetland was inundated

Salinity was negatively correlated with depth (rho = -0.93, df = 21, p <0.01). The lake was hypersaline (51,000 – 236,000 µS/cm) at depths of less than 1 m and saline (16,770 – 56,800 µS/cm) at depths between 1 and 1.52 m (Figure 1). Lowest salinities were in the subsaline range (5730 – 8355 µS/cm) and occurred when the lake was 2.28 m or deeper. Depths between 1.52 and 2.28 m were not recorded during the monitoring period.

Salinity varied from year to year, with 1999, in particular, having higher salinity than was observed at similar depths in other years. Water persisting in 1999 had its origin in summer inflow during 1998 and it is possible that this inflow came from a different part of the catchment with higher salinity compared to typical winter inflows.

Ionic composition was dominated by sodium and chloride. Cations followed a dominance hierarchy of $Na^{+} > Mg^{2+} > Ca^{2+} > K^{+}$ and for anions $Cl^{-} > SO_4^{2-} > HCO_3^{-} > CO_3^{2-}$. The relative proportions of Ca^{2+} and HCO_3^{-} were higher in spring 2003 and 2005 (Figure 1); otherwise proportions were consistent from year to year.

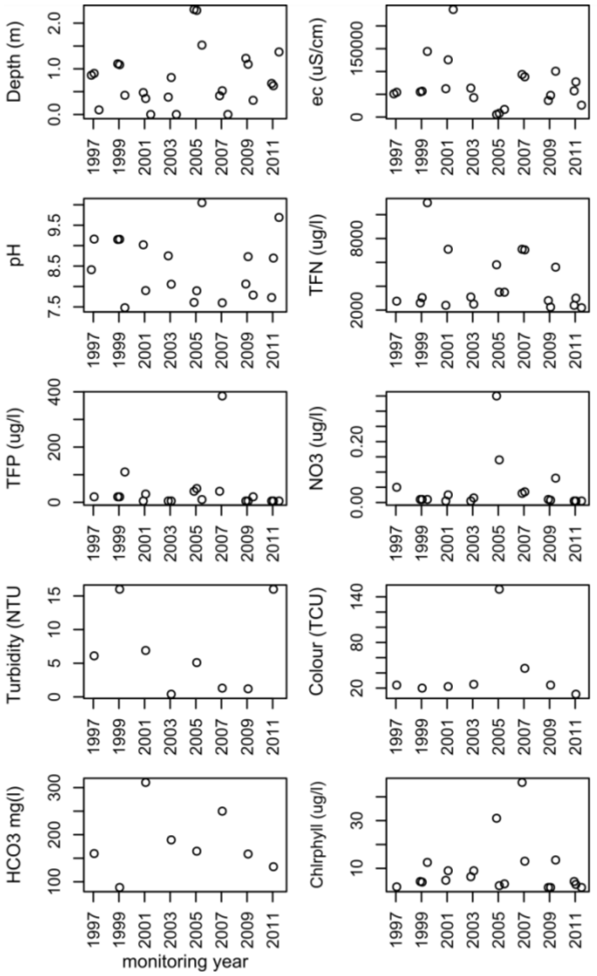

Figure 1. Water chemistry parameters at Lake Coyrecup for late-winter, spring and autumn sampling occasions between 1997 and 2012. Ec is electrical conductivity, TFP total filtered phosphorus, TFN total filtered nitrogen, NO_3^{2-} nitrate, HCO_3^{-} bicarbonate ion and total chlorophyll is the sum of the photosynthetic pigments chlorophyll a, b and c and phaeophytin. Tick marks are positioned at spring sampling.

5.4 Nutrients and chlorophyll

Total filtered nitrogen (TFN) concentrations tended to be relatively high (e.g. Appendix 2 Pinder *et al.*, 2009), particularly in autumn as the lake was drying (Figure 1). The full range of values observed was 2200 – 11000 µg/l with lowest values associated with the lake being full and less saline. In late-winter 2005, following the flooding inflows of that year, relatively lower TFN concentrations (2200 µg/l) coincided with relatively high (0.35 mg/l) concentrations of nitrate/nitrite.

With the exception of two extreme values, total filtered phosphorus (TFP) varied between 2 and 50 µg/l (Figure 1). High concentrations in spring 2007 (385 µg/l) coincided with high concentrations of TFN (ca 7000 µg/l) and may be the result of nutrient retention and evapoconcentration of the large inflow volumes in 2005 when TFP was 50 µg/l. Similarly, high TFP concentration in autumn 2000 (135 µg/l) coincided with the highest concentration of TFN (11000 µg/l) and occurred in the drying phase of a hydrocyle of approximately 23 months duration. It seems likely that when water persists in the lake nutrients are retained and accumulate from further inflows. This did not however result in a trend of increasing nutrient concentrations across the monitoring period.

On most sampling occasions chlorophyll concentration was between 2.0 and 13.5 µg/l and increased with increasing salinity ($rho = 0.52$, $df = 17$, $p < 0.05$) and nutrients (Figure 1). On most occasions this relationship reflected increased primary production when the concentration of nutrients increased because of evapo-concentration as the lake dried. However, the highest chlorophyll concentrations of 49 µg/l and 31 µg/l suggested algal blooms in late-winter 2005 and 2007, and were associated with low or moderate salinity. This primary productivity was probably more strongly influenced by increasing nutrient concentrations from inflows as the lake filled and a change in algal community structure at lower salinities.

6 Fauna

6.1 Aquatic invertebrate diversity

Eighty three species of aquatic invertebrate were collected from Coyrecup Lake. This included four species of rotifer collected during 1999, 2005 and 2007 but this group was not processed for 2009 and 2011 samples. To enable comparison of richness across all years the four rotifer species were dropped from analyses, resulting in small adjustments to annual values of richness (Fig. 2b). Further discussion of the invertebrate community excludes rotifers.

All species are common and widely distributed in south-western Australia or more broadly and are typical of moderately saline, especially secondarily saline, wetlands.

Only a small proportion of the species pool was present on most sampling occasions, with richness varying greatly; from 9 – 23 species when the lake was saline to 48 species under sub-saline conditions in 2005 (Figure 2). A very high rate (64%) of single occurrence species was observed; principally because of the large number of species (35) which only occurred in 2005 during conditions that were not repeated during the study period. The proportion of singleton species amongst years other than 2005 was a more typical 27%.

While richness was lower when the lake was saline, abundance was higher with several species occurring at abundances in excess of 10000 individuals per sample. The largest of these were *Coxiella* snails, the amphipod *Austrochiltonia subtenuis* and the ostracod *Mytilocypris mytiloides* which are likely to be important food items for waterbirds. Additionally, many smaller microcrustacea including; *Daphnia* (cladocerans), *Diacypris* (ostracods), and *Calamoecia* (copepods), were abundant. These abundant species were absent or in lower abundance in 2005. High abundance of some aquatic invertebrates, especially smaller crustacea, seems to be typical of moderately saline wetlands.

Richness was positively correlated with depth (rho= 0.96, df=6, p< 0.01) (Figure 2) and negatively correlated with salinity (rho = -0.75, df=6, p<0.05).

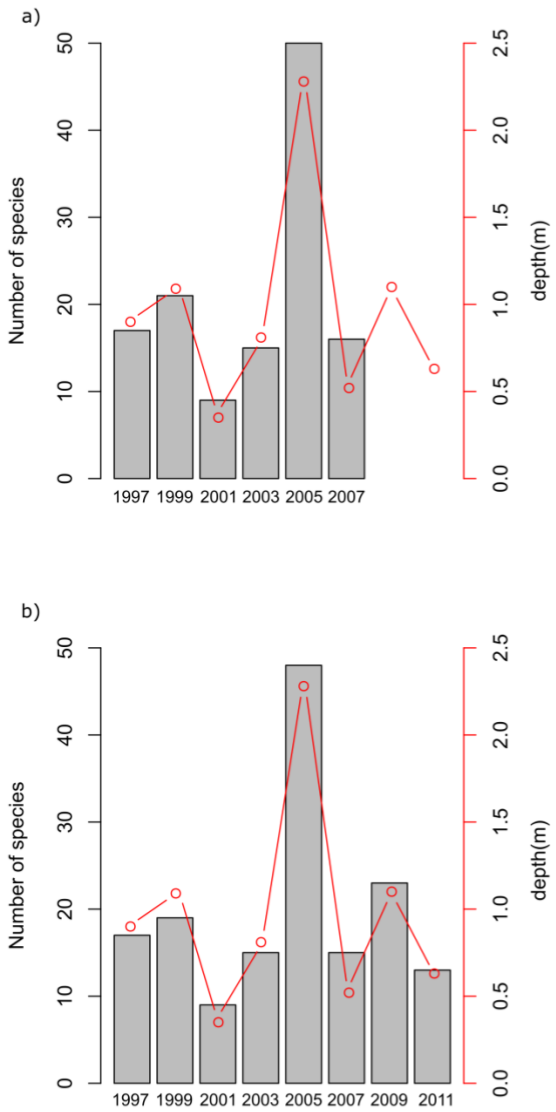

Figure 2. Invertebrate richness in spring of each monitoring year with depth (o) at the time of sampling; a) entire suite of collected species, b) without rotifers and protists.

The higher species richness in 2005 also resulted in an increase in families represented; with 30 present compared to a mean 12.8 ± 3.7 families across the remaining years. Similarly, the richness of less salt tolerant species, particularly from assemblages E and F (sensu Pinder *et al.*, 2004), increased at this time; while the richness of typically saline assemblages H and G, which comprised most of the fauna in other years, declined. Assemblage E species include a high proportion of insects which have active dispersal capabilities (e.g. winged adults) and are likely to have colonised from wetlands elsewhere in the region. This contrasts with assemblage F species and both assemblages H and G species which are dominated by poor (at least in the short term) dispersers more likely to colonise from propagules within in the wetland or possibly from other wetlands upstream.

6.2 Invertebrate community composition

An ordination (NMDS) of community composition over the monitoring period (Figure 3) identified two characteristics of the invertebrate community. Firstly, with the exception of 2005, the invertebrate community was relatively stable over time and of similar composition to secondarily saline wetlands (marker 12) and naturally saline wetlands (marker 11), while remaining distinct from the lower richness hypersaline marker wetlands (i.e. 13 and 14). At lower salinities (e.g. 1997, 1999 and 2009 when the lake was deeper) the community had higher richness (Figure 2) and was more like marker 11 (representing naturally saline wetlands) whereas at higher salinities (2001,2003, 2007 and 2011) the wetland was more similar to marker 12 (representing secondarily saline wetlands).

Secondly, the filling and reduced salinity of the wetland in 2005 resulted in a composition similar to that of naturally sub-saline wetlands (i.e. marker 4). This community differed from other years principally by the addition of species (see discussion of richness above). However, some halophilic species including *Coxiella* sp., *Diacypris spinosa* and *Platycypris baueri* were absent at the time of sampling. Despite long periods in which only relatively depauperate communities can persist, the community in 2005 indicates there is a potential for a more speciose community to develop when salinity is reduced.

Environmental factors affecting community composition were investigated using a constrained ordination (RDA) with non-significant environmental factors successively removed from the model in a stepwise process to identify significant correlations. This analysis (Figure 4) indicates that depth and pH were significantly correlated with community composition ($F = 4.2$, $df = 1$, $p = 0.002$ and $F = 2.6$, $df = 1$, $p = 0.002$ respectively). The first axis (RDA1) accounts for 42.4% of variance in composition due principally to the effects of lake depth. However, this axis is principally determined by the changes in community structure at maximum depth, i.e. 2005. This axis is not statistically significant ($F = 5.0$,$df = 1$, $p = 0.11$) and is not included in the model when the 2005 community is dropped from the analysis.

The second ordination axis (RDA2) is statistically significant ($F = 1.89$, $df = 1$, $p = 0.05$) and constrains 15.8% of the total variance in community composition. This axis describes an effect of pH and depth on the less rich annual communities, with those developing at greater depth (>1.0 m) and higher pH (*ca* 9.0), at the bottom left of Figure 4, separated from communities located at the top left and occurring at shallow depths (0.35 -0.8 m) and lower pH (7.6 -8.7).

The influence of depth over a range from 0.35 – 1.11 m on RDA2 and on communities at maximum depth (2.28 m) on RDA1, suggests that community composition has a non-linear response to depth involving a threshold depth (somewhere over 1.1 m) above which an additional suite of species can occur and cause community composition to change dramatically. The most obvious mechanism by which depth could cause such changes in community structure is through the correlated reduction in salinity and its physiological effects on colonising species.

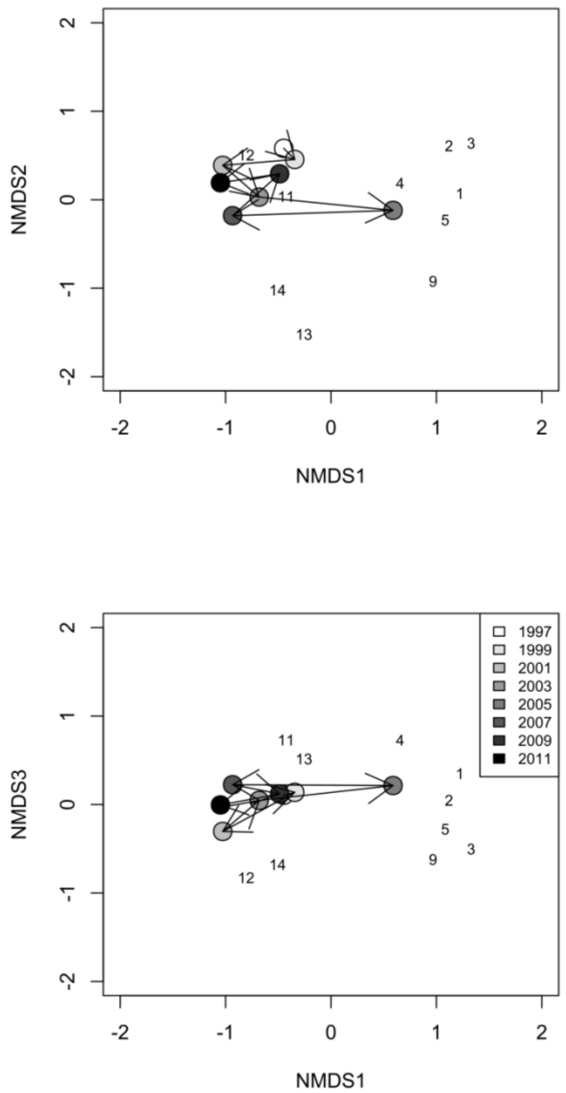

Figure 3. An ordination of spring invertebrate community composition (presence-absence) at Coyrecup Lake and 'marker' wetlands (see methods). This ordination had a low stress of 0.06. Marker wetland 1=fresh high richness, 2=subsaline sandy sump, 3=fresh, ephemeral wooded swamp, 4=naturally subsaline 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.

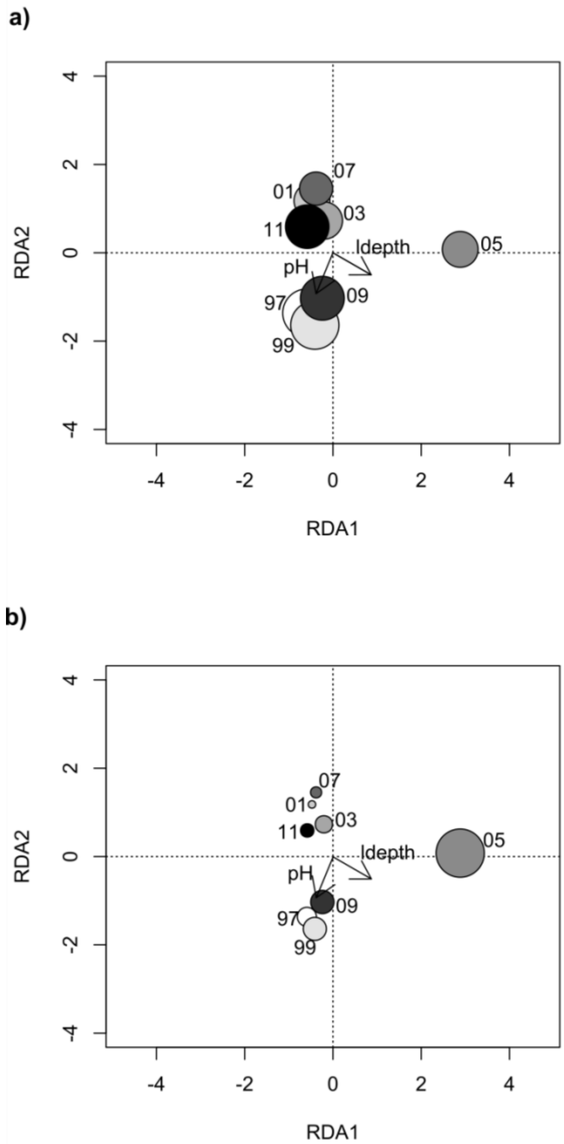

Figure 4. Redundancy Analysis for invertebrate community composition. Point size for each sample is scaled by a) pH and b) depth.

In summary, the invertebrate community at Coyrecup Lake consists of common and widespread halotolerant communities, similar to that occurring in other secondarily saline wetlands (Pinder *et al.*, 2004). In most years halotolerant species dominate and richness is < 23 species. Changes in composition were associated with changes in depth and pH, with species added as these variables increased, and above an undetermined threshold depth (>1.1 m) community structure has the potential to be considerably more diverse. This diversity derives from an increase in richness and a change from resident, salinity tolerant species, to ubiquitously distributed, mobile and broadly tolerant species. Otherwise, there was no directional trend in aquatic invertebrate richness or composition over the monitoring period.

6.3 Waterbird diversity

Three species of waterbirds observed at Coyrecup Lake are significant because of their low population numbers across the south-west of Western Australia. Hooded plover were observed on 5 occasions with abundances of from 1 to 9 individuals. The estimated population size for this species in Western Australia lies between 800 and 2500 individuals (Garnett *et al.*, 2011; Pinder *et al.*, 2012; Singor, 2013). Criterion 6 for meeting the requirements of listing as a wetland of international significance under the RAMSAR convention requires that the wetland regularly supports 1% of the individuals of a species (e.g. Department of Environment and Conservation, 2009). Given the lowest estimates of population size (800), the presence of 9 individuals at Coyrecup Lake in spring 2011 would exceed this 1% threshold. However, there is insufficient data to suggest this occurs regularly and Coyrecup Lake was not listed as a potential candidate for listing by Jaensch & Watkins (1999). Hooded plover were not observed at Coyrecup Lake by Jaensch *et al.* (1988) during the 1980s, despite low water levels in the early part of this period. Freckled duck were recorded on three occasions with 121 and 90 individuals counted in late-winter and spring of 2005 when the lake was full. This species was recorded in only 25 nature reserves including Coyrecup Lake, during the extensive surveys of Jaensch *et al.* (1988). Low occurrence in the south west prevented Halse et al (1994, 1995) from effectively estimating the size of the regional population, but their highest total count was 670 birds, suggesting Coyrecup Lake remains an important wetland for this species. Chestnut teal were recorded in either late-winter or spring of five sampling years and had abundances between 2 and 20 birds. With an estimated Western Australian population of about 40000 individuals (Halse et al. 1995) the abundance at Coyrecup Lake is not particularly significant.

The Australian shelduck and grey teal were the most frequently occurring species (95 and 90% of surveys respectively) and the most abundant species. Grey teal had a mean abundance of 832.8 ± 1108.5 individuals when present, with individual surveys in the range 26 to 4296 individuals. Australian shelduck had a mean abundance of 363.1 ± 435.5 and a range of 4 to 1510 individuals. Abundance of both these species was apparently not dependent on the depth or salinity of the wetland.

Pink-eared ducks occurred less frequently (38% of surveys) but had high abundance in late-winter 1997 (689 birds) and 2009 (1389), and in spring 2009 (1764). Occurrence of this species was associated with periods of lower salinity (<57,000 µS/cm) but abundance was probably influenced by extrinsic factors such as regional distribution and movement of the species. While the number of Australian shelduck observed were comparable to the abundance observed by Jaensch et al. (1988), the abundance of both grey teal and pink-eared duck were greater than the maxima recorded by these authors. When these species were present at the lake, total abundance of the waterbird community was frequently in excess of 2000 birds.

Australian wood duck occurred in only 2 surveys between 1997 and 2012 with 3 or fewer individuals on each occasion. Coyrecup Lake was seen as an important site for this species in the 1980s (Jaensch et al. 1988) and it is likely that the demise of fringing vegetation has severely reduced the value of the wetland as a habitat for this species.

Thirty species of waterbird were recorded in total, which is comparable to the 32 species from 23 surveys recorded between 1981 and 1985 (Jaensch *et al.*, 1988). Species richness of individual surveys ranged from 1 – 15 when birds were present (Figure 5) and was correlated with depth (rho = 0.68, df = 22, $p < 0.01$) and salinity (rho = -0.57, df = 19, $p < 0.02$). However, highest richness was not associated with the filling of the lake in 2005, when high depth and low salinity resulted in a predominance of ducks and diving species, but rather with moderate depths around 1 m. At these moderate depths additional wading and shore feeding species dependent on shallows were responsible for increased richness. While the absolute difference in richness was small it does suggest that filling of the lake restricted the habitats available to waterbirds. Increased richness of species using shallows was also responsible for evening out richness at shallower depths when fewer ducks and diving species were present.

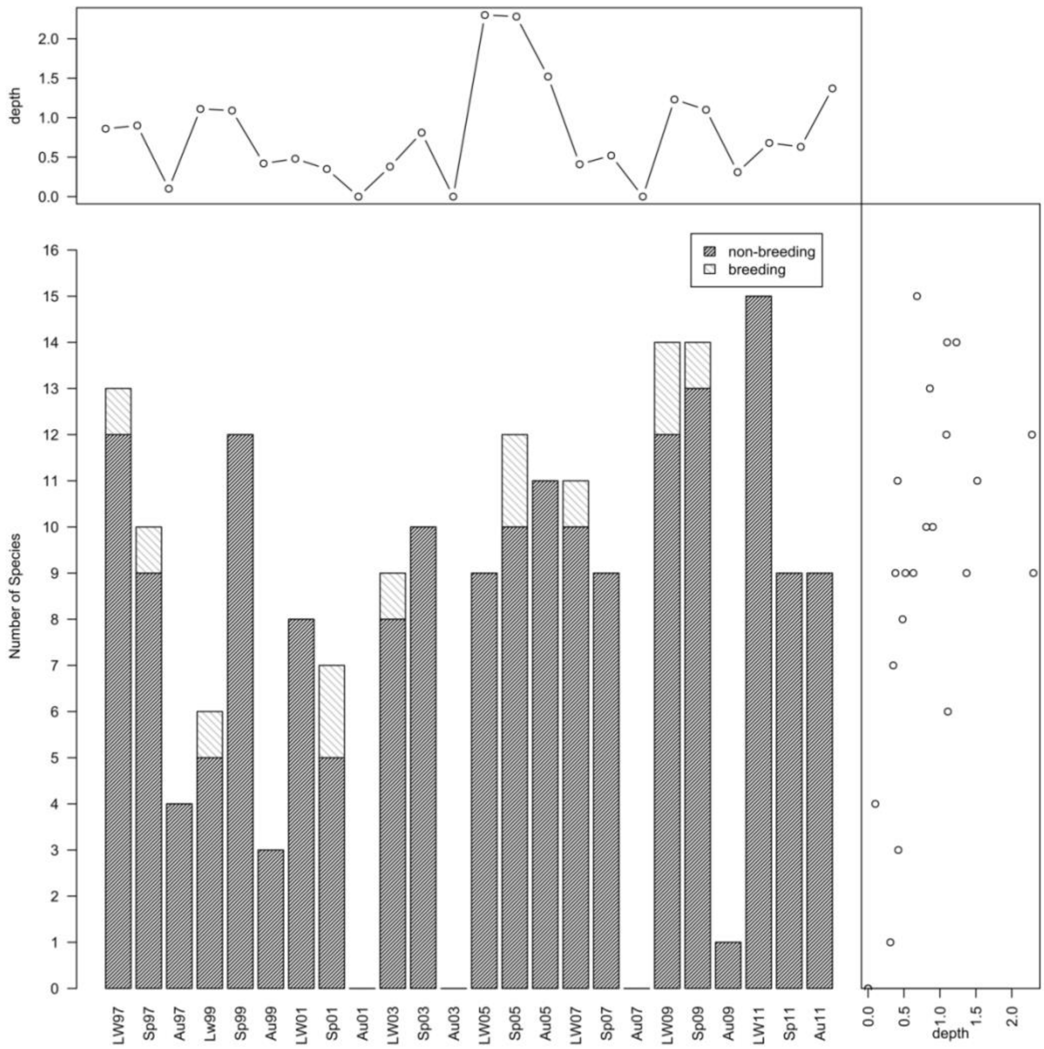

Figure 5. Waterbird species richness across the monitoring period, with depth plotted along the same time axis and as a scatterplot against richness.

Breeding was observed amongst four species: Australian shelduck, grey teal, pink-eared duck and red-capped plover. Breeding was evenly spread across the monitoring period with no evidence that the filling of the lake in 2005 increased breeding activity (Figure 5). Six species were recorded breeding during the 1980s and, additionally, old nests of cormorants and heron or spoonbill were noted in trees on the inflow creek (Jaensch *et al.*, 1988). It is likely that the demise of vegetation on the lake has shifted breeding of many species from the lake to the inflow creek (which was not surveyed) or even further afield.

6.4 Waterbird community composition

An ordination (NMDS) of species occurrence summed across the three seasonal surveys per monitoring year (Figure 6) was used to describe changes in the character of the community across the monitoring period. This ordination had a stress of 0.07 in two dimensions and indicates a broad range of community composition. A simple 'low richness' community occurring when water depth was low throughout the year, was most similar to the community at Lake Altham; a marker wetland representing shallow, saline wetlands with low community richness. At the opposite extreme, when the wetland was filled in 2005 it was most similar to the species rich communities of the Pinjareega and Toolibin marker wetlands. In years when the lake had depths of around 1 m for part of the year (e.g. 1997, 1999, 2009 and 2011), community composition was intermediate between these extremes. These intermediate communities included many dabbling and diving species present in 2005 as well as the small waders which dominated the low richness community. A high richness of species dependent on shallow, but not hypersaline, habitats, such as white-faced heron, yellow-billed spoonbill, and Australian white ibis, was also characteristic of intermediate communities.

While there was no evidence of a directional change in community composition across the monitoring period, comparison with historical data (Figure 6) suggests significant change since the 1980s. Data from surveys in the 1980s (Jaensch *et al.*, 1988) indicate that the annual community was very similar to that found at Lake Toolibin. This similarity persisted across a range of depths from 0.5 – 2 m. However, during the current study similar changes in depth and salinity had a much greater effect on community composition, which only approached that of the historical community when the lake was full and salinity was reduced.

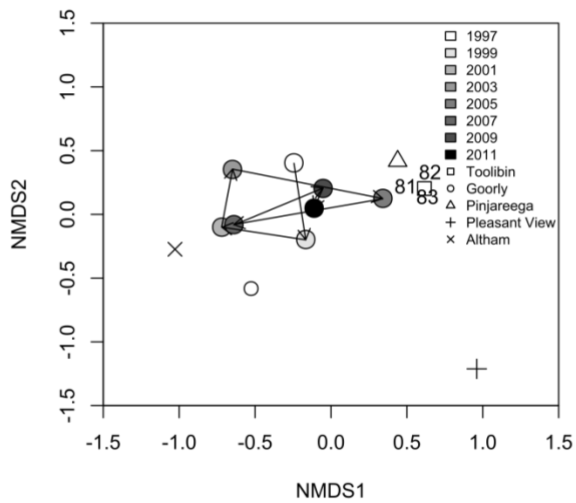

Figure 6. NMDS Ordination of annual waterbird species inventory compiled from late winter, spring and autumn surveys for each year. 1997 includes surveys from 1997/98 and 1999 from 1999/00 etc. The points 81, 82 and 83 represent historical data (see text) for 1981, 1982 and 1983 respectively.

A constrained ordination (redundancy analysis) of waterbird presence-absence identifies depth (log transformed) and pH as significant constraining variables (Figure 7). Collectively these two variables explain 30% of the variance in composition of waterbird communities with depth alone explaining

22%. Both constraining terms (depth: F = 4.6, df = 1 p < 0.01, pH: F = 1.8, df = 1, p < 0.05) and axes were statistically significant (RDA1: F = 4.7, df = 1 p <0.01, RDA2: F = 1.7, df = 1, p < 0.03). Depth could be replaced in the model by electrical conductivity (square root transformed) and both terms and axes remained statistically significant, but then only 28% of variance was explained, leaving depth a better predictor of composition.

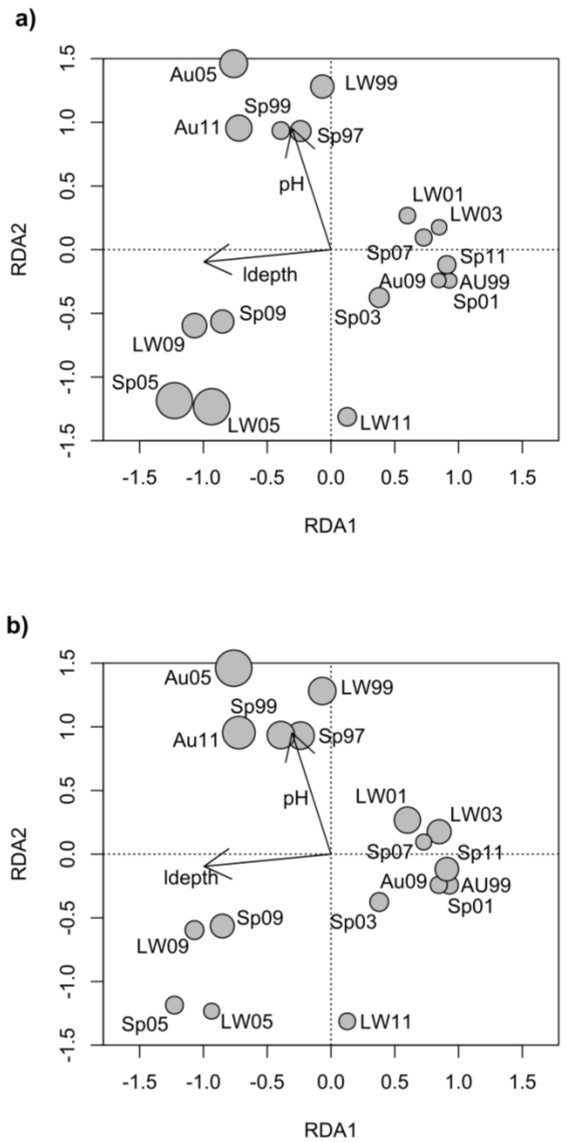

Figure 7. Constrained ordination of waterbird community composition for individual surveys at Coyrecup Lake. Seasonal surveys are labelled according to the monitoring year and the consecutive seasons LW =late-winter, Sp= spring, Au= autumn. Sample points are scaled by a) depth and b) pH and arrows indicate the direction and magnitude of the effect of these significant environmental variables.

Constrained by depth and pH the waterbird community composition falls into three groups (Figure 7) which largely conform to the groups already discussed in the context of the ordination of annual communities. The first of these groups lies in the upper left quadrant of the ordination and describes a community occurring at moderate depth and alkaline pH. This community had a high occurrence of species preferring shallow habitats, including the white-faced heron, yellow-billed spoonbill, Australian white ibis and black-winged stilt, in addition to a suite of ducks and diving species. The second group in the lower left quadrant of the ordination falls at the deepest end of the depth gradient and the neutral end of the pH gradient. The community at this time includes most of the records of hardhead, musk duck, Australasian shoveler and freckled duck and does not include species of small wader or the shallow water species occurring in the first group. The third and broader group lies to the right on RDA1 (Figure 7) and encompasses the sampling occasions when the lake was shallow and hypersaline and of variable pH (7-79 – 9.02). These communities have a higher occurrence of small waders like red-caped plover, banded stilt and red-necked stint and, with the exception of grey teal and Australian shelduck, support few species of duck.

In summary, thirty species of waterbird used Lake Coyrecup, including three species (hooded plover, chestnut teal and freckled duck) with low population sizes across the south west region. The mean total abundance was approximately 1300 birds per survey. These features suggest the lake remains important for waterbirds. However, community composition has altered since the 1980s and only approaches historical composition when the wetland is at its fullest and least saline. The community was structured by depth, salinity and pH during the study period, but it is likely that the demise of fringing vegetation has reduced the pool of species for which the wetland is suitable.

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Appendix 1. Depth and water chemistry data

Physico-chemical variables as used in analyses for Coyrecup Lake. Values for pH, conductivity, temperature, oxygen and TFN and TFP for the spring samples are averages of measurements from site A and site B. For other dates these measurements are for site A only. Other measurements are also for site A only.

Date	6/08/1997	25/10/1997	11/03/1998	29/08/1999	21/10/1999	18/03/2000	26/08/2001	1/11/2001	25/03/2002	8/08/2003	31/10/2003	26/03/2004	12/08/2005	28/10/2005	25/03/2006	10/08/2007	25/10/2007	3/04/2008	27/08/2009	30/10/2009	23/03/2010	2/09/2011	22/10/2011	30/03/2012
season	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au
Depth (m)	0.86	0.90	0.09	1.11	1.09	0.42	0.48	0.35	0	0.38	0.81	0	2.30	2.28	1.52	0.41	0.52	0	1.23	1.10	0.31	0.68	0.63	1.37
Conductivity (µS/cm)	51000	54400		55300	56800	144000	62200	125600	236000	63500	42750		5730	8355	16770	93400	88350		36200	47700	100600	57500	77200	26100
pH	8.41	9.16		9.15	9.155	7.48	9.02	7.90		8.75	8.055		7.61	7.89	10.05		7.6		8.06	8.73	7.79	7.73	8.695	9.69
TFN (µg/L)		2750		2600	3050	11000	2400	7100		3100	2500		5800	3500	3500	7100	7050		2800	2250	5600	2400	3000	2200
TFP(µg/L)		20		20	20	110	5	30		5	5		40	50	10	40	385		5	5	20	5	5	5
Chlorophyll-a (µg/L)		0.5		1	0.75	0.5	0.5	4		2	5.5		17	0.75	0.5	25	3		0.5	0.5	5	3	1.75	0.5
Chlorophyll-b (µg/L)		0.5		1	0.5	1	1	1.25		2	1.25		2	0.5	0.5	2	6		0.5	0.5	5	0.5	0.5	0.5
Chlorophyll-c (µg/L)		0.5		2	0.75	3	0.5	2.25		0.5	1		5	0.5	0.5	6	0.5		0.5	0.5	3	0.5	0.5	0.5
Phaeophytin-a (µg/L)		0.75		0.5	2.25	8	3	1.5		2	1.25		7	1	2	13	3.5		0.5	0.5	0.5	0.5	0.5	0.5
Temperature (°C)		25		16.8	21.45	18.6	17.8	34.5	26	14.92	16.05		14.3	16.35	18.6		25.0		16.3	27.65	22.0	13.4	24.34	21
Dissolved Oxygen(%)		144		131	162.2	81	150						84.4	83.7	166.9		130.1							
NO3 (mg/L)		0.05		0.01	0.01	0.01	0.005	0.025		0.005	0.015		0.35	0.14		0.03	0.035		0.01	0.0075	0.08	0.005	0.005	0.005
Turbidity (NTU)		6.1			16			6.9			0.4			5.1			1.3			1.2			16	
Colour (TCU)		24			20			22			25			150			46			24			12	
TDS (g/L)		40.9			42			100			30			5.9			70			34			56	
Alkalinity (mg/L)		130			113			255			155			135			205			130			108	
Hardness (mg/L)		9500			11000			26000			8400			1400			19000			7300			15000	
Si (mg/L)		1			2			3.6			0.75			3.3			2.8			0.1			0.5	
Na (mg/L)		11000			11800			30200			8370			1500			22000			9280			17700	
Ca (mg/L)		850			1080			2450			1060			172			1430			882			1530	
Mg (mg/L)		1800			1950			4860			1400			230			3820			1240			2630	
K (mg/L)		86			107			328			69.3			16.6			213			95.7			130	
Mn (mg/L)		0.1			0.05			0.1			0.001			0.003			0.0005			0.002				
Cl (mg/L)		24000			23000			64000			16000			2800			37200			16700			30800	
HCO3 (mg/L)		160			88			311			189			165			250			159			132	
CO3 (mg/L)		1			24			1			1			1			0.5			0.5			0.5	
SO4 (mg/L)		3000			3720			10600			3260			471			7510			3010			5850	
Iron(mg/L)					0.15			0.34			0.0025			0.11										
Tot Chlorophyll (µg/L)		2.25		4.5	4.25	12.5	5	9		6.5	9	0	31	2.75	3.5	46	13	0	2	2	13.5	4.5	3.25	2

Appendix 2. Aquatic invertebrate data

Species in this presence/absence 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	1997	1999	2001	2003	2005	2007	2009	2011
Turbellaria	Turbellaria	IF999999	1	2						
Nematoda	Nematoda	II999999	1	2	2	2	2	2	1	
Rotifera	Bdelloidea	JB999999					1		*	*
	Hexarthra fennica	JF040105		4					*	*
	Brachionus plicatilis s.l.	JP020219		1				3	*	*
	Lecane ludwigii	JP090136					1		*	*
Mollusca	Coxiella sp.	KG130299	5	4				3	4	1
Annelida	Naididae	LO049999		1						
(earthworms)	Ainudrilus nharna	LO052101					2			
	Enchytraeidae	LO089999		1		2	1		1	
Arachnida	Mesostigmata	MM9999A2					1			
(water mites)	Trombidioidea	MM9999A6					1			
Cladocera	Pleuroxus cf. foveatus	OG0325A0					4			
(water fleas)	Daphnia carinata	OG040201					4			
	Daphnia pusilla	OG040213	5						5	
	Daphnia queenslandensis	OG040214							4	
	Daphnia truncata	OG040217		5						
	Macrothrix breviseta	OG060201					3			
Ostracoda	Alboa worooa	OH080101					3			
(seed shrimps)	Australocypris insularis	OH080203	1	3	3	3	2	2	4	4
	Cyprinotus cingalensis	OH080602					2			
	Diacypris dictyote	OH080701			2					
	Diacypris spinosa	OH080703	4	4				4		
	Diacypris compacta	OH080704				3			5	5
	Mytilocypris ambiguosa	OH081201					2			
	Mytilocypris mytiloides	OH081204	5	4		2	2		4	
	Platycypris baueri	OH082601	3	3	3	3		3	4	4
	Sarscypridopsis aculeata	OH090101					2			
Copepoda	Calamoecia clitellata	OJ110208	5	5	5	4	4		5	5
	Mesocyclops brooksi	OJ310703					2			
	Apocyclops dengizicus	OJ311201	3	4				3		
	Meridiecyclops baylyi	OJ311701			2	4		2	4	5
	Pescecyclops sp. 442	OJ3120A0					3			
	Mesochra nr flava	OJ6103A1	4	2			3	1	3	3
Amphipoda	Austrochiltonia subtenuis	OP020102	4	4			3		2	
Isopoda	Haloniscus searlei	OR250101	4	3	2				1	1
Coleoptera	Allodessus bistrigatus	QC091101					1			
(beetles)	Antiporus gilberti	QC091603					1			
	Sternopriscus sp.	QC091899					1			
	Necterosoma sp.	QC092099					1		2	1
	Megaporus howittii	QC092103					1			
	Rhantus suturalis	QC092301					1			
	Lancetes lanceolatus	QC092401					1			
	Berosus discolor	QC110409	1	1					2	1
	Berosus munitipennis	QC110418						1	1	
	Limnoxenus zelandicus	QC111401					1			
Diptera	Tipulidae	QD019999				1				
(flies, midges,	Aedes camptorhynchus	QD070502						1		1
mosquitoes)	Culicoides sp.	QD090899					1			
	Monohelea sp. 1 (SAP)	QD0919A0	1							
	Stratiomyidae	QD249999		1			1		2	
	Dolichopodidae	QD369999						1		2
	Ephydridae sp. 3 (SAP)	QD7899A7					1			
	Ephydridae sp. 6 (SAP)	QD7899B0		1		1			1	
	Ephydridae sp. 7(SAP)	QD7899B1					1	1		
	Muscidae sp. A (SAP)	QD8999A0				1	1	1	1	
	Muscidae sp. C (SAP)	QD8999A2							1	
	Procladius paludicola	QDAE0803	2	1		2			1	
	Procladius villosimanus	QDAE0804					2			
	Paramerina levidensis	QDAE1201					1			
	Corynoneura sp.	QDAF0699					1			
	Tanytarsus barbitarsis	QDAH0402			1	2	2	1		3
	Tanytarsus fuscithorax/semibarbitarsus	QDAH04D8	2							
	Chironomus tepperi	QDAI0414					2			
	Chironomus aff. alternans	QDAI04A0					3			
	Dicrotendipes conjunctus	QDAI0603					3			
Hemiptera	Agraptocorixa sp.	QH650399					1			
(waterbugs)	Micronecta sp.	QH650599					1			
	Anisops sp.	QH670499					2			
Odonata	Austrolestes annulosus	QO050102					1			
(dragonflies, damselflies)	Hemianax papuensis	QO121201					1			

	TAXON	LowestIDNC	1997	1999	2001	2003	2005	2007	2009	2011
	Hemicordulia tau	QO300102					1			
Trichoptera	Notalina spira	QT250504					1			
(caddisflies)	Triplectides australis	QT251103					1			

Appendix 3. Waterbird data

Abundance of species for each seasonal survey at Coyrecup Lake.

	6/08/1997	25/10/1997	11/03/1998	29/08/1999	21/10/1999	18/03/2000	26/08/2001	1/11/2001	25/03/2002	8/08/2003	31/10/2003	26/03/2004	12/08/2005	28/10/2005	25/03/2006	10/08/2007	25/10/2007	3/04/2008	27/08/2009	30/10/2009	23/03/2010	2/09/2011	22/10/2011	30/03/2012
Australian Shelduck	11	385	220	70	916	640	255	1242		10	69		2	57	359	143	1510		3	658		25	540	148
Grey Teal	939	26	40	30	470		2029	30		580	34		271	300	132	4296	1080		1521	285		1284	50	2426
Black Swan	76	99		32	13		35	2			3		1	45	29	80	12		110	137		10		169
Silver Gull	50	7		25	25					2	6			5	7	8	2		1	2		3	4	7
Hoary-headed Grebe	45	231			3					1	81		153	34					61	297		4	16	51
Red-capped Plover	56		25			15	46	79		78	12					275	20				17	18	170	
Banded Stilt	27		35		119			53		3	1					7	148			12		22	12	
Eurasian Coot	82	50											73	74	194				7	20				9
Pink-eared Duck	689										13		53	70	7				1389	1764		4		
Black-winged Stilt	66	10					14			12									18	20		1		
Red-necked Stint								109		14	3					70	6					2	96	
Australasian Shoveler													3	5					9	24		1		33
Hardhead	2													3		6			43	112		5		
Musk Duck					2								2	1					3	28		4		
Pacific Black Duck					4		2							4	10		6		8					
Chestnut Teal	2				20		19									14			2					
Hooded Plover						1	4									2						3	9	
White-faced Heron				7	16										41									31
Yellow-billed Spoonbill		1		2	1															1				
Freckled Duck	1												121	90										
Red-necked Avocet		4						6									8							
Australian White Ibis															1									4
Australian Wood Duck					3														1					
Sharp-tailed Sandpiper																						4	5	
Common Greenshank		1																						
Common Sandpiper																1								
Curlew Sandpiper										1														
Little Pied Cormorant															1									
Straw-necked Ibis															1									
Whiskered Tern											1									20				

Appendix 4 Invertebrate Marker Wetlands

Background

Ordination of invertebrate community composition is a simple tool for visualising the changes in composition over time; linking samples of greatest similarity by their proximity. However, the scale (and therefore ecological significance) of changes between samples is not identified. An ecological context for the observed differences between samples can be provided by including samples of known types (marker wetlands) in the ordination to define an ecological 'space'.

Marker wetlands for the invertebrate ordination were derived from a classification of 200 wetlands across the Wheatbelt (Pinder *et al.* 2004) which identified 14 wetland groups on the basis of invertebrate community composition. Eleven groups were relevant to the suite of wetlands in the monitoring program and from each of these the wetland having species richness closest to the group average was selected as a candidate marker wetland. Where multiple wetlands shared the average richness all were selected. An ordination of the selected wetlands was conducted and used to determine a minimum set that could define a useful ecological space. Where multiple samples from a wetland group were included those that differed most from other wetland groups were retained. Markers for wetland groups 10 and 11 were sufficiently similar that a single one from wetland group 11 was selected. The final set of ten marker wetlands is detailed in the following table.

Invertebrate ordination marker wetlands derived from the fourteen wetland groups described by Pinder *et al.* (2004)

Group	Name	Code	Richness	Salinity (ppt)	Group description
WG1	Calyerup Creek	SPS094	66	4	species-rich mostly freshwater wetlands. sampled in September 1998.
WG2	Job's Sump	SPS060	51	3.5	series of 8 shallow claypans with relatively high turbidity and some unique faunal elements. Job's sump has a sandy bed and is not turbid like other members of the group. Sampled in October 1997 when approximately 80% full
WG3	Nolba Swamp	SPS194	49	<1	group of northern tree swamps; freshwater wetlands dominated by an overstorey of trees, Nolba is episodically filled and was sampled while full in July 1998.
WG4	Maitland's Lake	SPS142	44	9.5	subsaline wetlands many of which were probably naturally saline but subject to secondary salinity. Maitland's was sampled in September 2000 at about 70% full.
WG5	Lake Caitup	SPS135	49	3.5	this lake is deep and fringed by sedges and melaleuca and represents a group of subsaline wetlands some of which are subject to secondary salinity but of less overall salinity than WG4. Lake Caitup was sampled in September 1998
WG9	Mt Le Grande Swamp	SPS133	66	<1	southern freshwater swamps found in the jarrah forest and Esperance sandplain region. Most are dominated by sedges and some include Yates. Sampled in September 1998
WG11	Dambouring Lake	SPS152	20	30	naturally saline wetlands in good condition. Sampled in September 1999
WG12	Beaumont Lake	SPS130	16	50	a shallow ephemeral clay pan in Beaumont Nature Reserve, represents a series of naturally hypersaline and secondarily hypersaline wetlands in the southern Wheatbelt. Sampled in September 1998

Group	Name	Code	Richness	Salinity (ppt)	Group description
WG13	Master's Salt Lake	SPS097	7	220	degraded hypersaline lake. Sampled in October 1997
WG14	Monger's Lake	SPS166	11	130	naturally hypersaline wetland with high species richness. Sampled in August 1999