Wheatbelt Wetland Biodiversity Monitoring

Fauna Monitoring at Wheatfield Lake 1997-2011

Report WWBM-FR05

David Cale and Adrian Pinder
Wetlands Conservation Program
Science and Conservation
March 2020

Department of **Biodiversity, Conservation and Attractions**
GOVERNMENT OF WESTERN AUSTRALIA

Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000

www.dbca.wa.gov.au

This report/document/publication was prepared by David Cale and Adrian Pinder

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

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

The recommended reference for this publication is:

Cale, D. and Pinder, A. (2020) Wheatbelt Wetland *Biodiversity Monitoring: Fauna Monitoring at Wheatfield Lake 1997 - 2011*. Department of Biodiversity, Conservation and Attractions, Perth.

Cover photo: Much of the flooded *Melaleuca* at the margin of Wheatfield Lake have died, but provide a safe site for communal breeding of species of ibis, spoonbill and cormorant.

Acknowledgements

Russell Shiel (Russel J. Shiel and Associates) identified the rotifers, cladocerans and protozoans. Stuart Halse and Jane McRae (Bennelongia Environmental Consultants) identified some of the ostracods and copepods. Edyta Jasinska and Melita Pennifold (DBCA) sorted and identified the 1997 and 2001 samples respectively. Stuart Halse (then of DBCA) conducted much of the field data collection prior to March 2002.

Contents

Summary 3
Background to the Wheatbelt wetland biodiversity monitoring project 4
Wetland description 5
Sampling Program 6
Physical and chemical environment 7
  Hydrology 7
  pH 8
  Salinity and ionic composition 8
  Nutrients and chlorophyll 9
  Summary of physical and chemical conditions 10
Fauna 10
  Aquatic invertebrate diversity 10
  Invertebrate community composition 13
  Summary of Invertebrate fauna 14
  Waterbird diversity 15
  Waterbird composition 17
  Summary of waterbird fauna 19
References 20
Appendix 1. Depth and water chemistry data 22
Appendix 2. Aquatic invertebrate data 23
Appendix 3. Waterbird data 27
Appendix 4. Invertebrate Marker Wetlands 29

Summary

Wheatfield Lake is part of the Warden Wetlands system, which is listed under the RAMSAR convention because of its importance to migratory shorebirds, the south-west populations of hooded plover and chestnut teal and its importance as a drought refuge for many species. The main threat to the Warden Wetlands system is altered hydrology; expressed as increased lake depth and duration of inundation.

Wheatfield Lake was monitored from 1997 to 2011 during which time it was permanent, with depths of 0.7 to 2.5 m. Depth dropped in 2009 and 2011 following operation of a gravity-fed pipeline designed to remove excess water from Wheatfield and connected wetlands. Salinity varied between 5050 and 24400 µS/cm with a mean annual (late-winter to autumn) salinity of 5591 ± 2702 µS/cm. Highest salinities coincided with lowest depths, i.e. 1997 and following the operation of the gravity-fed pipeline from mid-2009. Other chemical variables were correlated with changes in depth and salinity.

The invertebrate community showed strong similarity to other naturally saline communities in the Wheatbelt, particularly to communities of sub-saline wetlands rather than to those of hypersaline wetlands, pointing to the potential for increased salinity to alter community composition. The collected fauna comprised 137 species, including several notable for their marine affinities and/or coastal distributions. Species richness was correlated with lake depth and was lower after the operation of the gravity fed pipeline than earlier in the monitoring period. However, there was no evidence of persistent changes in community composition that would indicate a change in ecological character and the community in 2011 was similar to that of 1997. Continued operation of the pipeline should not further affect the invertebrate communities in this lake unless it assists with removing salt from the central wetland suite and then an increase in richness may be seen.

The waterbird fauna was diverse, with 45 species recorded in total and 16 to 26 present in each survey. Nine species were recorded breeding, including several colony nesting species which nested in large numbers in dead *Melaleuca cuticularis* trees flooded by the sustained high water levels. Wheatfield Lake continued to be important for chestnut teal which were present in 6 of the 8 monitored years with an abundance accounting for more than 1% of the population in the south west. The waterbird community at Wheatfield Lake was relatively constant during the monitoring period; with no evidence of sustained change in either community composition or species richness. However, the contemporary community differed from historical surveys; 4 species present historically were not recorded while 17 species were exclusive to contemporary communities. Most of the species in question occurred rarely and, at least in contemporary surveys, reflect greater sampling effort. However, 3 regularly occurring species may have benefited from the flooding of *Melaleuca* trees and the provision of protected breeding habitat.

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 . 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). One of those case studies was a report on Wheatfield Lake using data from 1997 to 2009.

Wheatfield Lake was included in the monitoring program because it has high conservation value (lies within a Ramsar wetland system) and was susceptible to decline due to altered hydrology and salinisation. The lake was also important as a representative of diverse saline wetlands and of south coastal wetlands. For the monitoring project it was given the site code SPM005.

Wetland description

Wheatfield Lake (33^{o} 48'S 121^{o} 55'E) lies 5km inland of the town of Esperance on the south coast of Western Australia. The wetland is naturally saline with an area of approximately 88.3 ha (Department of Environment and Conservation, 2009) and forms part of the central suite of a wetland chain collectively known as the Lake Warden wetlands system.

The Lake Warden wetlands system provides important feeding, breeding and refuge habitat for waterbirds, including migratory shorebirds, and has periodically supported abundances of hooded plover and chestnut teal in excess of 1% of the total population of these species in the south west. Consequently, the Lake Warden wetlands system is included in the Directory of Important Wetlands (Environment Australia, 2020) and was listed under the Ramsar Convention on wetlands in 1990 (Department of Environment and Conservation, 2009). Within the wetland complex, Wheatfield Lake has consistently been the most important wetland for chestnut teal (Department of Environment and Conservation, 2009; Pinder *et al.*, 2010).

Increasing water levels and salinisation of the Lake Warden wetland system and its catchment were observed during the late 1990s and early 2000s and were identified as a threat to the wetland system (Department of Conservation and Land Management, 2006; see also Lane, Clarke & Winchcombe, 2015). Biodiversity values were threatened by rising water levels which caused death among riparian vegetation subjected to prolonged flooding (Cale *et al.*, 2011) and reduced shorebird diversity as shorelines were flooded, reducing the extent of shallow habitats (Robertson & Massenbauer, 2005).

Numerous studies have been conducted to understand the surface and groundwater hydrology of the Lake Warden wetlands system and develop systems to manage the altered hydrology (see synopsis by Drew, Lynn & Ferguson, 2015). Briefly, water enters Wheatfield Lake via Coramup Creek and flows east to west through Wheatfield Lake and thence into Lakes Woody and Windabout before entering Lake Warden. Outflow from Wheatfield Lake may occur across Fisheries Road into Bandy Creek when water level exceeds AHD 4.8 m (1.77 m at the depth gauge). When outflow occurs, the direction of flow may reverse toward Wheatfield Lake from Lake Warden if the latter also has depth exceeding AHD 4.8 m (Department of Conservation and Land Management, 2006).

To manage water depths within the Lake Warden wetlands system a gravity-fed pipeline was constructed in Wheatfield Lake and commenced operation in April 2009. This pipeline was designed to move water from the lake to Bandy Creek to reduce depths in the central suite wetlands (Wheatfield, Woody and Windabout lakes) and in Lake Warden. The pipeline removed $3x10^{6}$ m^{3} (see table 3 of Drew *et al.*, 2015) of water between opening in Apr 2009 and Feb 2014 (mostly in winter),, contributing to reduced water levels in the central suite (i.e. Wheatfield, Woody and Windabout), and in Lake Warden.

Waterbirds were regularly surveyed at Wheatfield Lake in the 1980s (Jaensch, Vervest & Hewish, 1988) when water levels across the Lake Warden wetlands system were relatively low and probably approximating the pre-land-clearing condition. During this period mean richness per survey was 10 species (Cale *et al.*, 2011 using data from Jaensch et al. 1988) and mean annual richness from three surveys (late-winter, spring and autumn) was 21 species. Monitoring of water birds on the lake between 1997 and 2009 (Cale *et al.*, 2011) occurred during a period of higher water levels and revealed a mean species richness per survey of 20 species and an average annual richness of 29 species. Differences in species richness were an important factor driving a shift in community structure between the 1980s and 1990-2000s (Cale *et al.*, 2011). Increasing water depth coincided with a decline in shorebird diversity in Lake Warden (Robertson & Massenbauer, 2005) as a result of reduced areas of shallow water and beach habitat. This same study also recognised that changes in depth would have less impact in Wheatfield Lake because the lake's bathymetry would result in only small changes in habitat extent. Indeed, small increases in diversity of shorebird species were observed in Wheatfield Lake when water levels were low in autumn both before and after the first year of operation of the gravity pipeline (Cale *et al.*, 2011), but they were never abundant. Increased diversity amongst shorebird species was also noted for November and February surveys in 2010 and 2011 after the gravity pipeline began operation (Pinder *et al.*, 2010, 2012).

Vegetation of the littoral zone of Wheatfield Lake is dominated by *Melaleuca cuticularis* over scattered sedges including *Isolepis nodosa* and *Baumea juncea*(?) (Ogden & Froend, 1998). Vegetation decline (as loss of basal area) was identified for the sub-littoral zone and showed a close relationship to elevation (Cale *et al.*, 2011). *Melaleuca cuticularis* persisted above the zone of prolonged inundation, but a combination of flooding and salinity resulted in extensive death or reduced condition of plants at lower elevations. The condition of remaining plants at these lower elevations was observed to increase after 2010 when water levels were lower and recruitment of *M. halmaturorum* and *M. cuticularis* occurred in at least 2012 (unpublished data Mike Lyons DBCA).

Aquatic invertebrates collected up to 2009 as part of the State Salinity Strategy biodiversity monitoring program have been reported on previously (Cale *et al.*, 2011) and reveal that the lake has a diverse macro-invertebrate fauna with mean species richness of 55.4 drawn from a large species pool. This species pool included two species more typical of estuarine systems and a number of other species rarely encountered elsewhere in the Wheatbelt. Cale et al. (2011) concluded that there was no evidence of a change in community composition across the period 1997 – 2009, rather that differences between years were likely to be the result of high species turnover across annual hydrological cycles. Given this high species turnover they predicted that reduced depth due to the gravitational pipeline would not reduce invertebrate diversity provided that a range of depths and salinities were maintained seasonally to enable individual species to persist periodically.

Sampling Program

Wheatfield Lake has been monitored since 1997 with a total of 24 sampling visits for waterbirds and eight for aquatic invertebrates (Table 1). All data to 2009 have already been reported (Cale *et al.*, 2011) and are extended here by the three sampling visits in 2011/12. Two sites were sampled (see separate report detailing methods for the monitoring programs). Site A was located adjacent to the bird hide on the lake's south-east shore and site B was situated immediately inside and on the southern bank of the channel connecting the lake's main basin with Woody Lake downstream.

Table 1. Site visits, collected data sets and depth measurements for Wheatfield Lake, 1997- 2012. Autumn (Au) survey dates are labelled with the same year code as the previous spring (Sp) and late-winter (LW) surveys to denote that all three were part of the same monitoring cycle.

Sample	Monitoring Year	Date	Invertebrates sampled?	Waterbirds surveyed?	Depth
LW97	1997/98	5/08/1997	×	✓	NA
Sp97	1997/98	17/11/1997	✓	✓	2
Au97	1997/98	10/03/1998	×	✓	0.7
LW99	1999/00	26/08/1999	×	✓	2.5
Sp99	1999/00	19/10/1999	✓	✓	2.5
Au99	1999/00	23/03/2000	×	✓	2
LW01	2001/02	21/08/2001	×	✓	1.77
Sp01	2001/02	23/10/2001	✓	✓	1.92
Au01	2001/02	27/03/2002	×	✓	1.34
LW03	2003/04	13/08/2003	×	✓	1.78
Sp03	2003/04	22/10/2003	✓	✓	1.91
Au03	2003/04	29/03/2004	×	✓	1.36
LW05	2005/06	9/08/2005	×	✓	1.65
Sp05	2005/06	26/10/2005	✓	✓	2.01
Au05	2005/06	24/03/2006	×	✓	1.43
LW07	2007/08	8/08/2007	×	✓	1.81
Sp07	2007/08	23/10/2007	✓	✓	1.87
Au07	2007/08	1/04/2008	×	✓	1.2
LW09	2009/10	26/08/2009	×	✓	1.7
Sp09	2009/10	27/10/2009	✓	✓	1.58
Au09	200910	25/03/2010	×	✓	0.82
LW11	2011/12	31/08/2011	×	✓	1.06
Sp11	2011/12	21/10/2011	✓	✓	1.05
Au11	2011/12	28/03/2012	×	✓	0.82

Physical and chemical environment

Physico-chemical data is provided in Appendix 1.

Hydrology

Wheatfield Lake was permanent over the study period with a depth range of 0.7 to 2.5 m (mean = 1.59 ± 0.49 m). Water depths prior to November 1999 (when a gauge plate was installed) were estimated and may be overestimated; particularly at the greatest depths. However, the relatively high autumn depth measured at the gauge in 1999/00 confirms the high depths estimated earlier in that hydrological cycle.

Between 1999 and 2007, water depth was similar from year to year with maxima in spring and minima in autumn (Fig. 1) and generally above 1.2 m. In 2009 and 2011, minimum depths continued to occur in autumn, but spring depths were slightly lower than those of late-winter, probably as a result of water removal by the pipeline. Autumn depth did not show a statistically significant trend across the monitoring period. However, depths of 0.82 m in autumn 2010 and 2012 were lower than every other year except 1997. Similarly, spring depth in 2009 (1.58 m) and 2011 (1.05 m) was lower than in previous monitoring years (minimum depth 1.87 m). Water depth was < 1.06 m throughout 2011/12.

pH

Water pH varied in the range 6.7 to 9.1. There was a statistically significant trend of pH increasing across the monitoring period irrespective of season (Mann-Kendall Tau = 0.317, $p < 0.05$) and an increasing trend for pH in autumn (Mann-Kendall Tau = 0.714, $p < 0.05$), but not for other seasons. Water pH > 9 was not recorded until spring 2007 and was then recorded on 4 of the 8 subsequent sampling occasions. The lake had maximum pH (9.1) in spring and autumn 2007 and spring 2009. Water pH increased with electrical conductivity (rho= 0.55, df= 20, $p < 0.05$) and temperature (rho = 0.44, df = 19, $p < 0.05$) and was inversely related to depth (rho = -0.48, df = 19, $p < 0.05$), nitrate (rho = -0.59, df = 18, $p < 0.05$) and colour (rho = -0.75, df = 7, $p < 0.05$).

Salinity and ionic composition

Linear regression indicates a strong linear relationship ($r^2 = 0.80$, df= 6, $p < 0.01$) between total dissolved solids (TDS) and electrical conductivity; TDS (g/l) = 0.0006*ec (μS/cm)+0.0085, indicating the latter was an adequate measure of salinity within the wetland.

Ionic composition was consistent across the monitoring period with sodium and chloride ions dominating on all occasions. Cations followed a pattern of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ while anions followed a pattern of $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$, except in 2007 when carbonate and bicarbonate ions had reversed positions.

Salinity varied between 5050 and 24400 μS/cm and was negatively correlated with water depth and followed a similar (though inverse) seasonal pattern, with highest salinities in autumn and lowest salinities at highest water depth; usually in spring. This equated to a broad range of salinities (mean range 5591 ± 2702 μS/cm) within a year; from subsaline in late-winter and spring to saline in autumn. While seasonal salinities differed between years no significant trend was apparent. However, there was a significant trend (Mann-Kendal tau = 0.86, $p < 0.01$) for the minimum salinity within a year to increase across the monitoring period.

The maximum salinity of 24400 μS/cm was recorded in autumn 2010 and was associated with the lowest depths recorded. However, in autumn 2012, at a similar depth, salinity was lower at 14910 μS/cm. Data from the Bureau of Meteorology (2016) suggest above average rainfall for Oct-Dec 2011 which, in conjunction with the outflow of the gravity pipeline, may have reduced the salt load of the lake.

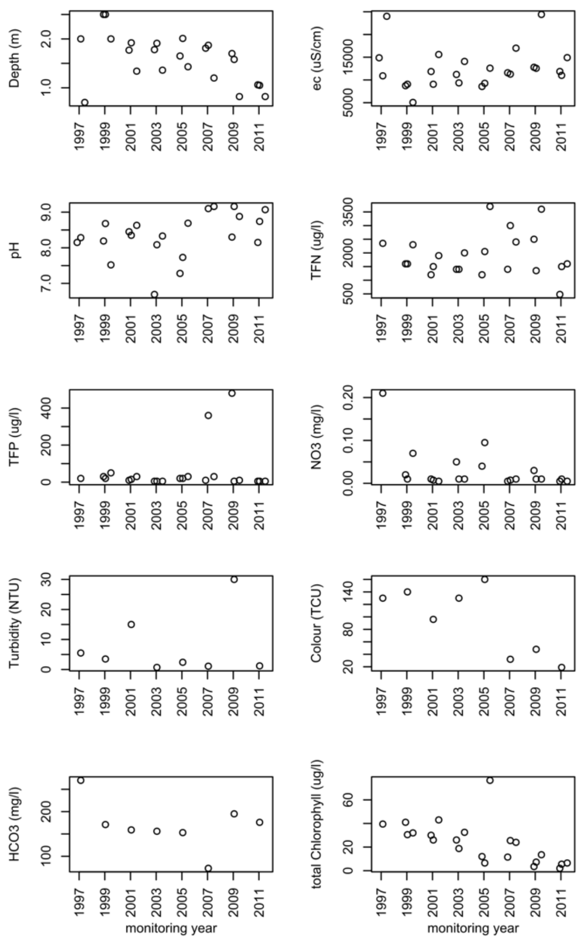


Figure 1. Water chemistry parameters at Wheatfield Lake for late-winter, spring and autumn sampling occasions between 1997 and 2012. ec is electrical conductivity, TFP total filtered phosphorus, TFN total filtered nitrogen, NO3 nitrate, HCO3 bicarbonate ion and total chlorophyll is the sum of the photosynthetic pigments chlorophyll a, b and c and phaeophytin. Tick marks are positioned at spring sampling.

Nutrients and chlorophyll

Total filtered nitrogen (TFN) concentration was relatively constant across the monitoring period with a mean value of 1910 ± 786 μg/l. Contrary to previous conclusions (Cale *et al.*, 2011), TFN appeared to be homogenously distributed across the lake; with little difference between the two sampling sites except in spring 2007. The highest recorded TFN concentration, 4600 μg/l, was recorded at site A in spring 2007 and coincided with a very high concentration, 700 μg/l, of total filtered phosphorus (TFP), whereas nutrient concentrations at site B were 1400 μg/l TFN and 20 μg/l TFP. In other years with paired site data there was no discrepancy between sites. Where nutrient data were only collected at site A the concentration of TFN was only high following seasonal evapoconcentration and the concentration of TFP was high (480 μg/l) only in late-winter 2009. Site A is frequently sheltered from the wind and it is likely that high nutrient concentrations at this site were rare and due to a point source such as carrion or a regular waterbird perch possibly in conjunction with reduced lake-mixing locally.

Nitrate concentration rarely exceeded 100 µg/l and was most often at the level of detection (10 µg/l), suggesting that it made up only a small part of the total concentration of available nitrogen in the system. The mean (of two sites) concentration of TFP ranged from 5 to 480 µg/l, with a mean across years of 53 ± 120 µg/l.

Chlorophyll concentration was variable between sites, but without consistent pattern. There was a significant declining trend for mean chlorophyll concentrations across the monitoring period (Mann-Kendall tau = -0.587, df = 20, $p < 0.01$) which was strongly dependent on a declining trend for winter and spring samples (Mann-Kendall tau = -1.0 and -0.7 respectively; df = 7, $p < 0.01$) since there was no such trend for autumn. This trend was not matched by a trend in total filtered nitrogen or phosphorus and chlorophyll concentration was not correlated with any other water chemistry variable; offering little to explain the cause of declining chlorophyll. However, a scenario in which increases in the annual minimum salinity, as observed toward the end of the monitoring period (see salinity section above), altered algal community composition and productivity, could generate the observed pattern.

Summary of physical and chemical conditions

Wheatfield Lake is strongly seasonal despite being permanent across the monitoring period. Water depth, salinity and pH varied seasonally and in conjunction with chlorophyll appear to have changed across the monitoring period. These changes are not strongly associated with the operation of the gravity pipeline, with evidence of trends particularly for minimum-salinity and pH apparent earlier. However, the annual variability of depth and pH has decreased since the pipeline was first opened.

Fauna

Aquatic invertebrate diversity

At least 137 taxa were collected from Wheatfield Lake. While most taxa are widely represented across wetlands of the south-west, seven species: the aquatic earthworm *Paranais litoralis*, hydrozoan *Cordylophora* sp., the amphipod *Melita kauerti*, snail *Ascorhis occidua,* copepods *Onychocamptus bengalensis* and *Gladioferens imparipes* and *Exosphaeroma* isopods have marine or estuarine affinities and are likely to be restricted to coastal wetlands. These seven species are part of a larger assemblage with restricted distributions and described as assemblage I (Pinder *et al.*, 2004). This assemblage is associated with wetlands that tend to have some flow, southerly latitude, moderate salinity and are in coastal locations. Including the seven species with marine affinities, 15 species of this assemblage were recorded at Wheatfield Lake and three of these (*O. bengalensis*, *G.imparipes* and *Cyprideis australiensis*) were present on all occasions. Between 7 – 12 species (15 -25 % of richness) were present each year making this assemblage important in describing the character of the Wheatfield Lake fauna.

A large number of species (57) were collected only once. These single occurrence species spanned a range of abundances, but few are likely to have had such low occurrence in samples because they are numerically rare. While some may represent species more commonly encountered elsewhere, the majority may represent species which occur more frequently as part of communities outside the normal sampling window; responding to seasonal changes in physical and biological conditions within

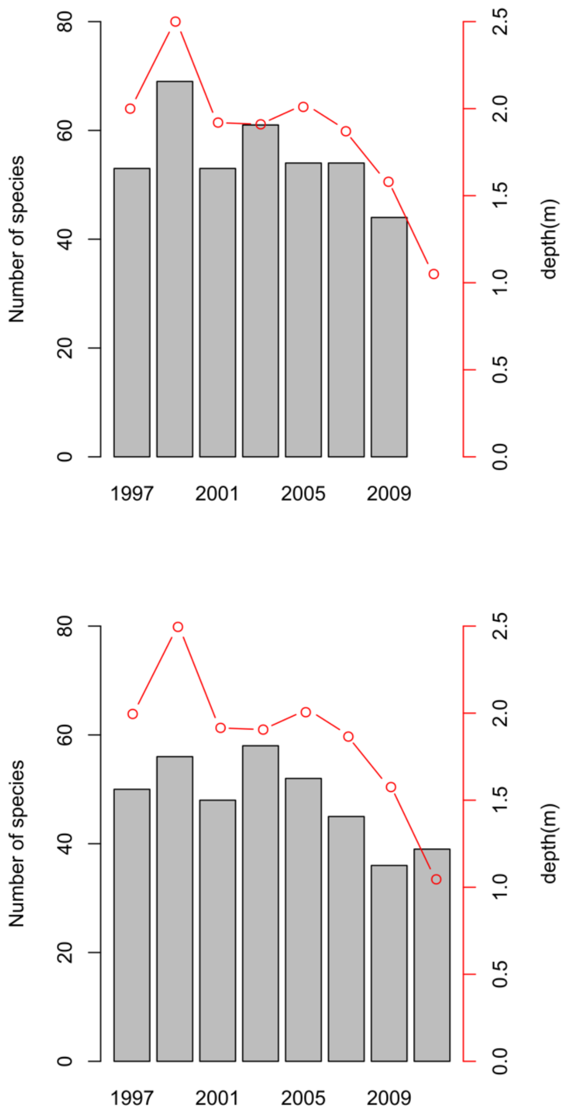
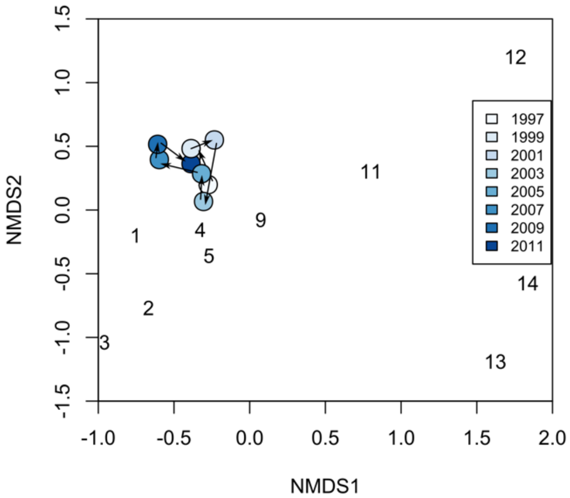


Figure 1. Invertebrate richness and depth in spring of each monitoring year at Wheatfield Lake. a) The full suite of invertebrate taxa and b) all invertebrate taxa except Rotifera and Protista. Open circles are depth.

the wetland. The presence of this group of species suggests the total richness utilising Wheatfield Lake is considerably higher than the recorded 137 species (e.g. Cale *et al.*, 2011 Fig. 11).

Annual species richness between 1997 and 2009 ranged from 44 to 69 species (Fig. 2a). This included species of rotifer and protists which were a significant but variable component of the fauna and constituted between 3.8 and 17.4 % of annual richness. However, these groups were not processed for the 2011 sampling date and to compare richness across the entire monitoring period these groups were dropped from measures of species richness. Without the rotifers and protists, annual richness ranged from 36 to 58 species (Fig. 2b) and followed a similar pattern to the richness of the entire suite of species. Further discussion of invertebrate community data excludes the rotifers and protists.

Species richness was positively correlated with depth (rho = 0.74, $p < 0.05$, df = 7) and colour (rho = 0.8, $p < 0.05$, df = 7) and negatively correlated with pH (rho = -0.79, $p < 0.05$, df = 7) and total dissolved solids (rho = -0.73, < 0.05, df = 7). Some of these variables showed trends across the monitoring period; however, no statistically significant trend in richness could be identified, probably because richness only dropped off in 2009 and 2011. Richness in 2007 was only slightly lower than in previous years, but then dropped more significantly in 2009 (after the pipeline first opened) and recovered slightly in 2011 (despite even lower water levels). The lower richness in 2007 to 2011 coincided with lower spring depths and higher salinity than in all previous years (albeit only slightly more saline than in spring 1997. More detail of the groups that suffered particular loss of species is provided in the next section.



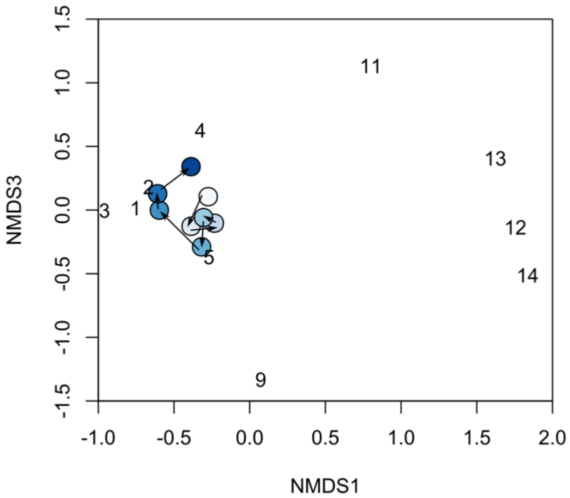


Figure 3. An ordination of spring invertebrate community composition (presence-absence) at Wheatfield Lake with 'marker' wetlands (see methods). For this ordination stress = 0.06. Marker wetland 1=fresh high richness, 2=subsaline sandy sump, 3=fresh, ephemeral wooded swamp, 4=naturally subsaline high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

Invertebrate community composition

An ordination (NMDS) of invertebrate species presence/absence at Lake Wheatfield indicates that community composition was relatively constant between 1997 and 2005 (Fig. 3). Composition was most similar to the “naturally subsaline” marker wetland (marker 4) and was more similar to fresher markers (1 and 5) than to the saline and hypersaline markers (11-14) (see Appendix 4). This suggests that there is potential for increases in salinity to result in significant change in the composition of the community.

Small changes in composition from 2007-2011 (seen especially on the axis 1 v 3 plot in Fig. 3) are largely the result of reductions in species richness. In 2009 aquatic beetles (coleoptera), which were generally represented by 2 to 5 species, were not present and the richness of dipterans other than chironomids, acarina (water mites) and odonata (dragonflies) was reduced to a single species each. Similarly, in 2011, while coleoptera recovered with 3 species present, acarina and cyclopoida (while rarely very diverse) were absent. These changes in composition do not result in a significant change relative to marker wetlands; reflecting a persistent similarity of the broader community present at Wheatfield Lake across the monitoring period but do present a series of annual communities distinguishable from earlier years.

The changes observed in 2007 (Fig. 3) follow the lowest recorded depth and a relatively high salinity (ca. 14000 μS/cm) in November 2006 (Lane *et al.*, 2017) and occur at a higher spring salinity (average 11275 μS/cm across two sites) than in previous years other than 1997. A similar salinity regime (before and at sampling) resulted in a similar community composition in 2009 soon after the pipeline was first opened. In 2011, with salinity still 11000 μS/cm, there was a further drift in composition, but back toward the composition of earlier years (e.g. 1997).

During the period 2007 to 2011, pH was also higher in Wheatfield Lake and was identified as the only statistically significant ($F= 1.33$, $df = 1$, $p < 0.05$) constraining variable (explaining 18% of compositional variance) in a redundancy analysis of invertebrate community composition (Fig.4). A total of 45.5% of the variance in community composition was explained by pH, electrical conductivity (log transformed) and colour. The redundancy analysis confirms the changes in invertebrate composition between the 1997 to 2005 and 2007 to 2011 periods and implicates pH as a driving variable. However, the observed changes in community composition are small and there is no group of species unique to communities occurring before or after this change; rather a varying mixture of species are absent each year between 2007 and 2011.

Water pH is important in controlling the equilibrium between different species of inorganic carbon and is in turn affected by changes in inorganic carbon that might be mediated by biological respiration and photosynthesis within the wetland (Talling, 2010). In productive wetlands diel changes in pH can be in the order of 1 pH unit (Maberly, 1996) and larger seasonal changes have been observed. Unpublished weekly data collected between June 2010 and June 2012 suggest the annual range in Wheatfield Lake is approximately 7.7 – 9.1 (DBCA Esperance unpublished data). The mean pH at which invertebrates were collected between 2007 and 2011 was 9.0 ± 0.22 while in the previous three year period (2001 to 2005) the mean was 8.0 ± 0.31 and in the three year period before that (1997 – 2001) it was 8.4 ± 0.21. So the pH gradient identified by the redundancy analysis may be small in a biological sense and the apparent effect of pH probably reflects changes in a suite of associated variables (e.g. salinity, alkalinity, chlorophyll, temperature etc; see Physical and chemical measures above) which may have affected biological respiration and photosynthesis and driven the changes in community composition. While both electrical conductivity (17.5% of variance) and colour (10% of variance) were not statistically significant constraining variables they reflected changes from one range prior to 2007 to a different range after

2007 and reinforce that changes in the broader lake chemistry may have driven changes in community composition.

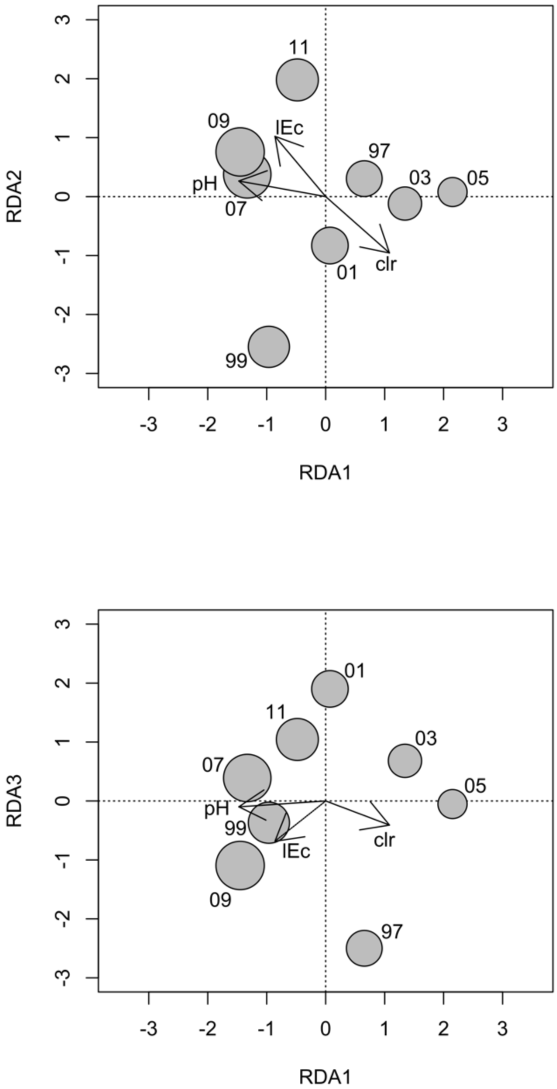


Fig 4 Redundancy Analysis for invertebrate community composition at Wheatfield Lake. pH was the only significant environmental parameter (RDA1) in a model comprising the constraints pH, log(ec+1) and colour. Point size for each sample is coded by pH.

Summary of Invertebrate fauna

The invertebrate fauna at Wheatfeld Lake was diverse and included species with marine affinities and distinctive requirements. This fauna contributes to the distinctive character of Wheatfield Lake while indicating a faunistic link to other high diversity subsaline wetlands. There was no statistically significant trend of species richness across the monitoring period, but richness was negatively correlated with depth and low water levels toward the end of monitoring were associated with lower richness. Reduced species richness, in years with lower water levels, resulted in variation in community composition that was not apparent earlier in the monitoring period. However, community composition in 2011, at the end of the study period, was approaching that of the first collections in 1997 and there is no evidence of persistent directional change.

Waterbird diversity

A total of 45 species were recorded from 24 surveys of Wheatfield Lake. This is three quarters of the richness (58 species) recorded for the entire central suite of the Lake Warden wetlands system (Wheatfield, Woody and Windabout Lakes) between Oct 2006 and February 2011 (Pinder *et al.*, 2012). Fourteen species had only a single occurrence across the monitoring period. Many of these were species of migratory shorebird suggesting that, rather than relying on the wetland, these species used it only opportunistically; however, two non-migratory shorebirds, the common greenshank and black-fronted dotterel, were frequently encountered, and likely to be resident.

Chestnut teal were observed during all surveys, with abundances ranging from 8 to 429 individuals. Published estimates (Wetlands International, 2006) indicate the size of the south-west population of chestnut teal is about 5000 birds, consequently Wheatfield Lake supported more than 1% of the population at some time during six of the eight monitored years (Appendix 3).The cause of lower abundance during 2003 and 2007 is not apparent from the physical data collected and may lie outside the wetland system. The Warden wetland system is also important for hooded plover but these were not recorded at Wheatfield Lake on any occasion and were not reported from the lake during surveys in the 1980s (unpublished data associated with Jaensch et al. 1988).

Nine species were recorded breeding: Australasian shoveler, grey teal, pink-eared duck, little black cormorant, little pied cormorant, yellow-billed spoonbill, darter, straw-necked ibis and white-faced heron. With the exception of broods of duck located on the lake or escaping to deeper water from the lake's margin all broods were associated with nesting platforms in flooded *Melaleuca cuticularis* trees. The observed distribution of breeding activity was sporadic across the monitoring period, but this is an artefact of the calendar-based sampling regime which may have missed the breeding season in some years (Cale *et al.*, 2011).

Species richness varied from 14 to 26 species per survey (Fig. 5), without a clear seasonal pattern or trend over time. Richness was correlated with salinity (rho = 0.41, df= 22, p= 0.05) such that richness was 14 – 21 species at salinities <10,000 µS/cm and 18 – 26 species in the salinity range 10,000 – 15,000 µS/cm. Richness levelled off (18 and 20 species) at salinities in excess of 15,000 µS/cm. These high salinities coincided with low water levels and enlarged areas of shallows and relatively high species richness was maintained because of an increased richness of shorebirds using these areas.

Total counts of waterbirds varied greatly between surveys (212 to 4542 birds) but was particularly high throughout 1997 (Cale *et al.*, 2011), especially in autumn when large numbers of grey teal, pink-eared duck and pacific black duck were present. Within a monitoring year, abundance was usually greatest (mean 1385 birds) in autumn (except during 1999/00) and generally lowest in spring (mean 535 birds) except in 1999, 2007 and 2011. A significant proportion of individuals present in autumn (50-80%, except in 1999 with 20%) were ducks, although Eurasian coot, hoary-headed grebe and little black cormorant were also occasionally abundant. The presence of large numbers of birds in autumn suggests congregation from across the region to make use of the permanent water present at Wheatfield Lake, when many other wetlands have dried. Reduced water-levels in autumn 2009/10 and 2011/12 did not greatly reduce abundance relative to autumn in other years nor alter the pattern of higher seasonal abundance in autumn. This is consistent with the idea that abundance increases due to factors (drying of other wetlands) beyond Wheatfield Lake.

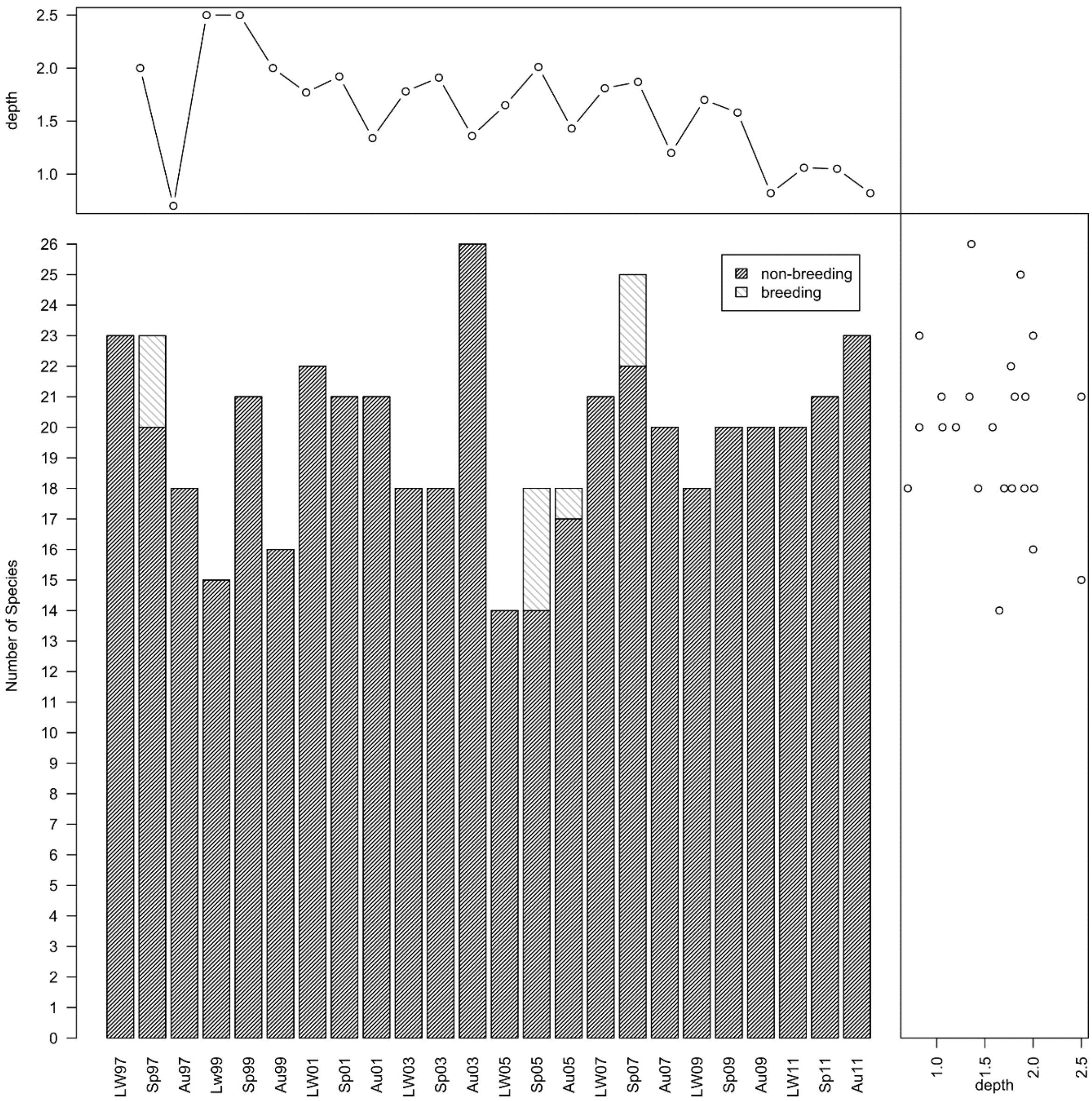


Figure 5 Waterbird species richness at Wheatfield Lake from individual surveys across the monitoring period. Seasonal surveys are labelled by year and the consecutive seasons LW =late-winter, Sp= spring, Au= autumn. Autumn survey dates are labelled with the same year code as the previous late-winter and spring surveys to denote that all three surveys were part of the same monitoring cycle.

Waterbird composition

An ordination of annual waterbird species composition shows a looping trajectory from year to year (Fig. 6) and does not suggest a directional change in community composition. Most species of waterbird were recorded at some time during every monitoring year. Consequently, there were only small differences of composition between whole years (Fig. 6) and species richness and single occurrence species were important components of inter-annual differences. The Wheatfield Lake community was distinct from, but most similar to, the Toolibin and Pinjareega 'marker' wetlands with which it shared similar richness. Because of the small differences between annual composition at Wheatfield Lake the scale of dissimilarity from other 'marker' wetlands (Altham, Pleasant View and Goorly) was exaggerated to the point where survey years could not be distinguished graphically. Consequently, these 'marker' wetlands were dropped from the analysis.

Historical community composition (Fig. 6) was reconstructed from 3 surveys of matching season (late-winter, spring and autumn) in each year from 1982 to 1985 (unpublished data associated with Jaensch *et al.*, 1988) Communities present in those years differ from those present since 1997. Firstly, there was much greater annual variation in community composition historically (Fig. 6). In part, this is explained by the conjunction of relatively lower richness in the 1980s and a high proportion (34%) of species which occurred in only 1 year. However, variability in wetland conditions may also have been important. Secondly, seventeen species were recorded exclusively during the current monitoring to 2011 and absent from historical surveys (i.e. all 33 surveys documented in unpublished data associated with Jaensch et al 1988). However, twelve of these were recorded in only one survey each and at low abundance; suggesting that their historical absence may be an artefact of differences in methodology, particularly lower sampling effort in the 1980s (see Cale et al. 2004). The remaining 5 species have regular occurrences and include three species; the yellow-billed spoonbill, Australian white ibis and straw-necked ibis which have probably benefited from changes in habitat between the two periods, particularly the increase in dead, inundated *Melaleuca* for nesting. Three shorebirds (sharp-tailed sandpiper, wood sandpiper and masked lapwing) only occurred during the 2011/12 surveys. All three of these species are reliant on exposed shoreline for foraging and their presence in 2011/12 (but not 1997/98 to 2009/10) is probably in response to lower water levels following the opening of the gravity pipeline, which resulted in 1) an increased occurrence of these species across the Lake Warden wetlands system generally (Pinder *et al.*, 2012) and 2) provided suitable habitat at Wheatfield Lake. Finally, four species were only recorded during the 1980s. The presence of clamorous reed warbler, Australian little grebe, marsh sandpiper and fairy tern are suggestive of shallower, fresher conditions during the 1980s, however only the fairy tern and Australian little grebe had as many as two occurrences suggesting they were not a common component of the fauna.

A constrained ordination (Redundancy Analysis) of waterbird abundance (Fig. 7) yielded the greatest insight into factors driving the composition of the waterbird community from survey to survey. This model based, on square-root transformed relative abundance, yields 3 significant constraining axes (RDA1 – 3) collectively explaining 41% of waterbird compositional variance ($F= 5.13, 3.16$ and 1.95, $df = 1$, $p< 0.01, 0.01$ and 0.05 respectively). Three variables (log electrical conductivity, square root total filtered nitrogen and log temperature), were significantly associated with composition ($F= 4.69, 2.30, 2.63$, $df = 1$, $p < 0.05$ respectively). Higher values of each were linked to autumn surveys which shared both high total abundance and a high relative abundance of ducks. As discussed above, this is likely linked with the use of Wheatfield Lake as a refuge when other wetlands dry over summer.

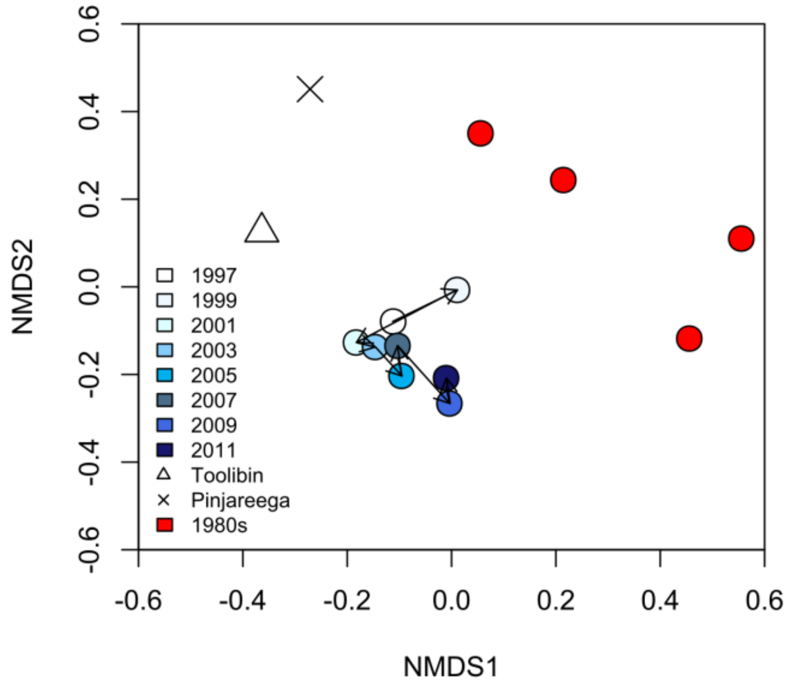


Figure 6. NMDS Ordination of annual waterbird species inventory compiled from late winter, spring and autumn surveys for each year. 1997 includes surveys from 1997/98, 2001 from 2001/02 etc. 'Marker' wetlands (see methods) reflect different wetland types as follows: Toolibin is sub-saline with wooded over storey; Pinjareega is a secondarily saline open basin. Historical data from matching seasonal surveys in 1982-1985 (unpublished data associated with Jaensch et al. 1988).

This characteristic of the waterbird community is most apparent when contrasted against years when it did not occur. For example, during the Au99 survey (March 2000) water depth was high and salinity and temperature were low for that season and reflected greater presence of water in the region. Under these conditions, Wheatfield Lake supported a fauna more typical of spring surveys, i.e. with lower total abundance (424 birds) and a low relative abundance of ducks (approximately 20% of birds); suggesting these species were dispersed as wetlands elsewhere still held water.

Autumn surveys also included a greater occurrence of species of the small shorebird guild (63% of records) which, while of low abundance, were able to take advantage of larger areas of exposed shoreline, particularly across the northern part of the wetland. When the lake was deeper, as during most late-winter and spring surveys, the waterbird community included more diving species (69% of records) but abundance of this guild was higher in autumn, principally due to the abundance of little black cormorant, hoary-headed grebe and Eurasian coot, which may have aggregated in autumn as ducks did.

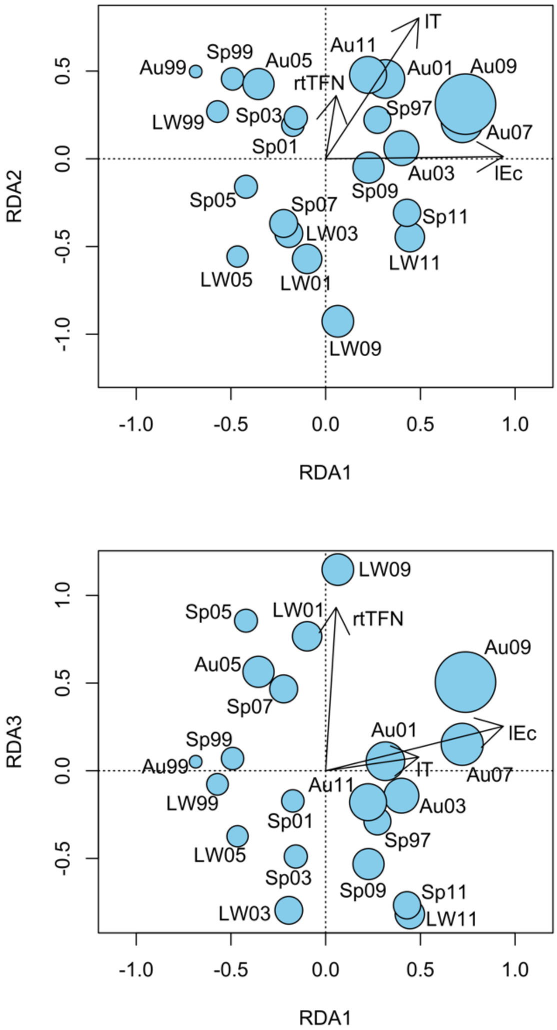


Figure 7 Constrained ordination of waterbird community composition (abundance) for individual surveys at Lake Wheatfield. Seasonal surveys are labelled by year and the consecutive seasons LW =late-winter, Sp= spring, Au= autumn. Autumn survey dates are labelled with the same year code as the previous late-winter and spring surveys to denote that all three surveys were part of the same monitoring cycle. Sample points are scaled by electrical conductivity and arrows indicate the direction and magnitude of significant environmental variables (rt = square root of total filtered nitrogen; lT = log_{10} temperature, lEc = log_{10} electrical conductivity).

Summary of waterbird fauna

The water bird fauna of Wheatfield Lake was diverse. Forty-five species were recorded from 24 surveys, each with a mean richness of 26 species. Breeding was recorded for 9 species and *Melaleuca* trees flooded by higher water levels were a particularly important breeding habitat.

Waterbird richness increased with salinity up to about 15,000 µS/cm but at higher salinities, typically in autumn at lowest water levels, richness levelled off and relatively high richness was maintained by increased richness of shorebirds. By contrast, total abundance (which ranged from 212 to 4524 individuals) was typically highest in autumn as a result of aggregation of waterbirds, principally ducks, from other drying wetlands in the region.

Annual species composition (i.e. aggregated across seasons) was similar from year to year and did not indicate a directional change in the community during the monitoring period. However, the contemporary community differed from historical surveys; 4 species present historically were not recorded while 17 species were exclusive to contemporary communities. Most of the species in question occurred rarely and at least in contemporary surveys reflect greater sampling effort, however 3 regularly occurring species may have benefited from the flooding of *Melaleuca* trees and the provision of protected breeding habitat.

References

Bureau of Meteorology (2016). 2011 daily rainfall for Esperance station 9789. *Climate Data Online [http://www.bom.gov.au/climate/data/; accessed 25/02/2020]*

Cale D.J. (2005). *Drummond Natural Diversity Recovery Catchment Aquatic Invertebrate Survey.* Department of Environment and Conservation, Perth.

Cale D.J. & Halse S.A. (2006). *Salinity Action Plan Wheatbelt Wetlands Monitoring Programme: Altham, Ardath, Bennetts, Blue Gum, Bryde, Campion, Coomalbidgup, Coomelberrup, Coyrecup, Dumbleyung, Eganu, Fraser, Logue, Paperbark, Parkeyerring, Pleasant View, Ronnerup, Towerrinning, Walyormouring, Wheatfield and Yaalup waterbirds. A series of 21 waterbirds pamphlets published by WA Department of Environment & Conservation, Perth.* Western Australian Department of Environment and Conservation.

Cale D.J. & Halse S.A. (2004). *Salinity Action Plan Wheatbelt Wetlands Monitoring Programme: Altham, Ardath, Bennetts, Blue Gum, Bryde, Campion, Coomalbidgup, Coomelberrup, Coyrecup, Eganu, Fraser, Logue, Noobijup, Paperbark, Parkeyerring, Pleasant View, Ronnerup, Towerrinning, Walyormouring, Wheatfield and Yaalup waterbirds. A series of 21 waterbirds pamphlets published by WA Department of Environment & Conservation, Perth.*

Cale D.J., Halse S.A. & Walker C.W. (2004). Wetlands monitoring in the Wheatbelt of south-west Western Australia: Descriptions, waterbird, aquatic invertebrate and groundwater data. *Conservation Science Western Australia* **5**, 20–135

Cale D.J., Lyons M., McCormick C., Pinder A. & Walker C. (2010). *State Salinity Strategy Wetland Monitoring Report: Lake Eganu 1998 to 2007*. Department of Environment and Conservation, Perth.

Cale D.J., McCormick C., Lyons M.N. & Pinder A.M. (2011). *State Salinity Strategy Wetland Biodiversity Monitoring Report: Lake Wheatfield 1997 to 2009*. Department of Environment and Conservation, Western Australia.

Department of Conservation and Land Management (2006). *Lake Warden Natural Diversity Recovery Catchment, Recovery Plan 2005-2030. Preliminary draft 2.*

Department of Environment and Conservation (2009). *Ecological Character Description of the Lake Warden System Ramsar Site: A Report by the Department of Environment and Conservation.* Prepared by G. Watkins, Department of Environment and Conservation, Perth, Western Australia.

Drew M., Lynn T. & Ferguson K. (2015). *Lake Warden Natural Diversity Recovery Catchment: Hydrology Program Synopsis 1997 - 2015.* Department of Parks and Wildlife, Kensington, Western Australia.

Environment Australia (2020). Directory of Important Wetlands. *Australian Wetlands Database [http://www.environment.gov.au/water/wetlands/australian-wetlands-database/directory-important-wetlands; accessed 25/02/2020]*

Government of Western Australia (2000). *Natural Resource Management in Western Australia: The Salinity Strategy*. Government of Western Australia, Perth.

Government of Western Australia (1996a). *Salinity: A Situation Statement for Western Australia*. Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection and Water and Rivers Commission, Perth.

Government of Western Australia (1996b). *Western Australian Salinity Action Plan*. Government of Western Australia, Perth.

Halse S.A., Cale D.J., Jasinska E.J. & Shiel R.J. (2002). Monitoring change in aquatic invertebrate biodiversity: sample size, faunal elements and analytical methods. *Aquatic Ecology* **36**, 1–16

Jaensch R.P., Vervest R.M. & Hewish M.J. (1988). *Waterbirds in nature reserves of south-western Australia 1981-85: reserve accounts*. Royal Australasian Ornithologists Union, Melbourne.

Lane J., Clarke A. & Winchcombe Y. (2017). *South west wetlands monitoring program report 1977 – 2016*. Department of Parks and Wildlife, Perth.

Lane J.A.K., Clarke A.G. & Winchcombe Y.C. (2015). *South West Wetlands Monitoring Program Report 1977 – 2014*. Western Australian Department of Parks and Wildlife, Perth.

Lyons M.N., Halse S.A., Gibson N., Cale D., Lane J.A.K., Walker C., *et al.* (2007). Monitoring wetlands in a salinizing landscape: case studies from the Wheatbelt region of Western Australia. *Hydrobiologia* **591**, 147–164

Maberly S.C. (1996). Diel, episodic and seasonal changes in pH and concentrations of inorganic carbon in a productive lake. *Freshwater Biology* **35**, 579–598. https://doi.org/10.1111/j.1365-2427.1996.tb01770.x

Ogden G. & Froend R.H. (1998). *Salinity Action Plan : wetland vegetation monitoring, 1997/1998*. Dept. of Conservation and Land Management, Joondalup, W.A.

Pinder A.M., Cale D.J., Halse S.A. & Quinlan K.D. (2012). *Waterbird monitoring of the Warden and Gore Wetlands in December 2011 to February 2012*. Department of Environment and Conservation, Western Australia.

Pinder A.M., Cale D.J., Leung A.E. & Halse S.A. (2010). *Waterbird and Invertebrate Monitoring of the Warden and Gore Wetlands in November 2009 and February 2010*. Department of Environment and Conservation, Western Australia.

Pinder A.M., Halse S.A., McRae J.M. & Shiel R.J. (2004). Aquatic Invertebrate assemblages of wetlands and rivers in the wheatbelt region of Western Australia. *Records of the Western Australian Museum* **Supplement**, 7–37

Robertson D. & Massenbauer T. (2005). Applying Hydrological Thresholds To Wetland Management For Waterbirds, Using Bathymetric Surveys And GIS. In: *Applying Hydrological Thresholds To Wetland Management For Waterbirds, Using Bathymetric Surveys And GIS*.

Talling J.F. (2010). pH, the CO_2 System and Freshwater Science. *Freshwater Reviews* **3**, 133–146. https://doi.org/10.1608/FRJ-3.2.156

Wetlands International (2006). *Waterbird Population Estimates*, 4th edn. (Eds S. Delany & D. Scott), Wetlands International, Wageningen, The Netherlands.

Appendix 1. Depth and water chemistry data

Physico-chemical variables measured at Wheatfield Lake. In spring, values of pH, conductivity, temperature, oxygen, nutrients and photosynthetic pigments are the mean of both site A and site B. For other dates measurements were made at site A only.

Date	5/08/1997	17/11/1997	17/11/1997	10/03/1998	26/08/1999	19/10/1999	19/10/1999	23/03/2000	21/08/2001	23/10/2001	23/10/2001	27/03/2002	13/08/2003	22/10/2003	22/10/2003	29/03/2004	9/08/2005	26/10/2005	26/10/2005	24/03/2006	8/08/2007	23/10/2007	23/10/2007	1/04/2008	26/08/2009	27/10/2009	27/10/2009	25/03/2010	31/08/2011	21/10/2011	21/10/2011	28/03/2012
season	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	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	B	A	A	A	B	A	A	A	B	A	A	A	B	A
Depth (m)	-999	2	2	0.7	2.5	2.5	2.5	2	1.77	1.92	1.92	1.34	1.78	1.91	1.91	1.36	1.65	2.01	2.01	1.43	1.81	1.87	1.87	1.2	1.7	1.58	1.58	0.82	1.06	1.05	1.05	0.82
Conductivity (μS/cm)	14870	10900	10900		8730	9010	9110	5050	11850	9080	9020	15590	11200	9340	9350	14070	8560	9260	9260	12580	11580	11250	11300	16990	12780	12610	12510	24400	11860	11210	10790	14910
pH	8.15	8.53	8.04		8.19	8.69	8.67	7.52	8.45	8.32	8.38	8.63	6.69	8.02	8.15	8.33	7.28	7.76	7.7	8.69		9.1	-9999	9.16	8.3	9.35	8.97	8.88	8.15	8.61	8.87	9.07
TFN (μg/L)		2200	2500		1600	1600	1600	2300	1200	1400	1600	1900	1400	1400	1400	2000	1200	2100	2000	3700	1400	4600	1400	2400	2500	1300	1400	3600	480	1700	1300	1600
TFP(μg/L)		20	20		30	20	20	50	10	20	10	30	5	5	5	5	20	30	10	30	10	700	20	30	480	5	5	10	5	5	5	5
Chlorophyll-a (μg/L)		46	0.5		32	22	24	13	21	13	19	21	16	11	0.5	27	4	2	6	0.5	4	8	14	9	2	0.5	11	5	0.5	3	3	5
Chlorophyll-b (μg/L)		6	0.5		2	5	5	3	0.5	0.5	0.5	2	2	2	2	0.5	1	0.5	1	19	0.5	2	2	2	0.5	0.5	0.5	5	0.5	0.5	0.5	0.5
Chlorophyll-c (μg/L)		4	0.5		2	2	2	5	0.5	1	2	2	2	4	2	4	1	0.5	1	5	2	2	3	4	0.5	0.5	0.5	3	0.5	0.5	0.5	0.5
Phaeophytin-a (μg/L)		21	0.5		5	0.5	0.5	11	8	8	8	18	6	6	10	1	6	1	1	52	5	14	6	9	0.5	0.5	0.5	0.5	0.5	1	2	0.5
Temperature (°C)		22	22		14.5	20.8	20.2	19.7	17.2	17	17	20	13.8	19.6	20.6	18	13.7	17.8	18.7	19.8		16.2	16.3	19.6	13.7	20.4	19.8	27.8	16.5	18.2	18.3	23.6
Dissolved Oxygen (%)	93.4	159	140		104	121.8	122.4	41	124	-9999	-9999	-9999	-9999	-9999	-9999	-9999	85.5	96.2	91.4	102		89.3	87.8	-9999								
NO3 (mg/L)		0.21	-9999		0.02	0.01	0.01	0.07	0.01	0.01	0.005	0.005	0.05	0.01	0.01	0.01	0.04	0.11	0.08		0.005	0.01	0.005	0.01	0.03	0.01	0.01	0.01	0.005	0.01	0.01	0.005
Turbidity (NTU)		5.5				3.5				15				0.7				2.4				1.1				30				1.2		
Colour (TCU)		130				140				96				130				160				32				48				19		
TDS (g/L)		6.7				5.5				5.4				5.3				6.4				6.6				7.9				6.6		
Alkalinity (mg/L)		220				140				130				128				125				150				160				145		
Hardness (mg/L)		1100				880				820				900				980				1100				1200				1100		
Si (mg/L)		11				11				12				6				8				1.4				0.3				1		
Na (mg/L)		2100				1700				1570				1720				1910				2180				2530				2250		
Ca (mg/L)		65				52				47				55				53.7				58.3				62.6				57		
Mg (mg/L)		220				181				170				186				206				231				253				225		
K (mg/L)		54				42				43				40.7				50.7				51.3				72				59.7		
Mn (mg/L)		0.01				0.01				0.01				0.0005				0.003				0.0005				0.0005						
Cl (mg/L)		3500				2900				2500				2800				3170				3420				4190				3700		
HCO3 (mg/L)		270				171				159				156				153				73				195				176		
CO3 (mg/L)		1				1				1				1				1				54				0.5				0.5		
SO4 (mg/L)		480				396				407				408				448				534				594				563		
Iron(mg/L)		-9999				-9999				0.08				0.045				0.17				-9999										
Tot Chlorophyll (μg/L)	0	77	2	0	41	29.5	31.5	32	30	22.5	29.5	43	26	23	14.5	32.5	12	4	9	76.5	11.5	26	25	24	3.5	2	12.5	13.5	2	5	6	6.5

Appendix 2. Aquatic invertebrate data

Wheatfield Lake aquatic invertebrate species matrix. 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	occurrences
Protista	Centropyxis sp.	BP020199							2		1
	Lesquereusia sp.	BP070199						2	3		2
	Protozoan sp	BP9999A3							4		1
Hydrazoa	Cordylophora sp.	IB020199	1	1	1		1	2	2		6
Turbellaria	Turbellaria	IF999999	1				1				2
Nematoda	Nematoda	II999999	2	3	2	1	2	4	4	3	8
Rotifera	Plumatella sp.	IO020199						1			1
	Macrotrachela sp. a (SAP)	JB0406A0	5								1
	Philodinidae	JB049999		3							1
	Bdelloidea	JB999999			2			4	2		3
	Hexarthra fennica	JF040105	5	5		2			2		4
	Testudinella patina	JF050201		3	1			1	2		4
	Brachionus leydigii	JP020215		2							1
	Brachionus plicatilis s.l.	JP020219		1	3	2		3	2		5
	Brachionus quadridentatus cluniorbicularis	JP020227			1			3	3		3
	Brachionus rotundiformis	JP020228	5	4							2
	Brachionus cf. nilsoni (SAP)	JP0202A6			1						1
	Keratella procurva	JP020308		2				2			2
	Keratella quadrata	JP020309		4							1
	Colurella adriatica	JP030101		3		1	1				3
	Colurella coluris	JP030102						3			1
	Lecane ludwigii	JP090136		2			1	1			3
	Synchaeta sp.	JP150399		2							1
	Trichocerca sp.	JP160399		2							1
Mollusca	Ascorhis occidua	KG021201			3	1	1	2	3	4	6
	Coxiella sp.	KG130299	4	3	1				3	1	5
Annelida	Hirudinea sp.	LH999999						1			1
(earthworms)	Naididae	LO049999		1	2	0	2				4
	Dero digitate	LO050201		1							1
	Pristina longiseta	LO050501				0					1
	Pristina leidyi	LO050507						1			1
	Paranais litoralis	LO050801		1	2	0	0	2	3	4	7
	Enchytraeidae	LO089999		1	1	1	0	1	3		6
Arachnida	Hydrachnidae	MM019999	1								1
(water mites)	Koenikea nr australica	MM1602A8		1			1				2
	Acercella falcipes	MM170101				1					1
	Pezidae	MM259999		1							1
	Oribatida sp.	MM9999A1	1	1	1	1	1	2	2		7
	Mesostigmata	MM9999A2	1	1	1	1	1	1			6
	Trombidioidea	MM9999A6		1		1	1				3
Cladocera	Alona sp.	OG030299				1					1
(water fleas)	Pleuroxus inermis	OG032502				1					1
	Daphnia carinata	OG040201	1			4	2		4	5	5
	Macrothrix breviseta	OG060201			1	4		2	3	2	5
Ostracoda	Cyprideis australiensis	OH040101	2	2	1	1	1	1	3	4	8
(seed	Ilyocypris australiensis	OH060101					1				1
shrimps)	Alboa worooa	OH080101	2		2	3	2			3	5
	Bennelongia frumenta	OH080388					1				1
	Candonocypris novaezelandiae	OH080403						3	3	3	3
	Cyprinotus cingalensis	OH080604								4	1
	Diacypris spinosa	OH080703	2	2	1		1		1	1	6
	Mytilocypris mytiloides	OH081204	2			2	1	1		4	5
	Reticypris clava	OH081501	1	2	1						3
	Ilyodromus sp.	OH081999							1		1
	Zonocypris sp BOS082	OH0828A1					2				1
	Sarscypridopsis aculeata	OH090101	1	2	2	1	1	3	3	5	8
	Leptocythere lacustris	OH100101	1	1	2	1		3	4	3	7

	TAXON	LowestIDNC	1997	1999	2001	2003	2005	2007	2009	2011	occurrences
	Kennethia cristata	OH110201	1	1	1			2			4
Copepoda	Gladioferens imparipes	OJ110401	4	4	4	4	2	4	3	5	8
	Halicyclops sp. 1 (SAP)	OJ3104A0	3	1	1	1	1		2		6
	Mesocyclops brooksi	OJ310703		1		1		4	1		4
	Pescecyclops sp. 442	OJ3120A0							1		1
	Mesochra baylyi	OJ610302	3								1
	Cletocamptus aff deitersi	OJ6104A0	1								1
	Onychocamptus bengalensis	OJ620101	2	3	3	1	2	3	4	4	8
	Schizopera clandestina	OJ630201				1					1
	Nitocra reducta	OJ640101		1	1	1	3	2			5
	Nitocra sp. 4 (SAP)	OJ6401A4		2					3		2
	Nitocra near sp. 4 (SAP)	OJ6401A5			1						1
Amphipoda	Austrochiltonia subtenuis	OP020102	4	3	3	4	2	3	3	4	8
	Melita kauerti	OP090402	1	1	2						3
Isopoda	Exosphaeroma sp.	OR130299	3	1	1		1	1	2		6
Decapoda	Palaemonetes australis	OT020201	2	1	1	2	1	1	1		7
Coleoptera	Haliplus sp.	QC060199								1	1
(beetles)	Allodessus bistrigatus	QC091101					1				1
	Paroster niger	QC091407		1							1
	Antiporus occidentalis	QC091615				1					1
	Sternopriscus multimaculatus	QC091805	1	1	1						3
	Necterosoma penicillatus	QC092001	1							1	2
	Lancetes lanceolatus	QC092401	1								1
	Berosus sp.	QC110499	2	1		1	1			2	5
	Enochrus sp.	QC111199						1			1
	Ochthebius sp.	QC130399			1			1			2
	Gymnocthebius sp. 1 (SAP)	QC1304A0	1								1
	Limnichidae	QC359999			1						1
Diptera	Tipulidae type A (SAP)	QD0199A0								1	1
(flies, midges,	Bezzia sp.	QD090499					1				1
mosquitoes)	Clinohelea sp.	QD090699					1				1
	Culicoides sp.	QD090899	1	1	1	1	2	1		4	7
	Monohelea sp. 3 (SAP)	QD0919A2		1	1						2
	Nilobezzia sp.	QD092099		1		1	1	2	1	2	6
	Tabanidae	QD239999			1	1	1				3
	Stratiomyidae	QD249999	2	2		1		1		2	5
	Empididae	QD359999		1							1
	Dolichopodidae	QD369999	2	1							2
	Sciomyzidae	QD459999				1					1
	Ephydridae sp. 2 (SAP)	QD7899A6	1					1			2
	Ephydridae sp. 3 (SAP)	QD7899A7	2			1					2
	Ephydridae sp. 6 (SAP)	QD7899B0			1		2				2
	Ephydridae sp. 7(SAP)	QD7899B1			1						1
	Muscidae sp. A (SAP)	QD8999A0				1					1
	Muscidae sp. D (SAP)	QD8999A3				1					1
	Procladius paludicola	QDAE0803	3	2	2	3		3	3	4	7
	Procladius villosimanus	QDAE0804	3			1	2				3
	Corynoneura sp. (V49) (SAP)	QDAF06A2			1	2	1				3
	Paralimnophyes pullulus)	QDAF1202		2	1	1	1	2			5
	Cladotanytarsus sp. A (SAP)	QDAH03A0		2							1
	Tanytarsus fuscithorax/semibarbitarsus	QDAH04D8	4	2	1	3	2	4	2	4	8
	Chironomus occidentalis	QDAI0408	4	2	2	2	2	3	3	3	8
	Chironomus aff. alternans	QDAI04A0	4			2	3			3	4
	Dicrotendipes conjunctus	QDAI0603	3	2	2	3	2	3	3	3	8
	Dicrotendipes sp. A (SAP)	QDAI06A0	3	2	2	1	2	2			6
	Kiefferulus intertinctus	QDAI0701		3		1		3	2		4
	Polypedilum nubifer	QDAI0804		1					3		2
	Polypedilum nr vespertinus	QDAI08A1			1						1
	Polypedilum nr. convexum	QDAI08A2	3								1
	Cryptochironomus griseidorsum	QDAI1901		2	1				2	1	4
	Cladopelma curtivalva	QDAI2201	2			3				3	3
Hemiptera	Agraptocorixa eurynome	QH650301				2					1
(waterbugs)	Micronecta robusta	QH650502	1	1	2	2	1	1	2	5	8
	Anisops thienemanni	QH670401				1					1
	Anisops hacker	QH670405		1							1
Lepidoptera	Lepidoptera (non-pyralid) nr. sp. 16 of JHH (SAP)	QL9999A0			1						1
Odonata	Austroagrion cyane	QO020501					1				1

	TAXON	LowestIDNC	1997	1999	2001	2003	2005	2007	2009	2011	occurrences
(dragonflies,	Ischnura heterosticta heterosticta	QO021002				1					1
damselflies)	Xanthagrion erythroneurum	QO021301				1	1				2
	Austrolestes analis	QO050101					1				1
	Austrolestes annulosus	QO050102	1	1	1	1		1		2	6
	Austrolestes aridus	QO050103		2		1		1			3
	Austrolestes io	QO050105					1	1	2	2	4
	Hemianax papuensis	QO121201				1		1			2
	Hemicordulia tau	QO300102	1	1		1					3
Trichoptera	Ecnomus pansus/turgidus	QT0804A0		1							1
(caddisflies)	Notalina spira	QT250504	1	3	1	1	2	1	2		7
	Oecetis sp.	QT250799	1	3				1		1	4
	Symphitoneuria wheeleri	QT250903		2	1		1			1	4
	Triplectides australis	QT251103	1					1			2

Appendix 3. Waterbird data

Abundance of waterbird species for each seasonal survey at Wheatfield Lake.

		1997			1999			2001			2003			2005			2007			2009			2011			Occurrence [1]
		Aug	Oct	Mar	Aug	Oct	Mar	Aug	Nov	Mar	Aug	Oct	Mar	Aug	Oct	Mar	Aug	Oct	Mar	Aug	Oct	Mar	Aug	Oct	Mar	
Chestnut Teal	*Anas castanea*	429	320	17	55	76	40	96	59	8	39	21	43	12	25	134	8	16	8	46	42	70	70	111	48	100.0
Eurasian Coot	*Fulica atra*	350	216	226	7	6	2	51	11	31	10	2	227	36	10	31	13	28	81	21	32	54	306	99	16	100.0
Little Pied Cormorant	*Phalacrocorax melanoleucos*	15	10	5	60	47	6	7	4	7	5	3	8	2	1	1	7	8	15	6	1	7	9		1	95.8
Pacific Black Duck	*Anas superciliosa*	78	92	250	55	57	18	71	12	144	5	6	356	10	25	561	32	14	196	18	33	17	47	34	280	100.0
White-faced Heron	*Ardea novaehollandiae*	2	5	5	3	15	4	4	2	4	8	6	9	1	3	25	1	8	6		2	4	2	5	4	95.8
Grey Teal	*Anas gracilis*	51	258	1450	4	82	10	8	20	242	27	31	285	1	2		21	26	269	56	127	144	155	356	254	95.8
Great Egret	*Ardea alba*	25	4	10	2	30		4	4	4		1	1	1	2	17	2	3	10	3	3		2	2	4	87.5
Little Black Cormorant	*Phalacrocorax sulcirostris*	24	79		115	350	272	14	27	129	62	62	84	139	48	268	12	69		5	29	2			113	83.3
Musk Duck	*Biziura lobata*	37	23	120	6	13	32	25	11		14	6	86	2	7	6	5	5		7	9	4	127	243	55	91.7
Yellow-billed Spoonbill	*Platalea flavipes*	13	2	30	5	9	24	18	3	57			37	9	20	50	5	10	32	36	6		5	3	1	87.5
Darter	*Anhinga melanogaster*	5			4		4	8	14	19	7	3	18	5	2	4	5	3	6	11	5	6	5	1		83.3
Hardhead	*Aythya australis*	120	16		12	1		1	2		137	8	96	281			2	15	1	15	44		108	63		70.8
Hoary-headed Grebe	*Poliocephalus poliocephalus*	14	47	301				6		126	70	31	106			3	8	7	39	2	16		100	24	46	70.8
Australian White Ibis	*Threskiornis molucca*			1	2	12	5	3		11			11			16	6	7	5	1	1	1	4	5	4	70.8
Blue-billed Duck	*Oxyura australis*	2	8		4	7	2	5	11		95	2					11	4								45.8
Pink-eared Duck	*Malacorhynchus membranaceus*	6	84	1670					2	62	2	3	181	2				2	50	7	5	329	1			62.5
Australian Pelican	*Pelecanus conspicillatus*							3	7	3		1	4		3	5	2	12	30	1		13			20	54.2
Great Cormorant	*Phalacrocorax carbo*	1	2		3			59	4	2	3		2	5				1							1	45.8
Great Crested Grebe	*Podiceps cristatus*	1	5			2			1			2	2		4	1		2	1					1	3	50.0
Australasian Shoveler	*Anas rhynchotis*	60	3	430			2	5		5	6			1					1			51	6	1	7	54.2
Australian Shelduck	*Tadorna tadornoides*	4	5			5			13	3			4		6	2		3			14		2	7	2	54.2
Common Sandpiper	*Tringa hypoleucos*		2	2		3	3		1	1		1			1						2	17		1	2	50.0
Freckled Duck	*Stictonetta naevosa*	3	1	3					2			2			1		1	1						12		37.5
Straw-necked Ibis	*Threskiornis spinicollis*			2		5		250					2		59	22	39	67		486						37.5
Nankeen Night Heron	*Nycticorax caledonicus*		1			2			2	19			37				1	1								29.2
Black Swan	*Cygnus atratus*	1					1				2		1				2	2			2			2		33.3

[1] % of surveys where water was present.

		1997			1999			2001			2003			2005			2007			2009			2011			Occurrence [1]
		Aug	Oct	Mar	Aug	Oct	Mar	Aug	Nov	Mar	Aug	Oct	Mar	Aug	Oct	Mar	Aug	Oct	Mar	Aug	Oct	Mar	Aug	Oct	Mar	
Common Greenshank	*Tringa nebularia*		1	15						15			20			1			3		1	4	3	1	3	45.8
Black-fronted Dotterel	*Charadrius melanops*	2		5									10			14			3			36	4		19	33.3
Swamp Harrier	*Circus approximans*						1	1			1		1				1			1	1		1			33.3
Silver Gull	*Larus novaehollandiae*					1		10										4		16		1		21	11	29.2
Australian Wood Duck	*Chenonetta jubata*	3																								4.2
Banded Lapwing	*Vanellus tricolor*					2																				4.2
Black-winged Stilt	*Himantopus himantopus*									3																4.2
Glossy Ibis	*Plegadis falcinellus*					1																				4.2
Pied Cormorant	*Phalacrocorax varius*										2															4.2
Red-kneed Dotterel	*Erythrogonys cinctus*												1													4.2
Red-necked Avocet	*Recurvirostra novaehollandiae*																		6			1				8.3
Spotless Crake	*Porzana tabuensis*																		2							4.2
Whiskered Tern	*Sterna hybrida*		62																							4.2
White-necked Heron	*Ardea pacifica*							1																		4.2
Masked Lapwing (southern)	*Vanellus miles*																							2	4	8.3
Red-necked Stint	*Calidris ruficollis*																					1				4.2
Sharp-tailed Sandpiper	*Calidris acuminata*																						1			4.2
White-bellied Sea-eagle	*Haliaeetus leucogaster*																					2				4.2
Wood Sandpiper	*Tringa glareola*																								1	4.2

Appendix 4. Invertebrate Marker Wetlands

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

Group	Name	Code	Richness	Salinity (ppt)	Group description
					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
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