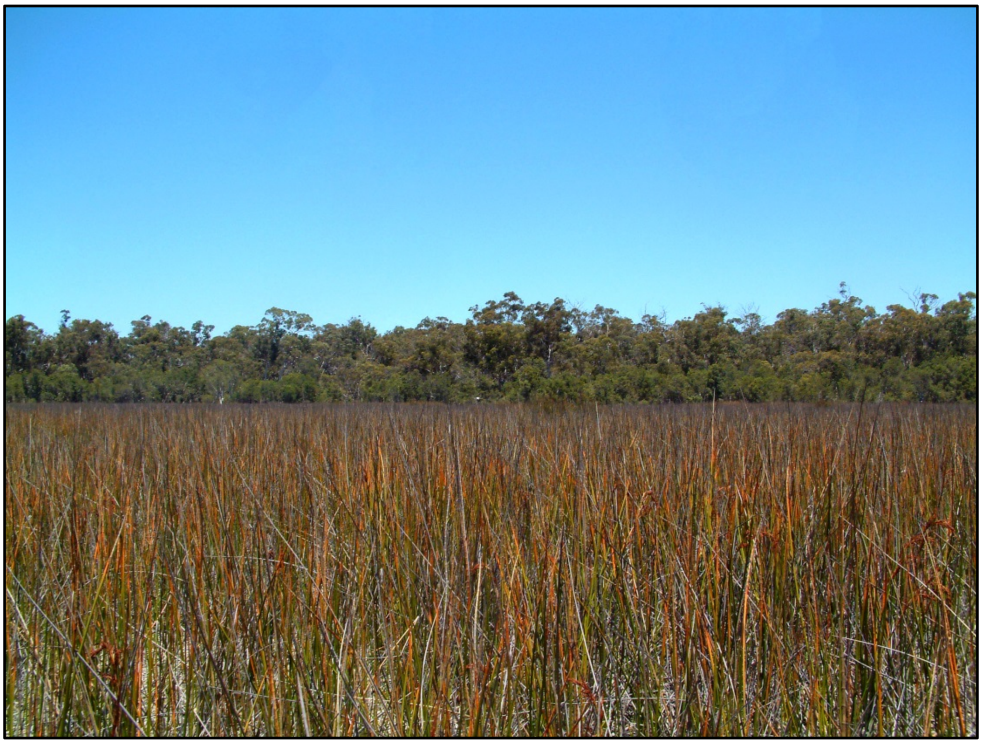
Wheatbelt Wetland Biodiversity Monitoring

Fauna Monitoring at Kulikup Swamp 1998-2013



Report WWBM-FR01

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Jan 2018

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The recommended reference for this publication is:

Cale, D. and Pinder, A. (2018) Wheatbelt Wetland *Biodiversity Monitoring: Fauna Monitoring at Kulikup Swamp 1998-2013*. Department of Biodiversity, Conservation and Attractions, Perth.

Cover photo: Kulikup Swamp photographed in December 2006 by Michael Lyons.

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. Rebbecca Dobbs and Melita Pennifold (DBCA) sorted and identified the 2000 and 2006 samples respectively.

Contents

1 Summary

This report presents the results of fauna monitoring at Kulikup Swamp located 30km east of Boyup Brook in the Western Australian Wheatbelt, undertaken between 1998 and 2013. This wetland was monitored as part of a biological monitoring program, established as a contribution to the Salinity Action Plan (Government of Western Australia, 1996b), to investigate the ongoing effects of salinisation on wetland biodiversity in the inland agricultural zone. The program included 28 wetlands selected based on their salinity (naturally saline, secondarily saline, fresh) and salinity trajectory, amongst other factors. Kulikup Swamp was included in the program as an example of a high conservation value freshwater wetland that was expected to maintain its condition in the medium term.

Kulikup Swamp is a fresh, seasonally inundated basin wetland, with salinity during the monitoring period ranging from 246 to 1003 µS/cm. In most years the lake has a depth < 0.2 m, but depths to 0.5 m occur roughly once per decade. The lake bed is dominated by stands of *Baumea* that are likely to be important not only as habitat but as the basis of food chains. The invertebrate fauna includes at least 175 species, with 59 to 79 species (excluding rotifer and protists) present each year. The composition of the invertebrate community was constant relative to other wetland types, suggesting no persistent change in community composition over the monitoring period. Variability in composition was not significantly related to salinity or to other measured environmental parameters. The strong presence of an assemblage of broadly distributed species with a preference for fresh to sub-saline conditions (assemblage F sensu Pinder *et al.*, 2004) aligned the Kulikup invertebrate community with other high richness freshwater wetlands and this assemblage may be a useful indicator of the wetland's health. Lower richness in 2006 and 2008 was associated with a small increase in salinity and other changes in water chemistry following a decadal filling event in 2005. However, the importance to the invertebrate community of small changes in salinity, relative to hydrological disturbances from the decadal filling event itself, are not clear. The invertebrate fauna includes a range of endemic species that appear to be restricted to such freshwater seasonal swamps in south-western Australia. In contrast to the invertebrate community, waterbird diversity was low (3 species in total), probably because the wetland has a short hydroperiod and cannot support resident populations and a limited number of waterbirds use these types of densely vegetated wetlands.

Over the monitoring period there has been no directional change in the hydrology or water chemistry and composition of the fauna has been relatively stable. However, groundwater monitoring suggests that groundwater of elevated salinity is rising and may soon be expressed at the wetland. This is likely to result in changes to the flora and fauna and continued monitoring of this wetland is therefore warranted.

2 Background to the Wheatbelt wetland biodiversity monitoring project

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

The department’s response to the latter task was two-fold. Firstly, re-expansion of a long-term monitoring program (later known as the South West Wetlands Monitoring Program or SWWMP. This program monitored depth, salinity and pH at wetlands across the south-west and was established in the late 1970s to provide data on waterbird habitats (Lane *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 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 *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).

Kulikup Swamp was included in the monitoring program as a representative of freshwater wetlands in good condition expected to remain unchanged in the medium term and which had a history of data collection (Lane *et al.*, 2017). It was given the site code SPM011.

3 Wetland description

Kulikup Swamp is a reed dominated basin with a flat clay bed. The major inflows to the lake are probably direct rainfall and runoff from local slopes, but there has been no analysis of surface flows. The wetland is located adjacent to the townsite of Kulikup 30 km east of Boyup Brook (33° 49' S 116° 40' E) and has also been referred to as Boyup Brook 18239 (Halse *et al.*, 1993; Lane *et al.*, 2017) and with the alternate spelling, Kulicup (Ogden *et al.*, 1998; Cale *et al.*, 2004b). The wetland occupies an area of 24.5 ha (Halse *et al.*, 1993), within the Kulikup Nature Reserve (Res. No. 18239) and is buffered from adjacent farmlands by at least 150 m of intact vegetation on its north, west and south sides. There has, however, been some development on the east side of the lake where largely abandoned sports facilities resulted in some vegetation clearing in the past and there is an old railway easement along the southern side. Ogden & Froend (1998) note that the edge of the wetland basin was used as a horse racing course in the 1940s/50s.

The vegetation has previously been described (Halse *et al.*, 1993; Ogden *et al.*, 1998) and consists of a zone of *Baumea articulata* which dominates the lake bed and gives way to a zone of *Melaleuca cuticularis* trees and shrubs over *Baumea juncea and Baumea* sp. This latter zone coincides with the lakes high water mark (Halse *et al.*, 1993) and above high water *M. cuticularis* becomes less common grading to absent, leaving a narrow sedgeland zone of *Baumea* spp. Outside this zone of sedgeland is a narrow zone of eucalypt woodland over sedge which may indicate a previous flood line (Halse *et al.*, 1993). Upper slopes surrounding the wetland support *Eucalyptus wandoo* and *Eucalyptus decipiens* woodland (Ogden *et al.*, 1998).

Lake depth has been monitored in September and November since 1980 (Lane *et al.*, 2017) and while the lake is frequently dry in these months it has generally had depth between 0.1 and 0.3 m and exceptionally (in 3 years) more than 0.5 m. Salinity data collected in conjunction with depth indicate that since monitoring began only two years had salinity in excess of 1 ppt (maximum ~1.8 ppt). The groundwater table was believed to be about 9 m below local ground level and of "moderate salinity (450 mS/m)" (George *et al.*, 1993). However, groundwater monitoring[1] indicates, firstly, that the regional groundwater table has risen to within 4m of ground level and secondly, the presence of shallower lenses of water above the regional water table. These shallower lenses typically rose and fell on an annual cycle but have shown a trend of decreasing fall in summer because of the higher regional water table. The lenses are of similar salinity to the regional groundwater and are likely to express at the surface more frequently and for longer periods in the near future, changing the hydrology and water chemistry of the wetland.

4 Sampling Program

For detailed sampling methods, including data analysis, refer to Cale *et al.* (2004b) and the separate program summary document to be published as part of this series. Kulikup Swamp was visited on 24 occasions between 1998 and 2013; in late winter (LW), spring (Sp) and early Autumn (Au), every second year (Table 1). However, the wetland only held water on 11 of these visits. The wetland was dry on all visits after October 2008 although water was sometimes present between visits (see Lane

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[1] Department of Biodiversity, Conservation and Attractions unpublished data. Interpreted by Colin Walker (Geo & Hydro).

et al., 2017) . When the wetland was dry, a complete survey of waterbirds was rarely conducted; rather birds were ‘listened for’ and binoculars were used from a few locations to confirm that no species were present. The location of spring sampling sites varied with year dependent on where suitable areas of standing water could be found. Site A was located between the southern shoreline and the depth gauge (in from the eastern shore) and was dominated by extensive stands of *Baumea articulata*. Site B was variously located along the south western and western shore where a series of connected pools included clumps of *B. articulata* and a patchy overstorey of *Melaleuca cuticularis*.

Table 1. Site visits, collected datasets and depth for Kulicup Swamp, 1998 – 2013.

Sample	Monitoring Year	Date	Invertebrates sampled	Waterbirds surveyed	Depth (m)
LW98	1998/99	26/08/1998	×	✓	0.09
Sp98	1998/99	6/11/1998	✓	✓	0.1
Au98	1998/99	20/04/1999	×	✓	0
LW00	2000/01	1/09/2000	×	✓	0.22
Sp00	2000/01	11/10/2000	✓	✓	0.2
Au00	2000/01	16/02/2001	×	✓	0
LW02	2002/03	28/08/2002	×	✓	0.01
Sp02	2002/03	23/10/2002	✓	✓	0.08
Au02	2002/03	26/03/2003	×	×	0
LW04	2004/05	30/08/2004	×	✓	0.01
Sp04	2004/05	3/11/2004	×	×	0
Au04	2004/05	23/03/2005	×	×	0
LW06	2006/07	14/09/2006	×	✓	0.16
Sp06	2006/07	18/10/2006	✓	✓	0.1
Au06	2006/07	22/03/2007	×	×	0
LW08	2008/09	27/08/2008	×	✓	0.09
Sp08	2008/09	14/10/2008	✓	✓	0.05
Au08	2008/09	25/03/2009	×	×	0
LW10	2010/11	26/08/2010	×	×	0
Sp10	2010/11	24/10/2010	×	×	0
Au10	2010/11	30/03/2011	×	×	0
LW12	2012/13	9/08/2012	×	×	0
Sp12	2012/13	8/11/2012	×	×	0
Au12	2012/13	21/03/2013	×	×	0

5 Physical and chemical environment

Physico-chemical data is provided in Appendix 1.

5.1 Hydrology

Kulikup Swamp was shallow or dry on all visits (Table 1). A maximum depth of 0.22 m was recorded in spring 2000, but mean depth for the 11 occasions when water was present, was 0.10 ± 0.06 m. The lake filled seasonally each monitoring year between 1998 and 2008. Depth was highest during spring in 1998 and 2002 and during late-winter in the remaining years. The lake was dry in the autumn of all monitoring years. In 2010 and 2012 the lake did not contain water in any sampled season (LW, Sp or Au) and yet in 2012, September depth (between late-winter and spring visits) was approximately 0.08m (Lane *et al.*, 2017), indicating that small amounts of inflow may dry within a few weeks.

Depths recorded for this project were similar to those recorded by Lane et al. (2017) during years between monitoring (i.e. odd numbered years from 1997 to 2013); when peak depths were between 0.1 – 0.25 m except in 2001 and 2007 when the wetland was dry and in 2005. In 2005, depth was > 0.5 m; a depth otherwise recorded in only 1983 and 1996, i.e. once per decade (Lane *et al.*, 2017). The apparent drying trend (Figure 1) is an artefact of the biennial sampling regime which sampled both of the two dry years (2010 and 2012) over the eight year period between 2008 and 2014 (Lane *et al.*, 2017).

The two sampling sites were disconnected pools during sampling in 1998, 2002, 2004 and 2008. In 2000 the sampling sites were connected in late-winter and spring by flooding of most of the lake bed. In 2006 sites were connected during late-winter but were disconnected when invertebrates were sampled in spring. In 2004 both sites were dry in spring and no invertebrates could be collected.

5.2 pH

Kulicup had a pH range 7.30 to 8.19 and there were small differences in pH (and other variables; see below) between sites (Figure 1). These differences were trivial (0.03 – 0.06 pH units) when the sites were or had been connected (2006 and 2002), but more substantial (0.34 - 0.61 pH units) when the sites were disconnected.

5.3 Salinity and ionic composition

The wetland was fresh on all sampling occasions, with salinities (as electrical conductivity) ranging between 246 and 1003 µS/cm (mean = 658.1 ± 245.8 µS/cm) (Figure 1). There was a significant regression of total dissolved solids (TDS) on electrical conductivity ($r^2_{adj} = 0.83$, df = 3, p = 0.02) and TDS (g/L) = 0.28 + 3.2 x 10-4 * ec (µS/cm), however the data contained considerable variance at the lowest values of TDS and conductivity. Ionic composition was consistent; with cation dominance following a Na>Mg>Ca>K hierarchy and bicarbonate ($HCO3^-$) was the dominant anion.

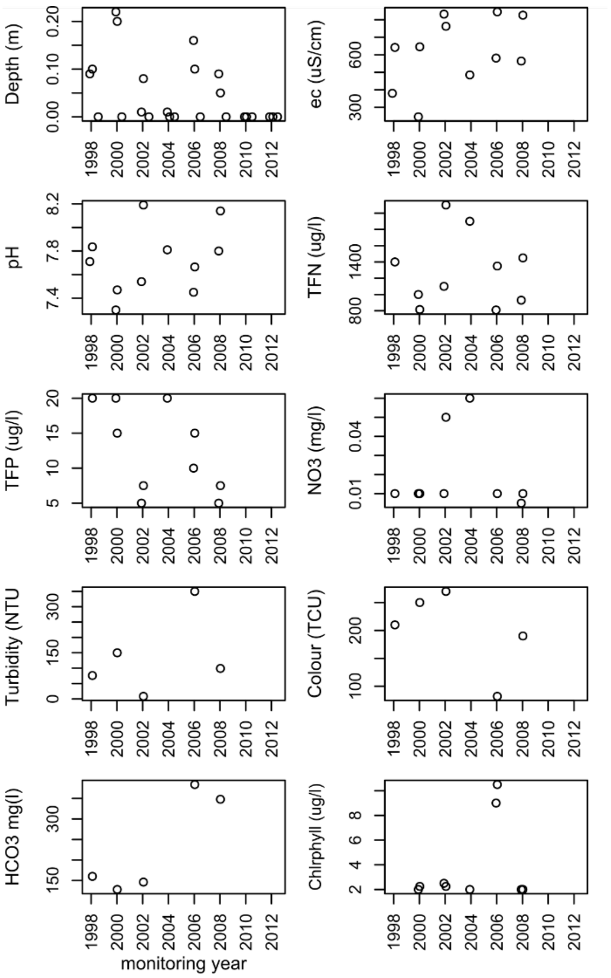

Figure 1. Water chemistry parameters at Kulikup Swamp for late-winter, spring and autumn sampling occasions between 1998 and 2013. ec is electrical conductivity, TFP total filtered phosphorus, TFN total filtered nitrogen, NO3 nitrate, HCO3 bicarbonate ion and total chlorophyll is the sum of the photosynthetic pigments chlorophyll a, b and c and phaeophytin. Tick marks are positioned at spring sampling.

There was no significant trend in salinity across the monitoring period for any season. However, in 2006 and 2008, following filling of the wetland to a depth >0.5 m in 2005, maximum salinity in the wetland (along with concentrations of HCO3-, alkalinity and hardness) was greater than in previous years. The highest salinity recorded was 1003 µS/cm at site A in spring 2008. A slight increase in salinity was also recorded in November 2006 and 2008 by Lane et al. (2017), but was not apparent in 2009 and subsequent years, repeating a pattern observed by these authors in 1993. During the 1980s salinity appears to have been more variable (Lane et al., 2017). It seems likely that large inflows increase the salt load of the wetland and subsequent evapo-concentration causes higher than average salinities. Given that this effect is relatively short term, salt load probably trends back toward the average through interaction of lake and groundwater.

While the wetland remained fresh across all samples, differences between sites suggested a heterogeneous spatial distribution of salinity. Spring salinity at site B tended to be greater than at site A between 1998 and 2002 (mean difference of 463 ±153 µS/cm), but less than site A in 2006 and 2008 (mean difference -294 ±84 µS/cm) when site A was located further in from the wetlands margin.

The difference between sites was apparent even in 2000 when sites were connected; suggesting the wetland was poorly mixed and sites may have been filled from different sources of inflow (e.g. adjacent slopes).

5.4 Nutrients and chlorophyll

Total filtered nitrogen (TFN) ranged from 680 to 2700 µg/L (mean 1331.3 µg/L) and was negatively correlated with lake depth (rho =-0.62, df = 15, p = 0.01) (Figure 1). Such a pattern suggests a dilution effect (as the wetland fills) of dissolved nitrogen, however bioassimilation of nutrients at higher water levels cannot be discounted. Total filtered phosphorus (TFP) was generally low; mean concentration was 12.6 ± 6.5 µg/L and the maximum was 20 µg/L.

The concentration of chlorophyll was low on most occasions with a mean of 4.1 ± 3.3 µg/L and a maximum of 10.5 µg/L. Highest concentrations were observed in spring 1998 and late-winter and spring 2006 when water levels were slightly higher than the mean, but not in 2000 at the maximum observed depths. The concentration of chlorophyll did not differ between sampling sites and was not correlated with nutrient concentrations (TFN and TFP).

Low concentrations of chlorophyll in the water column suggest that primary production was occurring principally within the extensive reed beds (e.g. Ryder, 2000) or amongst attached algae such as diatoms. Given the short hydroperiod observed in all monitoring years it is likely the wetland food chain was largely dependent on detritus generated by the reed beds during the intervening dry period. High water colour (> 200 TCU) was recorded in all years except 2006 and would be consistent with relatively high concentrations of organic carbon in solution (Wetzel *et al.*, 1991), with decomposition of senescent reeds a likely source. Humic substances in water can inhibit planktonic algal production (Jackson *et al.*, 1980) and may explain the low concentrations of chlorophyll in most years. The lack of significant colour in 2006 following the high depths recorded in 2005 coincides with increased concentrations of chlorophyll and suggests a removal of humic substances and an increase in primary production within the water column.

5.5 Summary of physical and chemical conditions

Kulikup Swamp was fresh, usually shallow and often comprised disconnected areas of standing water. Nutrient levels were low and colour high, and these features may limit primary production in the water column in most years. The increased extent of filling in 2005 preceded changes in chemistry in 2006, including decreased water colour, increased chlorophyll, turbidity and HCO_3^- (the latter persisting into 2008).

6 Fauna

6.1 Aquatic invertebrate diversity

One hundred and seventy five invertebrate taxa were collected from Kulikup Swamp (Appendix 2). Rotifera, Cladocera, Coleoptera and Diptera were particularly species rich groups. The fauna included a species of rotifer (designated *Plationus* sp. nov. ‘Goonaping‘) currently believed to be undescribed (R. Shiel, University of Adelaide, pers. comm.) and otherwise known only from Goonaping Swamp (30km WSW of York) . A few other species are of note. While the calanoid copepod *Boeckella bispinosa* is not endemic to Western Australia (it also occurs, rarely, in Tasmania) it is listed as vulnerable (Reid, 2017) and has been recorded from just a few other clay-based and/or vegetated swamps in south-western Australia (e.g. Twin Swamps and the Greater Brixton Street wetlands). A species of orthocladiine chironomid (non-biting midges) (orthoclad 'sp. J') has also been rarely collected and mostly in shallow vegetated swamps in higher rainfall parts of the south-west. The ostracod *Paralimnocythere* 'sp. 262' is known only from Kulikup, four swamps in the Muir-Byenup Ramsar wetland suite, Ngopitchup Swamp (30km WNW of Tambellup) and Goonapping Swamp. While not an Australian endemic, the rotifer *Asplanchnopus hyalinus* Harring, 1913 has rarely been recorded from Western Australia (records from Kulikup, Noobijup Swamp and Lake Pleasant View). Such vegetated swamps, which are not common in south-western Australia, are critically important for these and a number of other rare and restricted invertebrate species. The remaining species recorded at Kulikup Swamp have been collected more-widely in the south-west.

A complete suite of invertebrate species were identified between 1998 and 2006 and total species richness of this suite ranged from 67 – 104 with a mean of 91 ± 17 (Figure 2). To reduce time and costs, rotifers and protozoans were not identified after 2006. Richness from 1998 to 2008 calculated without these groups ranged from 59 – 79 with mean of 71 ± 11 (Figure 2). When identified, rotifers and protists collectively comprised 11 – 26 % (mean 20 ± 0.06 %) of the total fauna.

Twenty seven species (55 %) of rotifers and protists were recorded only once in the four years these groups were collected. Amongst the remainder of the fauna, 43 species (25%) were collected in only one year. By contrast, a small proportion of species were collected on all occasions; i.e., 2 species (4%) of rotifers (*Keratella procurva* and *Trichotria tetracta similis*) and 23 species (13.5%) from the remaining invertebrate groups.

There was no significant correlation between richness 'with' rotifers and protists (S) and richness 'without' rotifers and protists (R) ($R_{Adj}^2 = 0.72$, df = 2, p = 0.09) and, with the limited data available, total richness (S) would be poorly predicted by R. With this limitation noted, subsequent discussion of the invertebrate community is based on the data with rotifers and protists excluded so that patterns across the entire monitoring period can be considered.

There was no statistically significant trend for species richness across the period of monitoring but richness in the later two surveys (2006 and 2008) was lower than the earlier three surveys. Species richness remained constant between 1998 and 2002 with lowest richness being 96% of maximum richness. Species richness was reduced to 76% of maximum richness in 2006 and 86% in 2008. Species richness was negatively correlated with total dissolved solids (TDS) (rho=-0.97, df=3, p<0.01) and positively correlated with colour (rho=0.90, df=3, p <0.05). There was apparently no influence of water depth or connectivity of sub-sites, with similar richness occurring in 1998 and 2002 during which time depth, season of peak depth, relative depth preceding sampling and connectivity of sites differed.

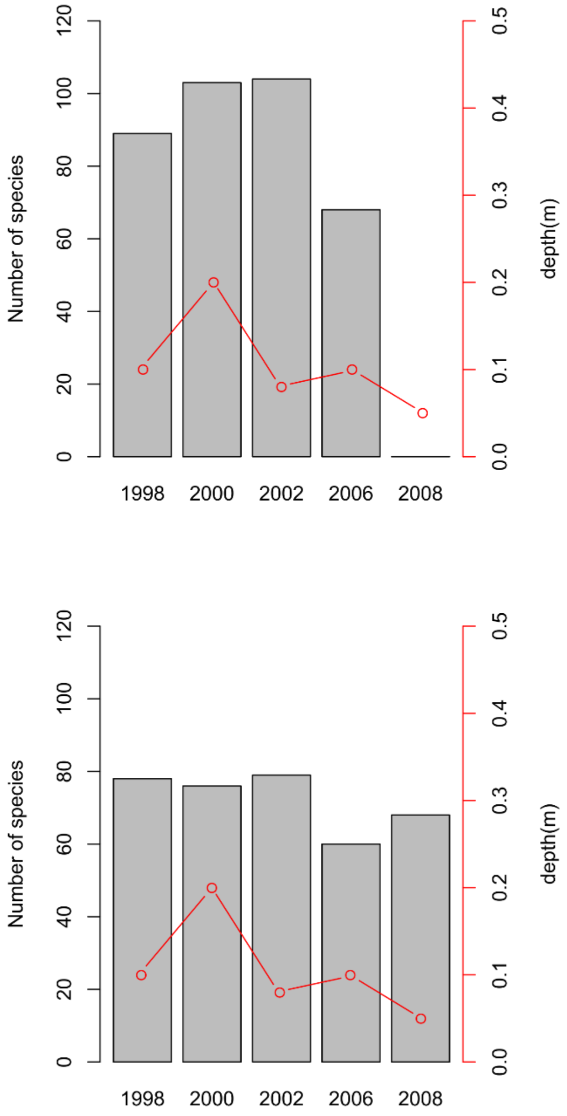

Figure 2. Invertebrate richness and depth in spring of each monitoring year at Kulikup Swamp. a) The full suite of invertebrate taxa and b) all invertebrate taxa except Rotifera and Protista. Open circles are depth.

In Western Australian Wheatbelt wetlands it has been suggested that the richness of aquatic invertebrates in freshwaters is highly variable and not influenced by salinities below 4.1 g/l (approx. 2400 µS/cm), or 2.6 g/l (approx. 1600 µS/cm) if halophilic species are excluded (Pinder et al., 2005). The presumption follows that a suite of other factors interacting dynamicaly are more likely to determine species richness in freshwater wetlands. Despite the coincidence of the highest levels of TDS and depressed richness in 2006 and 2008 which seems to have driven the correlation between richness and salinity, salinity remained in the “fresh” range (and an order of magnitude lower than the 4.1 g/l threshold) and probably did not strongly affect invertebrate richness. Moreover, salinity in these years was not substantially higher than in 2002. Kulikup experienced a decadal flooding event in 2005 after being dry in spring 2004. These hydrological disturbances might have affected invertebrate richness over and above any small increase in salinity. Hydrological disturbances that altered lake depth and hydroperiod and/or increased salinity would have a greater effect on resident species such as those of assemblage A than on the highly dispersive species (e.g. insects) of assemblage E; a situation observed in 2006. One of the largest changes in richness occurred within the Cladocera (water fleas). These were a significant component of species richness in the first year of sampling (Cale et al., 2004b), but richness of this group declined from 17 species in 1998 to 13 in 2000 and 2002 and again to 7 species in 2006 and 10 species in 2008 (Mann-Kendall tau = -0.894, p = 0.068). The reason for this decline in cladoceran richness is not known and not correlated with measured environmental variables.The species present have been collected elsewhere at similar or higher salinities than observed at Kulikup Swamp and are unlikely to be adversely affected by the observed salinity range.

6.2 Invertebrate community composition

Invertebrate communities included species from 7 of the assemblages described by Pinder et al. (2004). Assemblages F, E and A (with mean richness 20, 13.2, 10.6 respectively) had greatest richness on all occassions with the remainder represented by 3 or fewer species. Assemblages associated with saline or sub-saline systems (G,H and I) were not present on any occasion. The richness of assemblage F oscillated between 19 and 20 species except in 1998 when 24 species from this assemblage were present.

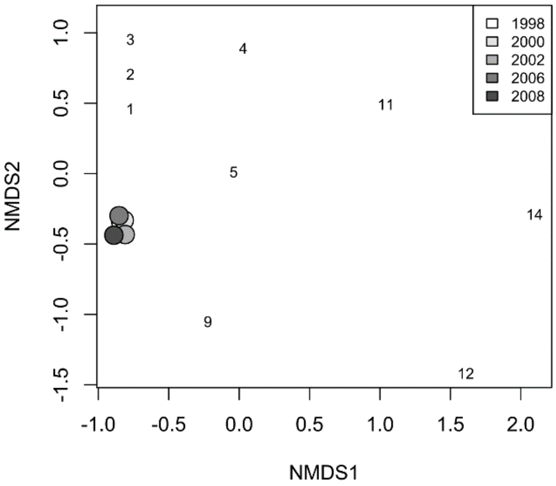

Figure 3. An ordination of spring invertebrate community composition (presence-absence) at Kulikup Swamp and ‘marker’ wetlands (see separate methods document). Ordination stress = 0.09. The 1998 and 2000 samples approximately coincide. Marker wetland 1=fresh high richness, 2=subsaline sandy sump, 3=fresh, 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.

There was no indication of a change in the character of community composition across the monitoring period. An ordination (NMDS) indicated that relative to marker wetlands community composition varied little; considerably less than the observed difference from marker wetlands (Figure 3). This relatively constant community composition, despite species loss in 2006 and 2008, reflects the unique assemblage of species collected at Kulikup Swamp compared to marker wetlands. Community composition shared elements present at high richness marker wetlands 1, 5 and 9 with which Kulikup Swamp had most similarity. In particular, invertebrate assemblage F (a widespread group of species with fresh to mildly subsaline salinity tolerance) is typically associated with all three of these wetlands and absent from all other marker wetlands used in this analysis. Thus, the richness of assemblage F describes a core component of the invertebrate community at Kulikup Swamp which linked the wetland to faunistically similar wetlands. Since the richness of this assemblage was relatively constant across the monitoring period, while other assemblages varied, it may be a useful indicator of the well-being of Kulikup Swamp; changes in its richness would suggest a substantial change in the character of the community.

A constrained ordination (RDA) to investigate relationships between community composition and environmental variables (Figure 4) was influenced by species loss in 2006 and 2008 and differences in water chemistry at this time (especially higher salinity and HCO3- and lower colour). However, as Figure 3 indicated, changes in invertebrate community composition between 1998 and 2008 were small relative to other wetland types and while electrical conductivity and water colour explained 52% of the variation in composition on two axes, these relationships were not statistically significant. Salinity remained within the tolerances of most species and a mechanism by which it may have changed community structure is not clear.

Changes in water chemistry (pH and salinity) of the scale observed in 2006 and 2008 have been observed in the past, as have decadal filling events like that of 2005 (Lane et al., 2017). On each occasion these changes were of short duration and it is to be expected that the same would be true following the 2005 filling and that changes in community composition and richness in 2006 and 2008 would not persist. This is supported by the partial recovery of richness in 2008 and evidence that the actual character of the community changed little. However, with the expected rise of the perched groundwater lenses underlying the wetland, more persistent changes in character may be expected in coming years.

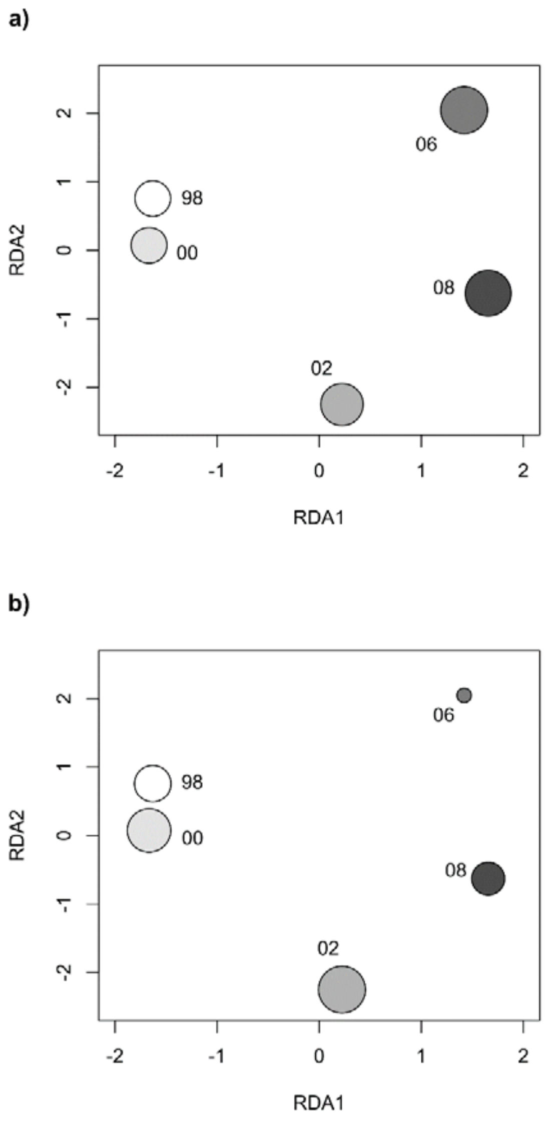

Figure 4. Redundancy analysis of invertebrate community composition constrained by electrical conductivity and water colour. Neither constraint was statistically significant. Point size for each sample is coded by a) electrical conductivity and b) water colour.

6.3 Waterbirds

Waterbirds were rarely encountered at Lake Kulikup during the study period. Three species: little grassbird (reed specialist), Pacific black duck (dabbler) and white-faced heron (large wader) were recorded at low abundance, i.e. 1 or 2 individuals. Each of these species was recorded only once and each during a different survey, consequently the maximum recorded richness was one species. No birds were seen at the highest depths or when the wetland was dry, but the few records were spread across the remaining depth range. Jaensch *et al.* (1988) recorded five species using Kulikup Swamp over five surveys in the early 1980s, with a total of 7 individuals. These were the above three species, plus single records of Purple Swamp Hen and Musk Duck.

With its extensive stands of reeds, shallow depth and relatively small size Lake Kulikup is probably used by birds only opportunistically. While the wetland appears to be suitable for reed specialist species like crakes and bitterns it is likely that the hydroperiod is too short in most years to support these species.

7 References

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Appendix 1. Depth and water chemistry data

Physico-chemical variables as used in analyses for Kulikup Swamp. 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	**26/08/98**	**6/11/98**	**20/04/1999**	**1/09/2000**	**11/10/2000**	**16/02/2001**	**28/08/2002**	**23/10/2002**	**26/03/2003**	**30/08/2004**	**3/11/2004**	**23/03/2005**	**14/09/2006**	**18/10/2006**	**22/03/2007**	**27/08/2008**	**14/10/2008**	**25/03/2009**
season	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au	LW	Sp	Au
Depth (m)	0.09	0.10	0	0.22	0.20	0	0.01	0.08	0	0.01	0	0	0.16	0.10	0	0.09	0.05	0
Conductivity (µS/cm)	380	642		246	645.5		832	762.5		485			581	845		564	826	
pH	7.71	7.835		7.30	7.47		7.54	8.19		7.81			7.45	7.665		7.80	8.14	
TFN (µg/L)		1400		1000	815		1100	2100		1900			810	1350		930	1450	
TFP(µg/L)		20		20	15		5	7.5		20			10	15		5	7.5	
Chlorophyll-a (µg/L)				0.5	0.5		1	0.75		0.5			0.5	0.5		0.5	0.5	
Chlorophyll-b (µg/L)				0.5	0.5		0.5	0.5		0.5			5	4.75		0.5	0.5	
Chlorophyll-c (µg/L)				0.5	0.5		0.5	0.5		0.5			0.5	4.75		0.5	0.5	
Phaeophytin-a (µg/L)				0.5	0.75		0.5	0.5		0.5			3	0.5		0.5	0.5	
Temperature (°C)	12.7	18.0		9.7	17.7		9.0	29.1		17.9			9.7	24.0		7.7	12.65	
Dissolved Oxygen(%)	102	94.5		62.1	77.85		53.7			104.4			62.6	116				
NO3 (mg/L)		0.01		0.01	0.01		0.01	0.05		0.06				0.01		0.005	0.01	
Turbidity (NTU)		76			150			8.3						350			99	
Colour (TCU)		210			250			270						82			190	
TDS (g/L)		0.42			0.42			0.41						0.62			0.6	
Alkalinity (mg/L)		130			105			120						315			285	
Hardness (mg/L)		80			53			84						180			140	
Si (mg/L)		48			26			20						15			16	
Na (mg/L)		75			75			87						155			178	
Ca (mg/L)		9			6			11						23.2			17.2	
Mg (mg/L)		14			9			14						30			24.1	
K (mg/L)		7			4			6						7.4			8.5	
Mn (mg/L)		0.01			0.025			0.01									0.0005	
Cl (mg/L)		56			52			100						155			116	
HCO3 (mg/L)		160			128			146						384			348	
CO3 (mg/L)		1			1			1						1			0.5	
SO4 (mg/L)		6			8			12						13.8			35.4	
Iron(mg/L)					11			0.76									0.056	
Tot Chlorophyll (µg/L)	0	0	0	2	2.25	0	2.5	2.25	0	2	0	0	9	10.5	0	2	2	0

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	1998	2000	2002	2006	2008	occurrences
Protista	Arcella megastoma	BP010105		1				1
	Arcella vulgaris	BP010106		1				1
	Difflugia cf. lithophila	BP0301A1		1				1
	Nebela sp.	BP040199	1					1
	Lesquereusia modesta	BP070101		1				1
	Euglypha sp.	BP090199		1	1			2
Hydrazoa	Hydra sp.	IB010199	1	1	1	1		4
Turbellaria	Zygopella pista	IF410201	1	1				2
	Turbellaria	IF999999	1	1	1			3
Nematoda	Nematoda	II999999	1	1	1	1	1	5
Tardigrada	Tardigrada	IR999999	1					1
Rotifera	Macrotrachela sp.	JB040699	1					1
	Philodinidae	JB049999	1					1
	Bdelloidea small contracted	JB9999A0		1				1
	Bdelloidea med-large contracted	JB9999A1		1	1			2
	Flosculariidae	JF039999	1					1
	Testudinella patina	JF050201		1	1	1		3
	Testudinella insinuata	JF050202		1				1
	Testudinella parva	JF050213			1			1
	Asplanchnopus multiceps	JP010201		1	1			2
	Asplanchnopus hyalinus	JP010202		1				1
	Brachionus quadridentatus quadridentatus	JP020248		1	1			2
	Keratella javana	JP020306			1			1
	Keratella procurva	JP020308	1	1	1	1		4
	Plationus sp. nov. (Goonaping)	JP0205A0		1				1
	Platyias quadricornis	JP020601	1	1	1			3
	Colurella adriatica	JP030101			1			1
	Lepadella ovalis	JP030201		1		1		2
	Lepadella biloba	JP030211			1			1
	Euchlanis dilatata	JP060101		1	1			2
	Euchlanis cf. meneta	JP0601A1		1	1			2
	Lecane bulla	JP090110	1		1	1		3
	Lecane hamata	JP090129			1			1
	Lecane ludwigii	JP090136			1			1
	Lecane luna	JP090137	1	1	1			3
	Lecane quadridentata	JP090154		1	1			2
	Lecane signifera	JP090159			1			1
	Lecane subtilis	JP090165		1				1
	Cephalodella gibba	JP130201			1	1		2
	Cephalodella forficula	JP130202			1	1		2
	Notommata sp.	JP130599			1			1
	Eosphora najas	JP130903		1				1
	Trichocerca rattus	JP160328	1					1
	Trichocerca tigris	JP160336		1				1
	Trichocerca weberi	JP160339		1				1
	Trichocerca cf. elongata tschadensis	JP1603A7		1	1			2
	Trichotria tetractis similis	JP170202	1	1	1	1		4
	Macrochaetus altamirai	JP170301		1				1
	Scaridium sp.	JP180199			1			1
Mollusca	Ferrissia petterdi	KG060101			1	1	1	3
	Glyptophysa cf. gibbosa	KG0702A5	1	1				2
Annelida	Dero nivea	LO050202	1					1
(earthworms)	Pristina longiseta/leydyi	LO050501	1	1	1	1	1	5
	Ainudrilus nharna	LO052101			1		1	2
	Enchytraeidae	LO089999	1	1	1		1	4
Arachnida	Eylais sp.	MM030199		1		1		2
(water mites)	Limnesia dentifera	MM120101				1	1	2
	Acercella falcipes	MM170101	1	1	1		1	4
	Piona murleyi	MM170303					1	1
	Arrenurus sp.	MM230199	1	1			1	3
	Pezidae	MM259999			1			1
	Oribatida sp.	MM9999A1	1	1	1	1	1	5
	Mesostigmata	MM9999A2	1	1	1	1	1	5
	Trombidioidea	MM9999A6	1	1	1			3
(clam shrimps)	Lynceus sp.	OF040199					1	1
Cladocera	Diaphanosoma unguiculatum	OG010106	1	1		1	1	4

	TAXON	LowestIDNC	1998	2000	2002	2006	2008	occurrences
(water fleas)	Alona rigidicaudis	OG030212	1					1
	Alona setigera	OG030214	1	1	1	1	1	5
	Alonella clathratula	OG030301	1	1	1			3
	Chydorus sp.	OG030999	1	1	1		1	4
	Dunhevedia crassa	OG031201	1	1	1	1		4
	Ephemeroporus cf. barroisi	OG0313A0	1					1
	Kurzia latissima	OG031601	1	1	1			3
	Leberis cf. diaphanus	OG0317A4	1	1	1	1	1	5
	Pleuroxus inermis	OG032502	1			1		2
	Armatalona macrocopa	OG033401	1	1			1	3
	Ceriodaphnia sp.	OG040199	1	1	1			3
	Daphnia carinata	OG040201		1	1			2
	Simocephalus exspinosus	OG040502		1				1
	Simocephalus elizabethae	OG040505	1		1	1	1	4
	Ilyocryptus smirnovi	OG050101	1	1	1			3
	Macrothrix indistincta	OG060211	1		1			2
	Macrothrix sp. a (of RJS)	OG0602A3	1					1
	Moina cf. micrura	OG0701A1			1			1
	Neothrix armata	OG090301	1	1	1	1	1	5
Ostracoda	Limnocythere mowbrayensis	OH010203	1		1			2
(seed shrimps)	Limnocythere sp. 477 (aff. porphyretica)	OH0102A4		1				1
	Paralimnocythere sp. 262	OH0103A1	1	1	1	1		4
	Alboa worooa	OH080101	1	1	1	1	1	5
	Bennelongia australis	OH080301				1	1	2
	Candonocypris novaezelandiae	OH080403		1	1	1		3
	Cypretta baylyi	OH080501				1	1	2
	Cypretta aff. globosa	OH0805A1	1	1		1		3
	Ilyodromus amplicolis	OH081901	1	1				2
	Ilyodromus sp. 255	OH0819A3	1	1			1	3
	Newnhamia fenestrata	OH110101	1	1	1	1	1	5
Copepoda	Boeckella bispinosa	OJ110104					1	1
	Boeckella robusta	OJ110118	1	1	1		1	4
	Calamoecia attenuata	OJ110203	1	1	1	1	1	5
	Calamoecia tasmanica subattenuata	OJ110211	1	1	1	1	1	5
	Microcyclops varicans	OJ310101	1	1	1	1		4
	Metacyclops sp. 434 (arnaudi sensu Sars)	OJ3102A2		1				1
	Metacyclops sp. 4	OJ3102A6			1		1	2
	Australocyclops australis	OJ310301					1	1
	Mesocyclops brooksi	OJ310703	1	1	1	1	1	5
	Eucyclops australiensis	OJ311001			1			1
	Canthocamptus australicus	OJ610101	1	1			1	3
	Australocamptus sp. 5	OJ6199A4	1		1	1		3
Amphipoda	Austrochiltonia subtenuis	OP020102	1	1	1	1	1	5
Decapoda	Cherax preissii	OV010113	1	1	1	1	1	5
Coleoptera	Haliplus fuscatus	QC060104	1	1	1	1	1	5
(beetles)	Uvarus pictipes	QC090701	1	1	1	1	1	5
	Limbodessus shuckhardi	QC091002	1	1	1	1		4
	Limbodessus inornatus	QC091006	1	1	1			3
	Allodessus bistrigatus	QC091101	1	1	1	1	1	5
	Antiporus sp.	QC091699	1	1	1	1	1	5
	Sternopriscus sp.	QC091899	1	1	1	1	1	5
	Necterosoma sp.	QC092099			1	1		2
	Megaporus sp.	QC092199	1		1	1	1	4
	Platynectes sp.	QC092299			1			1
	Spencerhydrus pulchellus	QC093302		1	1			2
	Berosus approximans	QC110404		1		1		2
	Enochrus deserticola	QC111105				1		1
	Limnoxenus zelandicus	QC111401			1	1	1	3
	Paracymus pygmaeus	QC111601	1	1	1	1	1	5
	Hydraena sp.	QC130199		1				1
	Scirtidae sp.	QC209999	1	1		1	1	4
	Hydrochus australis	QCA00106	1	1	1			3
Diptera	Tipulidae	QD019999				1	1	2
(flies, midges, mosquitoes)	Anopheles annulipes s.l.	QD070101	1		1		1	3
	Aedes alboannulotus	QD070501			1			1
	Aedes (Och.) ENM's sp nr stricklandi	QD0705A0		1			1	2
	Culex sp.	QD070799		1				1
	Culicoides sp.	QD090899	1			1		2
	Monohelea sp. 1	QD0919A0	1					1
	Monohelea sp. 3	QD0919A2					1	1
	Stratiomyidae	QD249999			1			1
	Empididae	QD359999			1			1
	Dolichopodidae	QD369999			1		1	2
	Muscidae	QD899999					1	1
	Procladius paludicola	QDAE0803	1			1		2

	TAXON	LowestIDNC	1998	2000	2002	2006	2008	occurrences
	Alotanypus dalyupensis	QDAE1001		1	1			2
	Paramerina levidensis	QDAE1201	1	1	1	1	1	5
	Pentaneurini genus C	QDAE99B8					1	1
	Corynoneura sp.	QDAF0699	1	1	1	1	1	5
	Paralimnophyes pullulus	QDAF1202	1	1	1	1	1	5
	Gymnometriocnemus sp. B	QDAF26A1		1	1	1		3
	Gymnometriocnemus sp.=ortho sp A	QDAF99A0					1	1
	Orthocladiinae sp. J	QDAF99A8					1	1
	Tanytarsus nr bispinosus	QDAH04B9	1	1	1		1	4
	Chironomus occidentalis	QDAI0408					1	1
	Chironomus aff. Alternans	QDAI04A0	1	1	1			3
	Dicrotendipes conjunctus	QDAI0603			1			1
	Polypedilum nubifer	QDAI0804	1					1
	Paraborniella tonnoiri	QDAI1701	1					1
	Cryptochironomus griseidorsum	QDAI1901			1	1		2
	Cladopelma curtivalva	QDAI2201	1		1		1	3
Hemiptera	Microvelia (Pacificovelia) oceanica	QH560101	1	1		1		3
(waterbugs)	Veliidae	QH569999			1			1
	Saldula sp.	QH600299	1					1
	Sigara truncatipala	QH650204			1			1
	Sigara mullaka	QH650206		1				1
	Agraptocorixa parvipunctata	QH650302	1	1		1	1	4
	Micronecta robusta	QH650502					1	1
	Micronecta gracilis	QH650503		1				1
	Anisops thienemanni	QH670401		1		1	1	3
	Anisops hyperion	QH670402		1		1		2
Lepidoptera	Lepidoptera (non-pyralid) sp. 3	QL9999A1	1					1
Neuroptera	Sisyra sp.	QN050199		1		1		2
Odonata	Xanthagrion erythroneurum	QO021301			1		1	2
(dragonflies, damselflies)	Austrolestes analis	QO050101	1	1	1	1	1	5
	Adversaeschna brevistyla	QO120201				1		1
Trichoptera	Hellyethira litua	QT030410		1				1
(caddisflies)	Ecnomus pansus/turgidus	QT0804A0			1			1
	Leptoceridae	QT259999		1				1

Appendix 3. Waterbird data

Abundance of species for each seasonal survey at Kulikup Swamp.

Year	Season	little grassbird	Pacific black duck	white-faced heron
1998	late winter			
1998	spring			2
1999	autumn			
2000	late winter			
2000	spring			
2001	autumn			
2002	late winter			
2002	spring			
2003	autumn			
2004	late winter		2	
2004	spring			
2005	autumn			
2006	late winter	1		
2006	spring			
2007	autumn			
2008	late winter			
2008	spring			
2009	autumn			
2010	late winter			
2010	spring			
2011	autumn			
2012	late winter			
2011	spring			
2013	autumn			

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