Wheatbelt Wetland Biodiversity Monitoring

Fauna Monitoring at Goonaping Swamp 1998-2012

Report WWBM-FR06

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Cover photo: Depth data logger in sump in lake bed at Goonaping Swamp photographed in November 2012. D. Cale.

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Russell Shiel (Russel J. Shiel and Associates) identified the rotifers, cladocerans and protozoans. Stuart Halse and Jane McRae (then of CALM) identified the ostracods and copepods prior to 2007. Edyta Jasinska, Melita Pennifold and Karen Sutcliffe (then of CALM) assisted with data collection including sorting and identifications for many invertebrate samples. Infrastructure established and maintained by the South West Wetlands Monitoring Program (SWWMP) was essential in understanding the historical and contemporary extent and duration of inundation at the wetland. Accordingly, the staff of that program (Jim Lane, Alan Clarke and Yvonne Wynchcombe; DBCA) are gratefully acknowledged.

Contents

1 Summary

Goonaping Swamp is a shallow, temporary wetland. During the study period the wetland had a consistent hydrocycle filling to a maximum depth of 0.2 m (across the lake bed) and having a hydroperiod of 4 – 7 months. The wetland was always fresh with salinity < 645 µS/cm. There was no evidence of a change in conditions within the wetland across the monitored period. Low rainfall in 2010 and 2012, at the end of the monitoring period, resulted in short hydroperiods and highest levels of salinity but these conditions did not persist in subsequent years (Lane, Clarke & Winchcombe, 2017). Groundwater did not appear to be rising below the wetland at least up until the cessation of data collection in January 2017 (unpublished data, DBCA)

The invertebrate fauna was diverse with a total of 196 species recorded and richness of an annual sample in the range 85 – 93 species. Rotifers and protists were a major component of the fauna accounting for 34% of species. Two species, the rotifer *Plationus* sp. nov and the cladoceran *Rak* sp. nov. are believed to be new undescribed species and each known from just one other wetland. Many invertebrate species were collected only once during the monitoring period and this contributed to a high turnover of species between sampling dates, such that any pair of dates only shared about half their combined invertebrate fauna. This has the consequence that a series of several years are required for all species to be encountered. Despite the high turnover of species a group of core species collected on most occasions unifies the community at Goonaping Swamp and makes it distinctive from the communities present at a wide range of other wetland types.

Goonaping Swamp was rarely important for waterbirds which probably encounter the wetland infrequently because of its small size and short hydroperiod and the low density of wetlands suitable for waterbirds in the surrounding area.

Climate-change and habitat damage by feral pigs are probably the main threats to this wetland. If climate change results in the wetland filling less frequently then changes in the wetland's fauna can be expected, including a decline in richness. However, to date there is no evidence of a decline in depths during spring (at least since 1998) and there is no evidence of temporal change in the fauna when the wetland has water.).

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, 1996) which provided the basis for a detailed action plan published as *Western Australian Salinity Action Plan* (Government of Western Australia, 1996). 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, 1996).

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 commenced in 1997 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; Cale & Pinder, 2018c, b a, 2019).

Goonaping Swamp was included in the monitoring program as a representative of ephemeral freshwater claypan wetlands with high conservation value and is situated within intact woodland (Cale *et al.*, 2004). It was given the site code SPM013.

3 Wetland description

Goonaping Swamp (32º 09' S 116º 36' E) is a shallow, temporary, freshwater clay pan located in Wandoo National Park 30 km west of Beverley. The wetland has an area of approximately 29 ha and is situated in undisturbed bushland, except for an area of agricultural land (approximately 1000 ha) 750 m to the north. Cartographic material (Department of Parks and Wildlife, 2012) indicates that a single drainage line entering Goonaping Swamp along its northern margin originates in this farmland. Gurner et al. (1999) also identified that inflow may occur via a drainage line entering at the south-west margin and that this was the only outflow.

The vegetation has been described in detail by Gurner et al. (1999) and includes *Melaleuca viminea* which dominates the majority of the lake bed and *Eucalyptus rudis* and *Melaleuca preissiana* on low elevations of the wetlands margins. Surrounding vegetation is woodland of *Eucalyptus marginata*, *Corymbia calophylla* and *Banksia* spp on deep sands and *Eucalyptus wandoo* on heavier soils.

In addition to the data presented here, lake depth has been monitored in September and November since November 2000 (Lane *et al.*, 2017). The lake was dry in November of 2000 and 2010 but otherwise contained water in both months of all years.

A classification of 223 Wheatbelt wetlands using the presence/absence of aquatic invertebrate species placed Goonaping Swamp within wetland-group-9 of Pinder *et al*. (2004). This group was described as 'southern swamps' and members occurred along the more mesic southern and south-western margins of the Wheatbelt. The fauna of this group typically included a high richness of species associated with freshwater and fewer halotolerant species than other wetland groups.

4 Sampling Program

Goonaping Swamp was visited 24 times during 8 monitoring years. Waterbirds were surveyed on 16 occasions and invertebrates collected on 6 occasions. However, in 2012, only a sump (*ca* 3 m^2) in the lake bed, at the depth gauge, held water from which invertebrates could be sampled and this sample has not been processed.

Table 1 Site visits and collected data sets for Goonaping Swamp, 1998- 2013.

Sample	Monitoring Year	Date	Invertebrates sampled	Waterbirds surveyed	Depth (m)
LW98	1998/99	26/08/1998	×	✓	0.6
Sp98	1998/99	9/11/1998	✓	✓	0.6
Au98	1998/99	20/04/1999	×	✓	0
LW00	2000/01	29/08/2000	×	✓	NA
Sp00	2000/01	3/10/2000	✓	✓	0.7
Au00	2000/01	12/02/2001	×	✓	0
LW02	2002/03	30/08/2002	×	✓	0.6
Sp02	2002/03	15/10/2002	✓	✓	0.54
Au02	2002/03	27/03/2003	×	×	0
LW04	2004/05	1/09/2004	×	✓	0.66
Sp04	2004/04	28/10/2004	×	×	<0.5
Au04	2004/05	23/03/2005	×	×	0
LW06	2006/07	14/09/2006	×	✓	0.63
Sp06	2006/07	18/10/2006	✓	✓	0.54
Au06	2006/07	19/03/2007	×	×	0
LW08	2008/09	28/08/2008	×	✓	0.65
Sp08	2008/09	13/10/2008	✓	✓	0.6
AU08	2008/09	25/03/2009	×	×	0
LW10	2010/11	26/08/2010	×	✓	0.48
Sp10	2010/11	24/10/2010	×	×	0
Au10	2010/11	31/03/2011	×	×	0
LW12	2012/13	10/08/2012	×	✓	0.16
Sp12	2012/13	10/11/2012	✓	✓	0.35
AU12	2012/13	22/03/2013	×	×	0

5 Physical and chemical environment

Physico-chemical data is provided in Appendix 1.

Hydrology

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Depth varied from 0 - 0.70 m at the depth gauge (Fig. 1). The depth gauge is located in a small sump in the lake bed and a depth of approximately 0.5 m (Lane *et al.*, 2017) is required before flooding of the wetland bed is observed, i.e. the bulk of the wetland had a depth range of 0 - 0.2 m. In 1998 and 2000, prior to the commissioning of the depth gauge, depth has been re- estimated by addition of 0.5 m to average depths observed across the lake bed (this being more accurate than subtracting 0.5 m from the larger data series).

The lake was dry in autumn of all monitoring years indicating a hydroperiod of less than twelve months. Data (unpublished) from a surface water depth logger positioned at the depth gauge from 31/3/2012 to 8/7/2014 indicated that the hydroperiod (wetting beyond the sump) for 2012 and 2013 was at least[1] 63 and 105 days respectively, i.e. roughly 2 – 3 months. In 2004, the lake (including sump) had dried by spring sampling. In spring 2010 and 2012 water was only present in the sump. Low water levels throughout 2010 and 2012 coincided with below average annual rainfalls at Mount Westdale (Bureau of Meteorology station 10920). This weather station, approximately 18 km SE of Goonaping Swamp at 32^{o} 16' S 116^{o} 40' E, had annual falls of 279 mm and 369 mm (respectively in those two years) compared to an average of 421 mm (2007-2015).However, the more regular depth measurements of Lane et al. (2017) do not show a drying trend for the wetland over the 1999 to 2017 period.

Depth to groundwater has been monitored in observation bores at the edges of Goonaping swamp since December 1999 (Cale *et al.*, 2004). Depth to groundwater varies seasonally; approaching the lake bed after filling and receding when the lake is dry. However, there does not appear to be a trend of rising groundwater (unpublished data to 2017 M Lyons DBCA). Groundwater is closest to the surface in the bore on the northern margin of the lake where it may be < 1m from ground level during wet months. Depth to groundwater is >4m even during wet months in bores on the south-west margin.

pH

The proportion of hydrogen ions (pH) varied from 5.83 – 8.13 (mean 6.98 ± 0.5). Most of the observed variation occurred between years (Fig. 1) with maximum pH in 2000, minimum pH in 2004 and pH close to the mean in most other years. Within a monitoring year pH varied by < 0.5 units. There was no correlation between pH and other chemical variables and it is likely that pH dynamics were dependent on features of the annual filling event and development of biological communities, for example algal blooms (see Nutrients and chlorophyll below).

Salinity and ionic composition

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[1] Hydroperiods calculated from first and last dates the water depth is greater than the depth of the sump and therefore indicating continuous inundation across the lakebed, however, localised pooling is likely before and after the sump fills/regresses

There was a significant regression of total dissolved solids (TDS) on electrical conductivity (r^2_{adj} = 0.808, df = 4, p = 0.009) and TDS (g/L) = 0.001 * ec (µS/cm) - 0.091. The wetland was fresh throughout the monitoring period with salinities (as electrical conductivity; Fig.1) ranging between 105 – 645 µS/cm (mean = 307.2 ± 156.5 µS/cm). A statistically significant trend of increasing salinity during late winter across the monitoring period (Mann-Kendall tau=, $p < 0.05$, df = 4) was strongly dependent on higher salinities during late-winter in 2010 and 2012 which coincided with lower depths as described above. Undoubtedly the sump in the lake bed concentrates salts following summer evaporation, but this would be much diluted when the lake bed floods. The trend is not apparent when data for the intervening 2011 or subsequent 2013-2014 years (from Lane *et al.*, 2017; page 93) are considered. Nonetheless, salinity was always in the range generally considered fresh (< about 3000 µS/cm).

Sodium (Na) was the dominant cation in all years; however, the hierarchy of other cations was variable because they were of similar concentration. Anion composition was consistent; with anion dominance following a Cl > HCO_3 > SO_4 > CO_3 pattern except in spring 2000 when HCO_3^- concentration was relatively low and equal to SO_4^-. The dominant ions, Na^- and Cl^-, were an order of magnitude greater concentration than other ions.

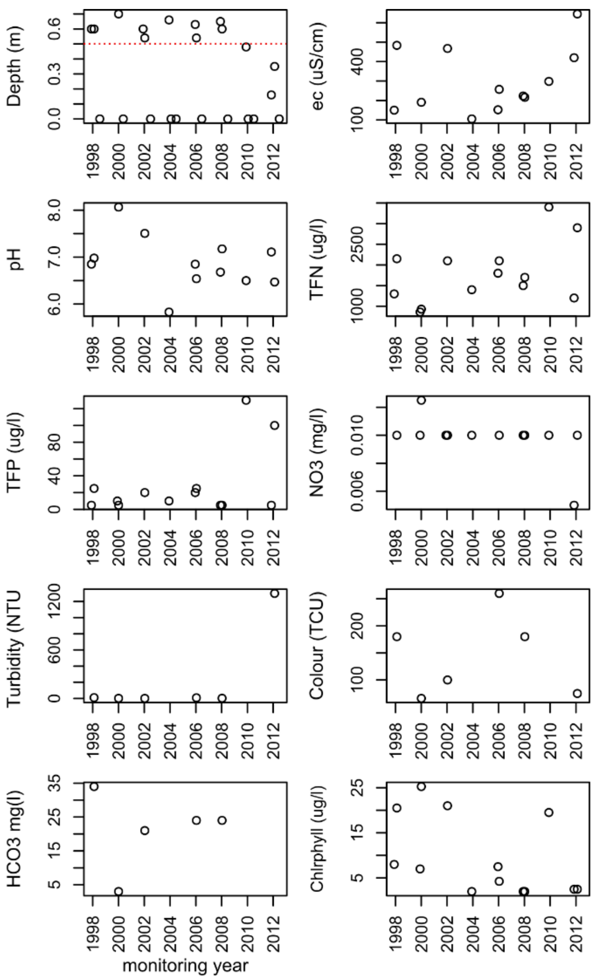

Figure 1. Water chemistry parameters at Goonaping Swamp for late-winter, spring and autumn sampling occasions between 1998 and 2012. Depth was recorded at the gauge and a dotted line denotes the depth above which most of the lake bed is flooded (see text), ec is electrical conductivity, TFP total filtered 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

Excluding sample dates when only the sump held water, total filtered nitrogen (TFN) ranged between 860 – 2150 µg/l (mean 1584 ± 469 µg/l) and total filtered phosphorus (TFP) between 5 – 25 µg/l (mean 13 ± 8.5 µg/l). Concentrations were elevated when only the sump held water (max TFN = 3400 µg/l, max TFP = 130 µg/l). There was a significant positive correlation between TFN and TFP (rho = 0.82, df = 11, $p < 0.01$). Nitrate ion concentration was close to the limit of detection (0.01 mg/l) throughout the study period, except in spring 2000 when the maximum of 0.02 mg/l was recorded. Differences in concentration of nutrients between sampling sites was small indicating their distribution was homogenous when both sites were inundated.

Chlorophyll concentration was variable both within and across monitoring years (range 2 - 25 µg/l). In spring 2000, maximum recorded chlorophyll concentration was associated with high pH (8.06) and NO_3^- concentrations and low concentrations of HCO_3^- ion, alkalinity, TFP and TFN (Fig. 1). Daytime water temperature was approximately 26^{o}C. Collectively, these data suggest a period of elevated primary production driven by NH_4^+ uptake and resulting in the depletion of dissolved carbon, phosphorus and nitrogen which presumably would eventually have slowed primary production.

In summary, at Goonaping Swamp a short seasonal hydroperiod with shallow filling in most years is combined with low salinity, circumneutral pH and low nutrient status to create a temporary wetland with the potential to support high biodiversity.

6 Fauna

Aquatic invertebrate diversity

At least 196 taxa were collected from Goonaping Swamp (Appendix 2). Of these, a total of 63 species (34%) were protists or rotifers. The next richest assemblage of species was the dipterans (30 spp) including a range of families but dominated by Chironomidae. Cladocera (24 spp) and Coleoptera (20 spp) were also important groups. Two species, the rotifer '*Plationus* sp. nov (Goonaping)' and the cladoceran '*Rak* sp. nov (Goonaping)' appear to be undescribed and are probably new species (Dr R Shiel). Some other species have restricted distributions in Western Australia. The cyclopoid *Australocyclops palustrium* is known only from Goonapping Swamp, two nearby wetlands (Little Darkin Swamp and Dobaderry Swamp), two wetlands in the Muir-Byenup system (near Manjimup) and from Arro Swamp north-west of Eneabba. Goonapping Swamp is the type locality for *Eulimnadia vinculuma*, first collected at this location in 1997 and described by Timms (2017). It is also known from only a few other locations on the Swan Coastal Plain (including one of the Perth Airport swamps) and from one site in the Muir-Byenup system south-east of Manjimup. The ostracod *Paralimnocythere* sp. '262' is known only from the Muir-Byenup wetlands, Ngopitchup Swamp (south-east of Kojonup), Kulikup Swamp (east of Boyup Brook – Cale and Pinder 2018c) and a single record at Goonapping Swamp (in 1998).

Protist and rotifer taxa were not identified in 2008; consequently, to assess trends across the entire monitoring period, richness was calculated for a reduced species list excluding these taxa. Annual richness with protists and rotifers included was within a narrow a range of 85 – 93 species and mean of 88.5 (± 3.5) species (Fig. 2a). Without the rotifers and protists, richness was more variable, with a range of 54 – 75 and mean of 63.3 (± 8.8) species (Fig 2b). Using linear regression, the richness of the fauna with rotifers and protists included was poorly predicted by the richness calculated without these taxa (r^2= 0.64, F = 3.61, df = 2, p > 0.5). Despite this shortcoming further discussion of invertebrate data concentrates on the community with protists and rotifers excluded.

There were a large number of singleton taxa; excluding rotifers and protists 41 species (31%) were collected only once. Amongst the rotifers and protists the rate of singletons was higher with 41 of 63 taxa (65%) collected only once. The high proportion of singleton taxa contributed to high β-diversity between annual communities. If measured as the richness of the species not shared by pairs of annual communities (Podani & Schmera, 2011), mean β-diversity was 88.8 (± 6.7) species which is more than half the mean total richness of 147.3 (± 7.1) species for pairs of annual communities, i.e. more than half of the fauna differed between years, or from a different perspective several years are required before the majority of species are encountered.

In contrast to the high number of singleton taxa, 20 species were collected on all occasions. Amongst these 'core' species half were typically freshwater species such as *Scapholeberis kingi* (Cladocera), *Eulimnadia vinculuma* and *Lynceus* sp. (Conchostraca), *Carbonocypris nunkeri* (Ostracoda) and *Onychohydrus scutellaris* (Coleoptera). The remaining core species were of more ubiquitous and tolerant character, e.g. *Procladius paludicola* (Chironomidae), *Allodessus bistrigatus* (Coleoptera), *Austrolestes analis* and *Hemianax papuensis* (Odonata).

Assemblages F, E and A (sensu Pinder *et al.*, 2004), in that order, contributed most to annual richness. While assemblage A is associated with freshwater swamps, assemblage F species tend to have tolerances from fresh to subsaline conditions and assemblage E tends to be broadly tolerant and consequently distributed ubiquitously.

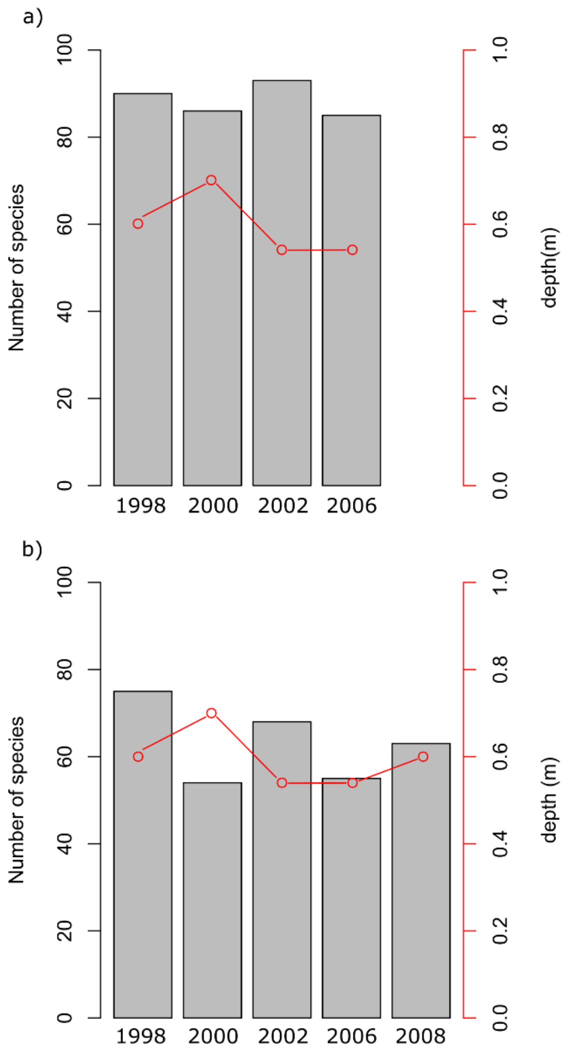

Figure 2. Invertebrate richness and depth in spring of each monitoring year. a) The full suite of invertebrate taxa and b) all invertebrate taxa except Rotifera and Protista.

Despite the prevalence of freshwater species, richness (excluding rotifers and protists) increased with increasing salinity (as electrical conductivity; $r = 0.9$, $df = 3$, $p < 0.05$). Species richness typically decreases with increasing salinity, although Pinder et al. (2005) found no relationship between the richness of freshwater species and salinity at concentrations < 2.6 g/l (approx. 4000 µS/cm). Additionally, at Goonaping Swamp there was no evidence of a shifting of richness from freshwater species to tolerant species (e.g. from assemblage A to E) as salinity increased nor any correlation (albeit with low statistical power) between salinity and the richness of the whole community (i.e. with protists and rotifers included). Given these observations, the relationship between richness and salinity may reflect a relationship between salinity and some other factor which was influencing species richness. In a small wetland of similar character to Goonaping Swamp, monthly sampling showed that species richness increased with time since filling and only peaked 4 – 5 months after filling (Pinder *et al.*, 2013). With different filling dates at Goonaping Swamp each year, the maturity of invertebrate communities at the time of sampling will also be different due to the fixed calendar sampling regime used. The observed increase of richness with salinity may reflect the coincidence of increasing salinity as the wetland begins to dry and evapo-concentrate salts, and the increasing maturation of the invertebrate community as the time since filling increases. It is likely that some of the β-diversity described above is also partly a product of sampling a community at different stages of maturity in different years.

Richness was not correlated with any other measured environmental variable. High chlorophyll concentrations in 2000 indicated a period of elevated primary production which might have been expected to result in increased richness, however the contrary was true with the lowest observed richness (with or without rotifers and protists) being recorded. Given the generally stable water chemistry invertebrate richness may be more strongly influenced by un-measured factors including hatching cues such as early season temperatures and the time since filling of the wetland (relative to sampling) and the extent of filled wetlands nearby which would act as sources of colonists.

Invertebrate community composition

An ordination (NMDS) of invertebrate community composition (Fig. 3) clearly distinguishes the Goonaping fauna from other wetland types. Most fresh, high richness types (e.g. markers 1, 2, 3, 5 and 9 – see Appendix 4) were equally similar, but lie between Goonaping and the saline marker wetlands which are markedly less similar. The clustering of samples from Goonaping is unexpected given the high β-diversity described above, but reflects the unique group of species that are shared across annual samples and not (at least as a collective) encountered in other wetland types. The majority of these characteristic species were micro-crustaeans. For example, the cladocerans; *E. vinculuma*, *Lynceus* sp., *Latinopsis brehmi*, *Ephemeroporus barroisi*, *Alona willsi*, and the ostracods *Bennelongia australis* and *Cabonocypris nunkeri* were found at Goonaping Swamp on most occassions, but were not present in any marker wetlands.

Total Dissolved Solids (square root transformed) was the only significant variable ($F = 1.43$, $df = 1$, $p < 0.05$) correlated with community composition in a constrained ordination (RDA) of species presence/absence (Fig. 4). Axis RDA1 (Fig. 4) is a linear representation of TDS accounting for 32 % of the variance in community composition as TDS increases from right to left. Changes in composition across this gradient involve a large number of species most of which were dispersed across the gradient. Twenty-eight species had a clear affinity for one or other end of the gradient at Goonaping Swamp, however these species have been collected elsewhere at salinities encompassing the entire range of the gradient. Like species richness (discussed above) it is likely that changes in community composition are in response to variables that were not measured such as time since filling (i.e. maturation of the community) rather than salinity itself.

In summary, the richness of aquatic invertebrate communities at Goonaping Swamp was high and relatively stable with collected environmental variables having little apparent influence. By comparison, community composition was much more variable across the monitoring period with a high proportion each year of species which were collected only once. However, because of a group of co-occurring species the Goonaping Swamp fauna maintains a character distinguishable from other wetland types. There is no evidence of a temporal trend in richness and composition of aquatic invertebrates at Goonaping Swamp.

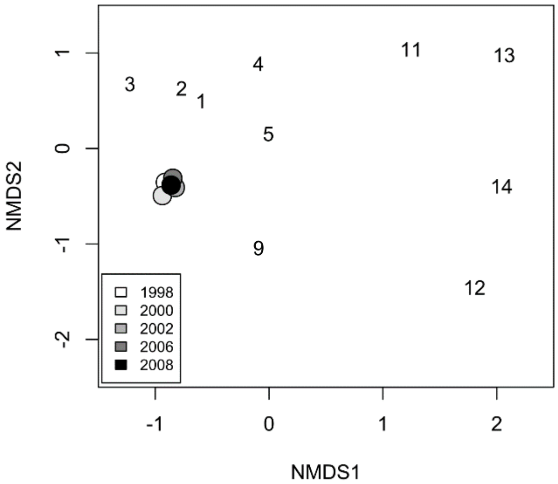

Figure 3. An ordination of spring invertebrate community composition (presence-absence) at Goonaping Swamp with 'marker' wetlands (see methods). For this ordination stress = 0.10. Marker wetland 1=fresh high richness, 2=subsaline sandy sump, 3=fresh episodic wooded swamp, 4=naturally subsaline high richness, 5=subsaline, high richness, 9 = fresh southern swamp, 11 =naturally saline in good condition, 12=naturally hypersaline claypan, 13=degraded naturally hypersaline, 14=natural hypersaline basin.

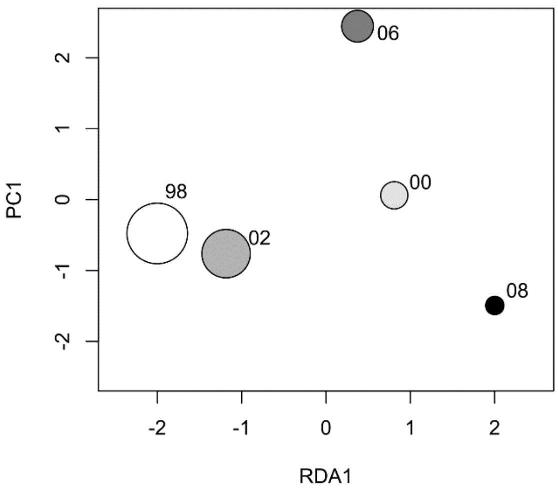

Figure 4 Constrained Ordination (RDA) of Goonaping Swamp invertebrate communities using total dissolved solids (TDS) as constraining variable. Point size is coded by TDS.

Waterbirds

Only two species of waterbird were recorded at Goonaping Swamp and these were encountered infrequently (Fig. 5 and Appendix 3). Pacific black duck were present in low abundance (1-3 birds) in spring 1998 and late-winter 2002 and 2004. A single white-necked heron was recorded in late-winter 2002. Neither species was recorded breeding. The low numbers of waterbirds and their infrequent occurrence precludes analysis of patterns, though it is interesting to note that no waterbirds have been observed since 2004.

The shallowness of Goonaping Swamp and the abundance of tadpoles and invertebrates would suggest the wetland as a particularly suitable feeding ground for large waders. Their infrequent occurrence may be due to the wetland's small size, relatively short hydroperiod and the low density of other wetlands in the area, all of which would reduce the frequency with which the wetland was encountered and result in it being used only opportunistically.

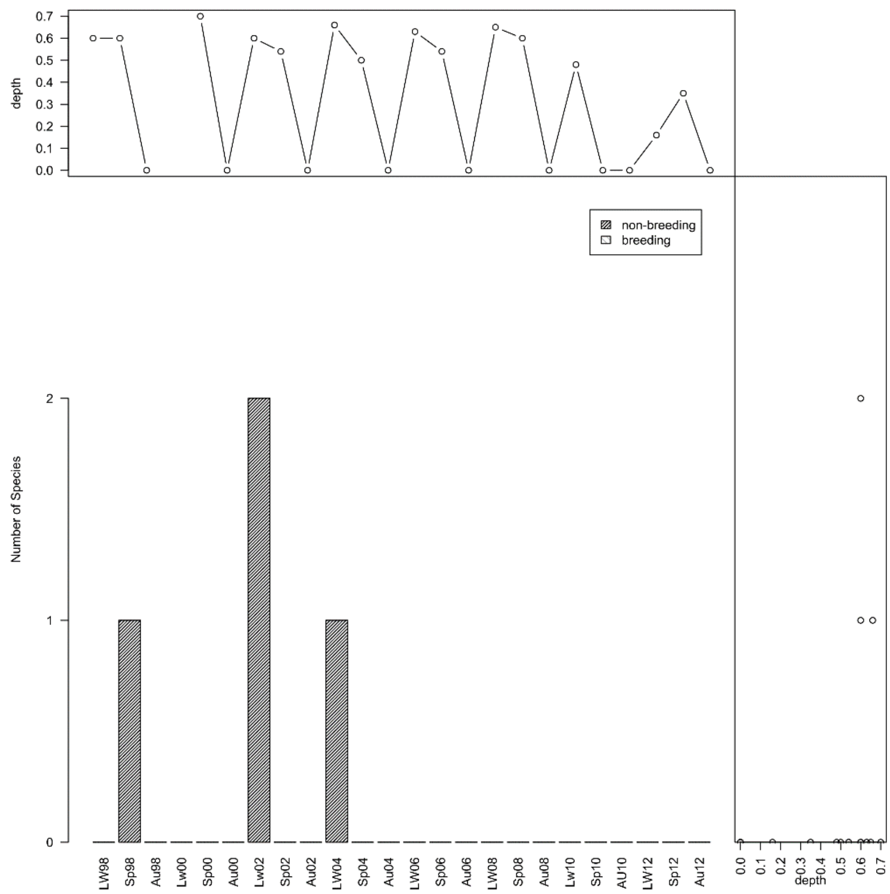

Figure 5 Waterbird species richness across the monitoring period

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Appendix 1. Depth and water chemistry data

Physico-chemical variables measured at Goonaping Swamp. In spring, values of pH, conductivity, temperature, oxygen, nutrients and photosynthetic pigments were measured at both site A and site B. The mean of these paired values was used in analyses. For other dates measurements were made at site A only. Depths before November 2000 were estimated from the lakebed and adjusted by + 0.5m for analyses (to account for the position of the depth gauge; see main text)

Date	26/08/1998	9/11/1998	9/11/1998	20/04/1999	29/08/2000	3/10/2000	3/10/2000	12/02/2001	30/08/2002	15/10/2002	15/10/2002	27/03/2003	1/09/2004	28/10/2004	23/03/2005	14/09/2006	18/10/2006	18/10/2006	19/03/2007	28/08/2008	13/10/2008	13/10/2008	25/3/2009	26/08/2010	24/10/2010	31/03/2011	10/08/2012	10/11/2012	22/03/2013
season	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	AU	LW	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Sp	Au	LW	Sp	Au	LW	Sp	Au
site	A	A	B	A	A	A	B	A	A	A	B	A	A	A	A	A	A	B	A	A	A	B	A	A	A	A	A	A	A
Depth (m)	0.1	0.1	0.1	0	-9999	0.2	0.2	0	0.6	0.54	0.54	0	0.66	0	0	0.63	0.54	0.54	0	0.65	0.6	0.6	0	0.48	0	0	0.16	0.35	0
Conductivity (µS/cm)	150	524	443		-9999	172	209			466	469		105			152	274	240		223	237	195		298			420	645	
pH	6.85	6.92	7.04		-9999	8.13	8			7.25	7.76		5.83			6.85	6.54	6.54		6.68	7.02	7.33		6.5			7.11	6.47	
TFN (µg/L)	1300	2400	1900		860	970	890			2000	2200		1400			1800	2200	2000		1500	1500	1900		3400			1200	2900	
TFP(µg/L)	5	30	20		10	5	5			10	30		10			20	30	20		5	5	5		130			5	100	
Chlorophyll-a (µg/L)	0.5	1			4	36	0.5			15	14		0.5			0.5	0.5	1		0.5	0.5	0.5		5			1	1	
Chlorophyll-b (µg/L)	1		6		0.5	0.5	2			0.5	0.5		0.5			0.5	0.5	0.5		0.5	0.5	0.5		7			0.5	0.5	
Chlorophyll-c (µg/L)	0.5		5		0.5	3	2			1	2		0.5			0.5	1	2		0.5	0.5	0.5		7			0.5	0.5	
Phaeophytin-a (µg/L)	6		27		2	0.5	6			2	7		0.5			6	1	2		0.5	0.5	0.5		0.5			0.5	0.5	
Temperature (°C)	19.4	36.6	32.5			28.3	26.6			19.2	21.6		6.2			21.1	21	19.6		14.4	21	25.8		18.1			19	18.3	
Dissolved Oxygen (%)		61.4	214			119.5	116.6			120.8	120.4		79.5			102.1	120.2	116.4											
NO3 (mg/L)		0.01	0.01		0.01	0.02	0.005		0.01	0.01	0.01		0.01				0.01			0.01		0.01		0.01			0.005	0.01	
Turbidity (NTU)		10				1.8				1.1							8				2.5							1300	
Colour (TCU)		180				66				100							260				180							75	
TDS (g/L)		0.4				0.18				0.32							0.21				0.12							0.72	
Alkalinity (mg/L)		28				3				18							20				20							25	
Hardness (mg/L)		26				17				30							16				7							32	
Si (mg/L)		10				7				1.5							5.2				3.3								
Na (mg/L)		100				57				89							52.8				43.2								
Ca (mg/L)		4				2				5							3				1.1								
Mg (mg/L)		4				3				4							2.1				1.1								
K (mg/L)		8				3				7							4.6				2.7	2.7							
Mn (mg/L)		0.01				0.025				0.03											0.001	0.001							
Cl (mg/L)		150				160				135							85				62	62							
HCO3 (mg/L)		34				3				21							24				24	24							
CO3 (mg/L)		1				1				1							1				0.5	0.5							
SO4 (mg/L)		4				3				4							2.7				2.4								
Iron(mg/L)						0.025				0.18											0.17								
Tot Chlorophyll (µg/L)	8	1	38	0	7	40	10.5	0	0	18.5	23.5	0	2	0	0	7.5	3	5.5	0	2	2	2	0	19.5	0	0	2.5	2.5	0

Appendix 2. Aquatic invertebrate data

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

	TAXON	LowestIDNC	1998	2000	2002	2006	2008	occurrences
Protista	Arcella discoides	BP010102		1		1		2
	Arcella hemisphaerica	BP010104				1		1
	Arcella megastoma	BP010105				1		1
	Arcella vulgaris	BP010106		2				1
	Arcella sp. c (SAP)	BP0101A3	1					1
	Arcella cf. polypora (SAP)	BP0101A6		1	1			2
	Centropyxis aculeata	BP020101				1		1
	Difflugia sp.	BP030199				1		1
	Pontigulasia rhumbleri	BP030501				1		1
	Nebela galeata	BP040103			1			1
	Nebela cf. pulcherrima (SAP)	BP0401A1		1				1
	Lesquereusia modesta	BP070101				1		1
	Lesquereusia spiralis	BP070102				1		1
	Euglypha sp.	BP090199		1	1	1		3
Turbellaria	Turbellaria	IF999999	1	1		2	2	4
Nematoda	Nematoda	II999999	4	2	2	1	2	5
Nematomorpha	Nematomorpha	IJ999999				1		1
Tardigrada	Tardigrada	IR999999		1	1			2
Rotifera	Philodinidae	JB049999	1					1
	Bdelloidea small contracted of RJS (SAP)	JB9999A0	2	1	2			3
	Ptygura cf. barbata	JF0305A3		2				1
	Testudinella patina	JF050201			2			1
	Testudinella insinuata	JF050202			2	1		2
	Testudinella parva	JF050213		1				1
	Brachionus quadridentatus	JP020220	4	2	2	1		4
	Brachionus calyciflorus gigantea	JP020239	1					1
	Keratella procurva	JP020308				1		1
	Plationus sp. nov. (Goonaping) (SAP)	JP0205A0		2	2			2
	Colurella sp.	JP030199				1		1
	Lepadella biloba	JP030211	1		1			2
	Lepadella cyrtopus	JP030242		1				1
	Dicranophorus epicharis	JP040405		1		1		2
	Euchlanis dilatata	JP060101	1	1		1		3
	Euchlanis dilatata lucksiana	JP060107		2				1
	Euchlanis incisa	JP060110				1		1
	Euchlanis cf. meneta	JP0601A1	1	1				2
	Ascomorpha tundisii	JP070105		1				1
	Lecane bulla	JP090110		1	2	1		3
	Lecane closterocerca	JP090112	4		1	1		3
	Lecane curvicornis	JP090117			1	1		2
	Lecane flexilis	JP090123			1			1
	Lecane haliclysta	JP090128		1				1
	Lecane hastata	JP090130			1			1
	Lecane hornemanni	JP090132		1				1
	Lecane ludwigii	JP090136		1	2	1		3
	Lecane lunaris	JP090138	4		1			2
	Lecane nana	JP090142		1				1
	Lecane obtusa	JP090145			1			1
	Lecane papuana	JP090148				1		1
	Lecane quadridentata	JP090154	4	1	2	1		4
	Lecane signifera	JP090159		1	1	1		3
	Lecane latissima	JP090174			1			1
	Lecane cf. rhenana (SAP)	JP0901A9		1		1		2
	Lecane cf. bifurca (SAP)	JP0901B6	4					1
	Lindia (Neolindia) deridderae	JP100102		1				1
	Lindia tolurosa	JP100104				1		1
	Tripleuchlanis plicata	JP120301				1		1
	Tetrasiphon hydrocora	JP130101		1				1
	Cephalodella gibba	JP130201	1	2	1	1		4
	Cephalodella forficula	JP130202		1	1			2
	Monommata maculata	JP130409				1		1
	Monommata sp. B (SAP)	JP1304A2	1					1
	Notommata cerberus	JP130503		1				1
	Notommata glyphura	JP130510		1				1
	Trichocerca myersi	JP160325		1				1

	TAXON	LowestIDNC	1998	2000	2002	2006	2008	occurrences
	Trichotria truncata	JP170206		1				1
	Macrochaetus altamirai	JP170301	1		1			2
Mollusca	Ferrissia petterdi	KG060101	1				1	2
(aquatic snails)	Glyptophysa sp.	KG0702A5	3	2	2	1	2	5
Annelida	Glossiphoniidae	LH019999			1			1
(leeches and	Naididae (ex Tubificidae)	LO049999			1			1
earthworms)	Pristina longiseta	LO050501					1	1
	Pristina leidyi	LO050507				1		1
	Ainudrilus nharna	LO052101		1			3	2
	Enchytraeidae	LO089999		1				1
Acarina	Eylais sp.	MM030199	1	1	2	2	2	5
(water mites)	Limnesia dentifera	MM120101	2			1	3	3
	Acercella falcipes	MM170101			1			1
	Arrenurus sp.	MM230199					1	1
	Halacaridae	MM249999					2	1
	Oribatida sp.	MM9999A1	2	2	2	3	3	5
	Mesostigmata	MM9999A2	1	1	1		2	4
	Trombidioidea	MM9999A6	1	1	2		1	4
	Mesostigmata sp.	MM9999D2					2	1
Conchostraca	Eulimnadia vinculuma	OF0202A3	1	2	2	2	1	5
(clam shrimps)	Lynceus sp.	OF040199	3	2	2	2	2	5
Cladocera	Latonopsis brehmi	OG010201	1	2	2	1	4	5
(waterfleas)	Alona rigidicaudis	OG030212					3	1
	Alona affinis	OG030213			2			1
	Alona setigera	OG030214	1	2	2	1		4
	Alona willisi	OG030217	1	2	2	1		4
	Alona n. sp.? (nr. affinis) (SAP)	OG0302B0	1					1
	Alona kendallensis	OG0302F1				1	3	2
	Chydorus sp.	OG030999	1		1	1		3
	Ephemeroporus barroisi s.l.	OG031301	1	1	2	1		4
	Leberis aenigmatosa	OG031701		2				1
	Leberis diaphana vermiculata	OG031708	2		1	1	3	4
	Leberis cf. diaphanus	OG0317A4		2				1
	Rak labrosus	OG032701	1			1		2
	Rak sp. nov. a (Goonaping) (SAP)	OG0327A0	1					1
	Rak sp. nov. b (Venemores) (SAP)	OG0327A1	2		1			2
	Armatalona macrocopa	OG033401	3	2	2	1		4
	Ceriodaphnia n. sp. b (Berner sp.#2) (SAP)	OG0401A4	3					1
	Ceriodaphnia n. sp. a (Berner sp.#3) (SAP)	OG0401A5	1					1
	Scapholeberis kingi	OG040401	4	2	1	1	3	5
	Simocephalus elizabethae	OG040505	3		2	1	4	4
	Simocephalus gibbosus	OG040506	1	2	3	1		4
	Macrothrix breviseta	OG060201		2	2	1	1	4
	Macrothrix indistincta	OG060211	1		2			2
	Neothrix sp.	OG090399			1			1
Ostracoda	Limnocythere dorsosicula	OH010201	3	1		1		3
(seed shrimps)	Limnocythere sp. 447 (aff. porphyretica) (SAP)	OH0102A2	2					1
	Paralimnocythere sp. 262 (south-west) (ridged)	OH0103A1	2					1
	Candonopsis tenuis	OH070101	1					1
	Bennelongia australis	OH080301	4	3	3	3	3	5
	Candonocypris sp. 682 (?novaezelandiae) (SAP)	OH0804A0	2					1
	Cypretta baylyi	OH080501	3	2	1		4	4
	Cypretta sp. 527 (SAP)	OH0805A0	3	2	1		3	4
	Cypretta aff. globosa	OH0805A1	1					1
	Cypretta sp. 648 (=684 of SAP)	OH0805B2	2					1
	Ilyodromus sp. 566 (aff. amplicolis)	OH0819A2	3	2	1		3	4
	Ilyodromus sp. 255 (south-west, CB)	OH0819A3	3					1
	Ilyodromus sp. 630 (SAP)	OH0819A7	2	2				2
	Caboncypris nunkeri	OH082301	4	2	2	1	4	5
Copepoda	Boeckella sp.	OJ110199					2	1
	Calamoecia attenuata	OJ110203	3	3	2	2	4	5
	Microcyclops varicans	OJ310101	2	2	2	3	2	5
	Australocyclops palustrium	OJ310303	2	3	2	3		4
	Mesocyclops brooksi	OJ310703	3	3	2		3	4
	Australocamptus sp. 5 (SAP)	OJ6199A4	1		1			2
Amphipoda)	Austrochiltonia subtenuis	OP020102					1	1
Coleoptera	Haliplus fuscatus	QC060104	2		1		1	3
(beetles)	Haliplus gibbus	QC060105				1		1
	Uvarus pictipes	QC090701					1	1
	Limbodessus shuckhardi	QC091002				1	2	2
	Allodessus bistrigatus	QC091101	1	1	2	1	2	5
	Paroster sp.	QC091499		2	1			2
	Chostonectes sp.	QC091599			1			1
	Sternopriscus sp.	QC091899	2	2	2	1	1	5
	Megaporus sp.	QC092199	1	1	1	2	1	5

	TAXON	LowestIDNC	1998	2000	2002	2006	2008	occurrences
	Platynectes sp.	QC092299		1				1
	Lancetes lanceolatus	QC092401	1					1
	Hyderodes sp.	QC092899			1		1	2
	Onychohydrus sp.	QC093499	1	1	1	1	1	5
	Exocelina ater	QC093905			1			1
	Berosus approximans	QC110404	2	2	3	3	3	5
	Paranacaena littoralis	QC110904	1					1
	Enochrus eyrensis	QC111102	1		1		1	3
	Limnoxenus zelandicus	QC111401		1			1	2
	Paracymus pygmaeus	QC111601	1		2		1	3
	Hydrochus australis	QCA00106	1		2	1	1	4
Diptera	Promochlonyx australiensis	QD050201		2			2	2
(ghost midges,	Anopheles annulipes s.l.	QD070101	1		2			2
mosquitoes,	Aedes (Och.) ENM's sp nr stricklandi (SAP)	QD0705A0					2	1
midges,	Culex (Culex) annulirostris	QD070709				2		1
march flies)	Alluaudomyia sp.	QD090299			1			1
	Bezzia sp. 2 (SAP)	QD0904A0			1			1
	Culicoides sp.	QD090899	1			1		2
	Monohelea sp. 1 (SAP)	QD0919A0					1	1
	Dasyheleinae	QD0999A2		1				1
	Tabanidae	QD239999					1	1
	Dolichopodidae sp. A (SAP)	QD3699A0			1			1
	Sciomyzidae	QD459999	1	1			1	3
	Ephydridae	QD789999				1	1	2
	Procladius paludicola	QDAE0803	3	2	2	2	3	5
	Ablabesmyia notabilis	QDAE1102				2		1
	Paramerina levidensis	QDAE1201	1	1	1			3
	Parakiefferiella sp.	QDAF0399			1			1
	Corynoneura sp. (V49) (SAP)	QDAF06A2	1		1			2
	Paralimnophyes pullulus (V42)	QDAF1202			1			1
	Cricotopus 'parbicinctus'	QDAF15A0		1				1
	Gymnometriocnemus spp. (not V44 or V45)	QDAF2699				1		1
	Limnophyes vestitus (V41)	QDAF2801		2			2	2
	Orthocladiinae SO3 sp. A (SAP)	QDAF99B4			1			1
	Tanytarsus fuscithorax/semibarbitarsus	QDAH04D8	1					1
	Chironomus aff. alternans (V24) (CB)	QDAI04A0	3					1
	Dicrotendipes pseudoconjunctus	QDAI0611		1				1
	Dicrotendipes 'CA1' wheatbelt (was lindae) (SAP)	QDAI06A4				2		1
	Polypedilum nr. convexum (SAP)	QDAI08A2	1					1
	Cryptochironomus griseidorsum	QDAI1901				1		1
	Cladopelma curtivalva	QDAI2201	3		1	2		3
Hemiptera	Microvelia (Pacificovelia) oceanica	QH560101			1	1		2
(water striders,	Saldula brevicornis	QH600201	1		1			2
backswimmers,	Sigara truncatipala	QH650204			1	1		2
boatmen)	Agraptocorixa parvipunctata	QH650302				1		1
	Anisops thienemanni	QH670401	3		2			2
	Anisops hyperion	QH670402	2					1
Lepidoptera	Lepidoptera	QL999999		1	0			2
Odonata	Austrolestes analis	QO050101	2	3	2	3	1	5
(dragonflies,	Austrolestes annulosus	QO050102					2	1
Damselflies)	Hemianax papuensis	QO121201	2	1	2	2	2	5
	Diplacodes bipunctata	QO170701	2					1
	Hemicordulia tau	QO300102			1		1	2
Trichoptera	Acritoptila globosa	QT030201					2	1
(caddisflies)	Oecetis sp.	QT250799					1	1
	Triplectides australis	QT251103	1			1	1	3

Appendix 3. Waterbird data

Abundance of species for each seasonal survey at Lake Pleasant View.

		26/08/1998	9/11/1998	20/04/1998	29/08/2000	3/10/2000	12/02/2001	30/08/2002	15/10/2002	27/03/2003	1/09/2004	28/10/2004	23/03/2005	14/09/2006	18/10/2006	19/03/2007	28/08/2008	13/10/2008	26/03/2009	26/08/2010	24/10/2010	31/03/2011	10/08/2012	10/11/2012	22/03/2013
Pacific Black Duck	*Anas superciliosa*		1					1			1														
White-necked Heron	*Ardea pacifica*							1																	

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

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