Aquatic invertebrate communities of wetlands along the Jurien coast of Western Australia

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Wetlands are a prominent feature of the coastal strip north and south of Jurien Bay. However, assessment of their conservation values and their vulnerability to anthropogenic disturbance is hampered by a lack of knowledge about their biotas. In spring 2011 a survey of aquatic invertebrates was undertaken to provide data that could be used to assess 1) potential effects of expanded gypsum mining in the region's salt lakes and 2) the dependence of the fauna on groundwater as a contribution to water resource planning. The survey collected 194 species, bringing the total number of species known from this area to 215. The fauna was dominated by species that are widespread in at least south-western Australia, with very few rare or restricted species. Community structure was strongly correlated with salinity, ionic composition, aquatic plant cover, organic litter and colour. The salt lakes had heterogeneous faunas and may be an important refuge for the endemic brine shrimp *Parartemia extracta*. In a region in which most wetlands are saline and/or ephemeral, the springs represent an important ecological refuge from drought for a large proportion of the fauna. However, there was little evidence of a groundwater-adapted fauna at the springs and there were few epigean species known to be associated with groundwater discharge.

KEYWORDS: aquatic invertebrates, conservation, springs, Western Australia, wetlands

INTRODUCTION

Extending north and south of Jurien Bay, along the mid-west coast of Western Australia, lies one of a number of complexes of mostly saline coastal wetlands located between Holocene dunes of the Perth Basin (Figure 1). Other such systems include the Hutt Lagoon wetlands (Pinder *et al.* 2012), the Yalgorup system (Hale & Butcher 2007) and the Cooloongup system (Conservation Commission of Western Australia *et al.* 2010). This region is hydrologically complex, reflected in the wide variety of wetland types present, including a series of partly connected saline playas and samphire flats known as the Leeman Lagoons, plus a variety of springs, vegetated swamps and a permanent anchialine lake (Lake Thetis). With human populations growing rapidly along this coast (Government of Western Australia 2012) planning for sustainable water resource utilisation is essential. At present there is very little information on epigean aquatic biodiversity in this region and its relationships with water quality and quantity, other than a couple of wetlands sampled by Pinder *et al.* (2004) and Susac *et al.* (2009) and listings of ad-hoc aquatic invertebrate collections from surficial and subterranean karstic habitats (Susac 2007). There has also been some assessment of stygofauna from aquifers in the Jurien area (Biota Environmental Sciences 2002). This paper contributes to sustainable water resource planning by describing and assessing the conservation significance of the invertebrate faunas of wetlands in the region, including many that are groundwater dependant. Also underlying this survey was the need to investigate patterns in the biodiversity of the region's salt lakes to inform decisions about potential expansion of gypsum mining.

Study area

The study area (Fig. 1) occupies approximately 500 km^2 of the Quindalup and Spearwood dune systems between about Cervantes and Coolimba; part of the northern Swan Coastal Plain which extends from the ocean inland to the Gingin Scarp. The area straddles the northern tip of the Perth IBRA7 subregion SWA02 and the western extent of the Lesueur Sandplains IBRA7 subregion GES02 (sensu Commonwealth of Australia 2012). A large proportion of the study area lies within conservation estate, with the largest reserves being Beekeepers Nature Reserve (66277 ha), Southern Beekeepers Nature Reserve (10862 ha) and Lesueur National Park (27234 ha). The region's climate is "subtropical with distinctly dry summers" (Bureau of Meteorology's modified Koppen climate classification: http://www.bom.gov.au/climate/environ/other/koppen_explain.shtml#appendix1, accessed 11 June 2013), with average annual rainfall between 500 and 600 mm (< 50 mm in summer) and average annual evaporation about 2000 mm. Jurien Bay has an average annual maximum temperature of 24.8°C and rainfall of 534 mm.

The region's wetlands have been mapped and classified using a modified geomorphic wetland classification system (Semeniuk 1987) by the Department of Environment and Conservation (DEC) (2012a). This was a 'stage 2' mapping and classification exercise *sensu* Department of Environment and Conservation (2007), which means it was designed to provide 'preliminary evaluation and prioritisation for future detailed assessment'. The most extensive wetlands are seasonally inundated salt lakes, of which the northern examples are known as the Leeman Lagoons. Water depths in the playas are determined by direct rainfall, runoff, tidal fluctuations, evapotranspiration and groundwater discharge from the Tamala Limestone (Kern

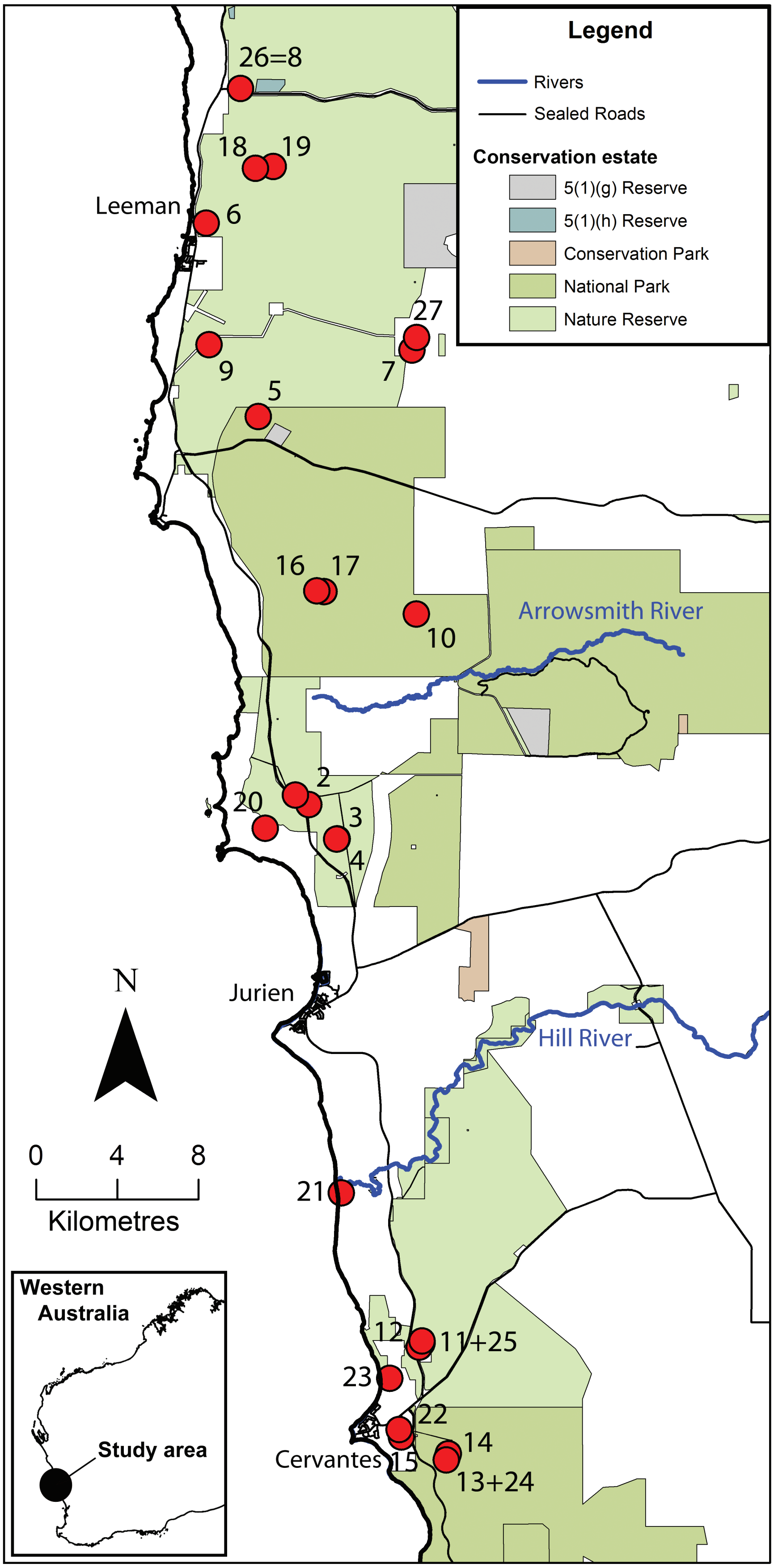

Figure 1. Map showing numbered sampling locations (see Table 1).

Table 1. List of wetlands sampled.

Site No.	Site name/ location	Wetland type	Date sampled	Latitude (S)	Longitude (E)	Invertebrate community group	Geomorphic class
1	Salt lake 9km N of Jurien.	Seasonal saline playa	12/09/2011	30.207	115.038	1	Sumpland
2	Samphire flat S of site 1	Samphire flat	12/09/2011	30.202	115.031	3	Sumpland
3	Samphire flat adjacent to site 4	Samphire flat	13/09/2011	30.223	115.051	3	Sumpland
4	Sedge swamp adjacent to site 3	Sseepage fed sedge swamp	13/09/2011	30.223	115.051	3	Sumpland
5	Samphire flats N of Coorow-Greenhead Road	Samphire flat	13/09/2011	30.022	115.013	2	Barlkarra
6	Salt lake near Leeman = site sampled by Susac et al. (2009)	Seasonal saline playa	13/09/2011	29.929	114.989	1	Sumpland
7	Little Three Springs (southern occurrence)	Spring	14/09/2011	29.990	115.087	-	Spring
8-99/8-11	Salt lake north of Coolimba-Eneabba Road = SPS178 of Pinder *et al*. (2004)	Seasonal saline playa	23/09/1999 14/09/2011	29.865	115.005	2	Sumpland
9	Salt lake 2km SSW of Leeman airstrip	Seasonal saline playa	14/09/2011	29.987	114.990	1	Sumpland
10	Diamond of the Desert Spring	Spring	15/09/2011	30.116	115.089	4	Spring
11	Samphire pan in Dingo Swamp complex	Samphire flat	16/09/2011	30.464	115.091	3	Sumpland
12	Salt lake in Dingo Swamp complex	Seasonal saline playa	16/09/2011	30.465	115.090	2	Sumpland
13	Claypan 4km ESE of Cervantes. Within wetland known locally as Bradley Springs	Seasonal freshwater lake	19/09/2011	30.518	115.103	5	Sumpland
14	Mound Spring 4km ESE of Cervantes. Within wetland known locally as Bradley Springs	Spring	19/09/2011	30.516	115.104	5	Spring
15	Lake Thetis	Permanent salt lake	19/09/2011	30.508	115.082	-	Lake
16	Eatha Spring	Spring	20/09/2011	30.105	115.045	-	Spring
17	Salt Lake adjacent to Eatha Spring	Seasonal saline playa	20/09/2011	30.105	115.041	1	Sumpland
18	Deadhorse Soak	Spring	21/09/2011	29.902	115.020	5	Palusplain
19	Sedge swamps west of Deadhorse Soak	Sedge fringed seasonal freshwater lake	21/09/2011	29.903	115.012	5	Sumpland
20	Moat wetland	Saline moat around earth mound	22/09/2011	30.218	115.017	2	Self-emergent
21	Sedge swamps at mouth of Hill River	Seepage fed sedge swamp	22/09/2011	30.392	115.053	3	Estuary-peripheral
22	Lake Thetis sedge swamp	Rehabilitated gravel pit	22/09/2011	30.505	115.080	5	Sumpland
23	Wealacutta Pool	Endorheic creekline	23/09/2011	30.480	115.076	5	River
24	Spring within site 13	Spring	27/02/2012	30.519	115.103	5	Spring
25	Spring in Dingo Swamp complex (within site 11)	Spring	27/02/2012	30.462	115.091	2	Sumpland
26	Little Three Springs (northern occurrence) = SPS202 of Pinder *et al*. (2004)	Spring	24/09/1999	29.865	115.005	4	Self-emergent

1997, Rutherford *et al.* 2005). The salt lakes are fringed by complexes of samphire dominated flats and basins, sedge swamps and springs, many of which are connected during periods of high water levels. Many of the springs are also maintained by freshwater discharge from the Tamala limestone section of the superficial aquifer. Some of the springs lie next to, or even within, the saline wetlands. Further inland, the Eneabba aquifer and possibly the Lesueur aquifer discharge at a number of additional springs (e.g. Little Three Springs and Diamond of the Desert Springs) (Rutherford *et al.* 2005). The freshwater sedge swamp on the southern side of the Hill River estuary appears to be maintained by water seeping from the primary dunes. A discontinuous narrow channel between Cervantes and Jurien Bay wind through primary and secondary dunes and appear to be old creek lines that no longer have surface connections with the ocean but retain permanent water. A number of other more ephemeral wetlands in the primary dunes are present but were not sampled because they lacked surface water when visited and would rarely have much surface water at any time. Finally, Lake Thetis is a permanent, saline collapsed doline lake, again within the Tamala Limestone, with a rocky bed and stromatolites listed as a threatened ecological community (Grey *et al.* 1990, Department of Environment and Conservation 2012b). There are also a few streams traversing the plain, most of which discharge into wetlands and caves rather than to the sea, the exception being Hill River, but none of these were sampled.

METHODS

Site selection

Twenty five wetlands were selected to represent the range of wetland water chemistry, hydrology and morphology present within the study area (Fig. 1, Plate 1 and Table 1). Data from two sites sampled in 1999 by Pinder *et al.* (2004) were also included in our analyses. One of the latter is the same as site 8 sampled in 2011for the present survey, so the two samples from this site are referred to as 8-99 and 8-11. The other site sampled in 1999 is referred to as site 26 in this paper but was coded as SPS202 by Pinder *et al*. (2004). Most wetlands are not formally named. Sampled wetlands included saline playas (sites 1, 6, 8, 9, 12 and 16, Plate 1F), samphire dominated flats or shallow basins (sites 2, 3, 5 and 11, Plate 1A), springs fed from groundwater discharging from the Tamala limestone and mostly within or adjacent to saline wetlands (sites 14, 16, 20, 24 and 25) (Plate 1E), more isolated eastern springs fed by the Eneabba and Lesueur aquifers (sites 7, 10 and 18, Plate 1B), a sedge swamp fed by water seeping from dunes at the mouth of the Hill River (site 21), a small area of sedges (site 4) watered by seepage from a dune near one of the salt lakes, a freshwater lake fringed by sedges (site 19, Plate 1D), Lake Thetis (site 15), an excavated wetland north of Lake Thetis (site 22) and Wealacutta Pool which is section of the relict stream channel north of Cervantes (site 23, Plate 1C).

Sampling

Water temperature and pH were measured in the field using a TPS WP-81 meter. Turbidity (nephelometric turbidity units – NTU) was measured with a TPS WP-88 turbidity meter. Up to 900 mL of water was passed through a glass microfiber filter paper and the paper retained and frozen for analysis of chlorophyll concentration. The filtrate was passed through a 0.45 μm pore filter paper and frozen for analysis of total filterable nitrogen and phosphorus concentrations. Unfiltered water was collected for analysis of total phosphorus and nitrogen concentrations, colour (true colour units – TCU) and concentrations of major ions. Analytical methods were APHA *et al.* (2012) 4500N-C,I for total and filterable nitrogen and phosphorus, APHA *et al.* (2012) 4500NO3-I for nitrate+nitrite, APHA *et al.* (2012) 2540C for total dissolved solids, APHA *et al.* (2012) 2120-C for colour, APHA *et al.* (2012) 1020 for chlorophyll concentration, APHA *et al.* (2012) 3120 for K^+, Na^+, Ca2$^+$ and SO_4^{2-}, colourimetric analysis for Cl^- and APHA *et al.* (2012) 2320 for bicarbonate/carbonate/alkalinity. All analyses performed by ChemCentre (www.chemcentre.wa.gov.au) on samples submitted 1 to 3 weeks after collection.

At each site two invertebrate samples were collected: a plankton sample using a net with 50 μm mesh to sweep through the water column and gently through sparse vegetation and a benthic sample using a net with 250 μm mesh to sample the dominant habitats (*e.g.* open water, detritus, vegetation and substrates). Each sample involved sweeping for a total of about 50 m (usually not contiguous). The benthic samples were elutriated in the field to remove heavier inorganic material, leaves and woody debris were washed and discarded and then the sample was preserved in ethanol. The plankton sample was preserved in buffered formalin. The entire contents of each sample were sieved and sorted in the laboratory and representatives of each taxon seen during sorting were removed. Invertebrates, other than rotifers and protozoans, were identified to species level where possible.

Data analysis

All analyses were performed using either the R statistical software v 3.0.0 (R Development Core Team 2013) run within RStudio 0.97.449 (RStudio 2013) or with Primer (Primer-E Ltd 2008). The dissimilarity index for all multivariate analyses was Bray-Curtis. Agglomerative cluster analysis of the invertebrate data was performed using the function hclust (R Development Core Team 2013) using average linkage and significance of clusters was tested using simprof in package clustsig (Whitaker & Christman 2010). Non-hierarchical cluster analysis was performed using the PAM function (partitioning around medioids) in the cluster package v 1.14.4 (Maechler 2013). The simper routine in vegan (Oksanen *et al.* 2013) was used to identify species characteristic of community groups identified by the cluster analysis. Non-metric multidimensional scaling ordinations were performed using the metaMDS function in the vegan package. These analyses excluded taxa not identified to at least family level and identifications were sometimes merged or excluded where identifications were incomplete (e.g. where there were only juveniles or the wrong sex). Concentrations of major ions were converted to percent contribution to total millequivalence of anions or cations. Abiotic variables were transformed to approximate normality and where two variables were highly

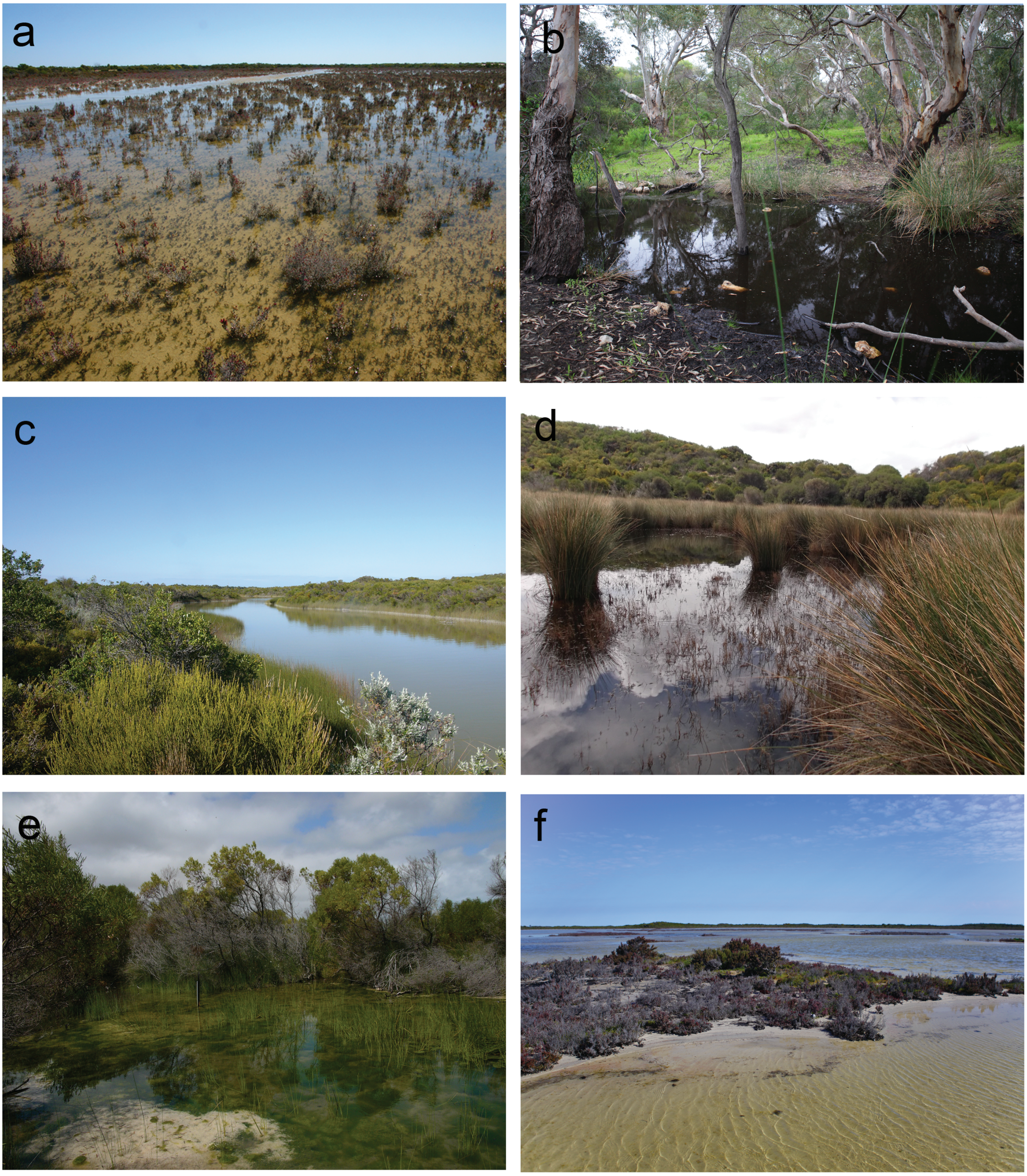

Plate 1. Photographs of representative wetlands. A, site 2: a samphire dominated flat; B, site 10, Diamond of the Desert Spring; C, site 23: Wealacutta Pool; D, site 19, a large freshwater sedge dominated wetland; E, site 14, pool on the edge of a mound spring ESE of Cervantes; F, site 9: a saline playa SSW of Leeman.

correlated (r^2>0.9) one was excluded from analyses. Distance-based redundancy analysis (db-RDA in the Primer DistLM routine) was used to identify variables that individually explained a significant proportion of variation in community composition, and these were then used in a multi-variable db-RDA, using step-wise model building. R^2 adjusted for number of parameters was used to assess model performance.

RESULTS

Physico-chemical environment

Table 2 lists physical and chemical data for the 25 wetlands sampled in 2011/12 and the two sites sampled by Pinder *et al.* (2004). Most sites were shallower than 50 cm when sampled, with the deepest being Lake Thetis at 110 cm. Total dissolved solids ranged from 0.66 g/L (site 10, Diamond of the Desert Spring) to 97 g/L (site 8-11 salt lake north of Coolimba-Eneabba Road), with 7 sites being fresh (< 3 g/L), 8 subsaline (3 to <10 g/L) and 12 saline (≥ 10 g/L). All were Na^{2+} and Cl^- dominated, mostly with Na^{2+} >70% (of milliequivalence) and Cl^- > 80%. Site 14 (a mound spring within the Bradley Springs complex) was notable for having only 59% Na^{2+} and 66% Cl^-, compensated for by higher Ca^{2+} and HCO_3^{2-} than all other sites. Based on ionic composition, salts in most of the saline wetlands (tds >10 mg/L) would precipitate via pathway 1A of Radke *et al.* (2002) (precipitation to Na^+, Ca^{2+}, Mg^{2+} and Cl^-) except for 8-99 and site 5 (samphire flats north of Coorow-Greenhead Road) which would precipitate to Na^+, Mg^{2+}, Cl^- and SO_4^{2-} via pathway 1B.

Clear water was the rule (NTU ≤ 33), although site 25 (the spring in Dingo Swamp) had a higher than average turbidity of 94.8 NTU resulting from fine clays accumulating at the spring following water receding

Table 2. Physical and chemical data for the sampled wetlands. The numbers for macrophyte cover and substrate are ranges of estimated surface area coverage: 1 = <20%, 2 = 21–40%, 3 = 41–60%, 4 = 61–80%, 5 = >80%.

	Site number (see Table 1)													
	1	2	3	4	5	6	7	8–11	8–99	9	10	11	12	13
Habitat														
Submerged macrophyte cover (%)	1	1	5	1	1	3	0	0	2	4	2	5	1	5
Emergent macrophyte cover (%)	0	3	2	5	5	0	0	0	2	1	1	1	3	1
Depth (cm)	15	12	28	21	70	26	35	10	70	10	34	45	14	110
Water chemistry														
Total dissolved solids (g/L)	28	12	6.8	6.6	34	71	4.8	97	24	55	0.66	8.5	27	5.4
Sum major ions (mg/L)	26.7	12.0	6.9	6.8	32.0	71.5	5.5	92.9	22.8	54.3	0.8	8.2	24.3	5.8
pH	8.68	8.92	8.47	7.88	8.07	8.34	7.90	8.31	8.62	8.68	7.81	8.59	8.98	9.02
Total nitrogen (mg/L)	1.2	5.6	3.3	3.4	4.2	1.3	2.2	4.6	–	3.3	0.46	2.6	3.7	1.7
Total filterable nitrogen (mg/L)	1.1	2.4	3.3	1.9	3.2	1.3	1	3.2	1.4	2.7	0.43	1.2	1.5	1.4
Nitrate (mg/L)	<0.01	<0.01	0.01	0.02	0.02	0.01	0.03	<0.01	0.01	0.01	0.01	0.01	0.01	0.03
Total phosphorus (mg/L)	<0.01	0.34	0.03	0.1	<0.01	<0.01	0.61	0.01	–	<0.01	0.02	0.01	0.02	<0.01
Total filterable phosphorus (mg/L)	<0.01	<0.01	0.02	0.05	<0.01	<0.01	0.33	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Total chlorophyll (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	0.005	<0.001	<0.001	<0.001
Temperature (0C)	26.4	27.4	17.9	16	30.4	27.6	17.5	29.9	23.1	28.1	24.5	18.9	20.2	19.2
Turbidity (NTU)	1.2	11.5	1.6	1.6	3	0.8	19.4	5.5	2.6	11.8	10.5	0	3.6	0.5
Colour (TCU)	5	46	220	310	180	5	280	6	16	9	120	100	22	82
Sodium (% millequivalents)	77.03	79.73	77.35	76.14	74.99	83.88	73.78	81.21	72.17	78.34	82.93	76.60	77.51	80.59
Calcium (% millequivalents)	4.41	4.93	6.69	8.08	15.32	5.70	10.18	6.45	12.96	7.03	6.21	8.32	8.55	6.22
Magnesium (% millequivalents)	16.75	13.34	14.26	14.11	8.00	8.44	10.95	9.56	13.34	12.65	9.43	12.66	12.01	11.34
Potassium (% millequivalents)	1.81	2.00	1.70	1.67	1.69	1.98	5.09	2.78	1.52	1.97	1.43	2.42	1.93	1.85
Chloride (% millequivalents)	80.58	86.74	83.65	83.55	86.22	90.94	79.11	90.95	81.89	86.64	85.20	81.87	83.30	88.09
Sulphate (% millequivalents)	18.87	11.15	10.25	9.72	12.80	8.86	2.76	8.93	17.57	13.17	5.59	15.06	16.35	9.17
Bicarbonate (% millequivalents)	0.35	2.09	6.08	6.72	0.98	0.13	18.11	0.09	0.53	0.08	9.08	2.42	0.18	1.77
Carbonate (% millequivalents)	0.20	0.01	0.01	0.01	0.00	0.07	0.02	0.04	0.01	0.10	0.13	0.65	0.17	0.98
Substrate														
silt+clay	3	2	2	1	5	1	2	3	5	4	3	4	5	4
sand+gravel	3	4	5	5	1	5	4	3	0	2	3	2	2	3
pebble+cobble	0	0	0	0	0	0	0	0	0	0	1	0	0	0
boulder	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bedrock	0	0	0	0	0	0	0	0	0	0	0	0	0	0
organic soil	0	0	0	0	0	0	0	0	–	0	0	0	0	0
benthic mats	1	1	5	0	5	1	0	5	–	4	0	4	0	0
particulate organic matter	0	1	0	2	0	0	5	0	1	0	5	0	0	1
litter (leafs and sticks)	0	1	0	2	1	0	4	0	1	1	5	0	0	1
logs	0	0	0	0	0	0	0	0	0	0	1	0	0	1

in the samphire pan (site 11) in which the spring lies. No sites had particularly coloured water, although the hydrologically connected and groundwater-fed sites 3 and 4 had water with 220 and 310 TCU respectively and site 7 (southern occurrence of Little Three Springs) had 280 TCU, the latter probably a result of tannins from the abundant leaf litter.

About half of the sites had no detectable phosphorus and most of the rest had concentrations at or only slightly above detection limits (0.01 to 0.02 mg/L). The most notable exceptions for phosphorus being site 2 (one of the samphire flats) and site 7 (southern occurrence of Little Three Springs) which had 0.34 mg/L and 0.61 mg/L total phosphorus respectively. Site 2 had no detectable filterable phosphorus which means it was all in particulate form or biologically assimilated. There was also no detectable chlorophyll at that site but there was an abundance of the cladoceran *Dapnia wardi* so the phosphorus may have been largely assimilated by grazing on phytoplankton. Site 7 also had no detectable chlorophyll even though half of the phosphorus was dissolved. This site consisted of a series of isolated shallow pools (the water sample was taken from the largest pool) with abundant leaf litter so the phosphorus may have come from decaying plant matter plus animal faeces around these, with algal growth limited by the dense canopy cover. Some sites had moderately high nitrogen (total > 3 mg/L) but these were all sites with TDS >6 g/L and some saline wetlands tend to be

Table 2. (cont.)

	Site number (see Table 1)												
	14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Habitat													
Submerged macrophyte cover (%)	4	0	0	1	5	5	1	5	5	5	0	0	1
Emergent macrophyte cover (%)	1	1	5	1	1	3	1	5	5	1	1	1	1
Depth (cm)	41	120	15	20	37	15	36	50	25	45	77	23	40
Water chemistry													
Total dissolved solids (g/L)	0.76	50	16	66	2	2.3	27	3.3	3	5.7	1.3	0.98	2.3
Sum major ions (mg/L)	0.9	49.4	15.9	68.3	2.3	2.5	24.0	3.3	3.2	6.0	1.5	1.1	2.5
pH	7.99	8.14	7.17	7.90	7.60	7.54	7.83	7.02	8.05	9.18	8.25	7.95	8.1
Total nitrogen (mg/L)	2	3.1	2.3	1.9	0.54	0.37	4.6	1.6	1	2.8	2.6	0.54	–
Total filterable nitrogen (mg/L)	2	2.9	2.3	1.6	0.54	0.29	4	0.76	1	1.8	2.6	0.54	0.77
Nitrate (mg/L)	1.7	0.01	1.8	<0.01	0.24	0.17	0.02	<0.01	<0.01	0.01	11	0.31	<0.02
Total phosphorus (mg/L)	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.07	0.01	0.01	<0.01	<0.01	–
Total filterable phosphorus (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Total chlorophyll (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.001	0.01
Temperature (0C)	23.2	20.6	21.8	25	21.2	21.2	–	19.5	20	13	23.8	29.3	18
Turbidity (NTU)	0	0	0	11.5	1	0	0.4	2.8	1.8	33	8.1	94.8	4.5
Colour (TCU)	6	2	3	4	26	11	190	190	100	27	6	10	100
Sodium (% millequivalents)	59.24	83.02	80.97	80.83	73.92	71.11	76.62	81.25	75.61	80.92	62.61	59.79	77.78
Calcium (% millequivalents)	30.55	3.26	6.46	6.72	16.61	19.40	9.00	5.54	9.86	1.52	22.10	23.16	4.89
Magnesium (% millequivalents)	8.81	11.32	10.93	10.01	7.66	8.08	12.40	11.20	12.70	15.63	14.12	15.08	14.29
Potassium (% millequivalents)	1.41	2.41	1.63	2.44	1.81	1.41	1.98	2.01	1.82	1.93	1.17	1.97	3.04
Chloride (% millequivalents)	66.41	91.57	89.67	89.25	82.08	80.27	86.41	87.73	80.45	85.48	72.37	68.65	81.72
Sulphate (% millequivalents)	5.47	7.79	8.44	10.55	4.13	5.19	11.54	7.72	8.42	6.22	6.96	7.56	3.47
Bicarbonate (% millequivalents)	28.00	0.50	1.88	0.19	13.74	14.50	2.04	4.52	11.10	4.83	20.52	23.61	14.73
Carbonate (% millequivalents)	0.11	0.14	0.01	0.02	0.05	0.04	0.00	0.03	0.03	3.47	0.14	0.18	0.08
Substrate													
silt+clay	3	0	3	3	1	4	5	4	2	1	5	5	1
sand+gravel	2	1	1	3	1	2	1	3	5	5	1	1	5
pebble+cobble	0	1	0	0	1	0	0	0	0	0	0	0	1
boulder	0	1	0	0	0	0	0	0	0	0	0	0	0
bedrock	0	4	0	0	4	0	0	0	0	0	0	0	0
organic soil	1	0	3	0	0	0	0	0	0	0	0	0	–
benthic mats	0	0	0	0	0	0	5	1	0	0	0	0	–
particulate organic matter	0	0	0	0	0	0	1	0	0	5	0	0	–
litter (leafs and sticks)	1	0	1	0	1	1	1	1	1	1	0	0	2
logs	0	0	1	0	0	0	0	0	0	0	1	0	1

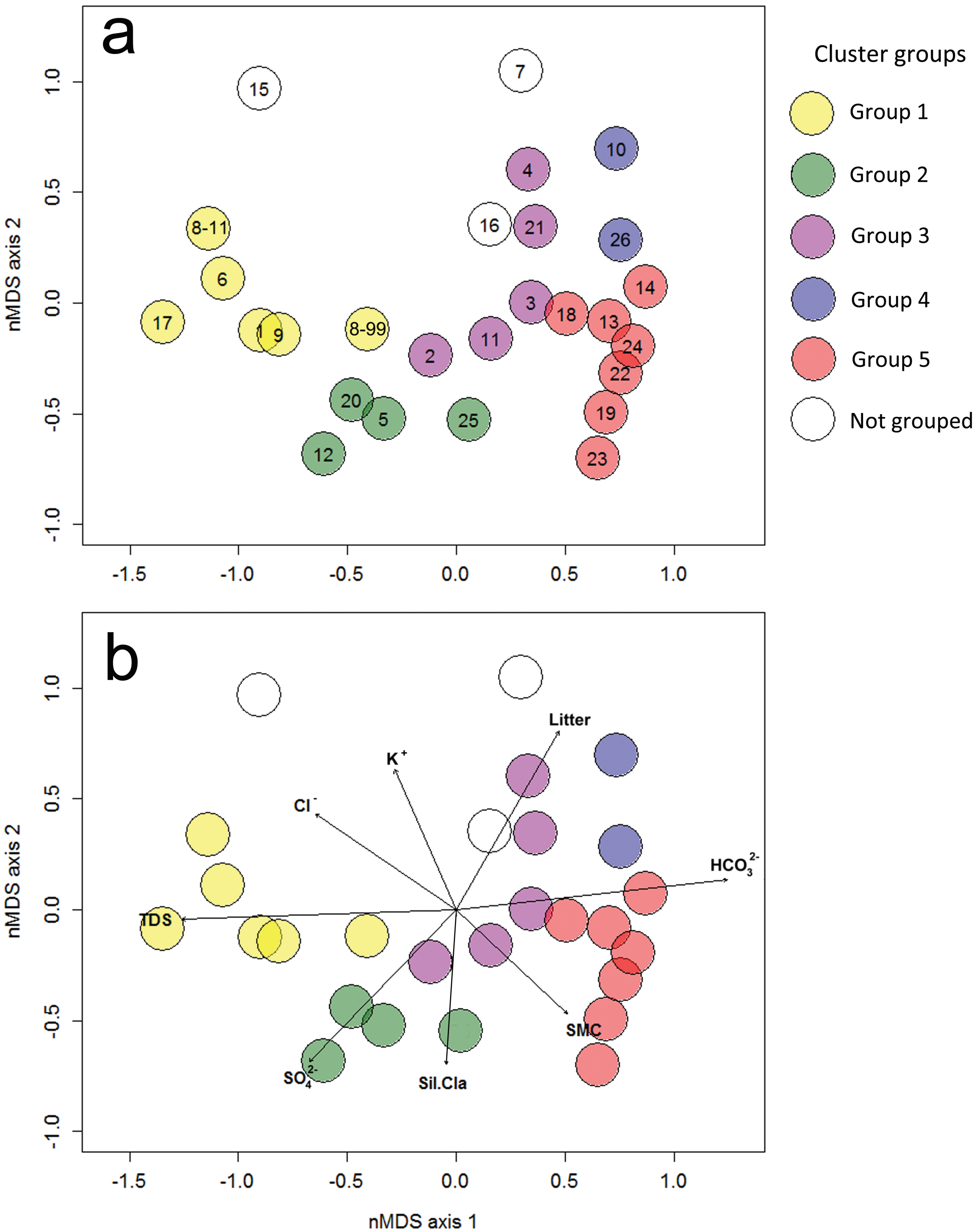

Figure 2. Two dimensional nMDS ordination of the Jurien invertebrate data. a, plot showing numbered sites coloured according to their membership of groups in the cluster analysis; b, same ordination with vectors indicating direction and strength of the relationships between environmental variables and ordination axis scores (representing community composition). TDS = total dissolved solids, Litter = leaf litter cover class, Logs = log cover class, SMC = submerged macrophyte cover class, Sil.Cla = silt+clay cover class. Stress = 0.17.

naturally high in nitrogen (Pinder *et al.* 2004). Average nitrogen concentration in freshwater wetlands was 1.1 g/L. Only two sites had chlorophyll much above the limit of detection (0.001 mg/L): site 27 (northern Little Three Springs) with 0.01 mg/L and site 26 (the playa north-east of Jurien Bay) with 0.009 mg/L.

Sediments were mostly dominated by silt/clay or sand/gravel or both, but Lake Thetis (site 15) and Deadhorse Soak (site 18) had limestone beds while site 16 (Eatha Spring) had primarily organic substrate. Few other sites had much organic matter, but the southern Little Three Springs (site 7) and Diamond of the Desert Spring (site 10) both had a layer of litter and particulate organic matter over the sediment and the palaeocreek (site 23) had a layer of organic particulates over the bed. Some of the samphire flats and other saline sites (sites 3, 5, 9 and 20) had mats of benthic algae. Coarse organic debris was usually scattered, except at site 7 (southern Little Three Springs) and site 10 (Diamond of the Desert Spring) which both consisted of pools under a canopy of trees.

Most of the saline playas had partial to nearly complete cover of *Ruppia* and/or Characeae across the bed though some were largely bare. These were invariably fringed by *Tecticornia* dominated plant communities, with this sometimes inundated. The *Tecticornia* dominated saline flats also often had a cover of *Ruppia* and/or Characeae, sometimes with patches of sedges. The palaeocreek had an almost complete and dense cover of Characeae with a narrow fringe of sedges along the banks. The springs varied from having no submerged or inundated plants (e.g. southern Little Three Springs, site 7) to almost complete cover of emergent macrophytes (Eatha Spring, site 16) or submerged macrophytes (Deadhorse Soak, site 18).

Invertebrate diversity

A total of 195 aquatic invertebrate taxa were collected during the survey reported here and an additional 20 species were recorded in the two sites sampled by Pinder *et al.* (2004), bringing the total to 215 taxa (Appendix 1). One of the species collected in 2011 (a *Lynceus* clam shrimp) was an opportunistic collection from a drying freshwater flat and was not included in analyses. Richness per sample ranged from 8 (site 6: one of the saline playas) to 72 (site 26: northern Little Three Springs) with an average of 30 and a median of 28. Most species collected in the present study (119) were insects, of which 36 were beetles and 48 were diptera. Most non-insects were ostracods or copepods (22 and 23 species respectively), annelids (12), water mites (12) or cladocerans (10). The frequency distribution of species occurrence was highly skewed with 43% of species occurring only once and only 8% occurring in more than a third of sites. Just over 40% of those singleton species occurred in one of just three wetlands: Deadhorse Soak (site 18), the sedge swamps west of Deadhorse Soak (site 19) and northern Little Three Springs (site 26).

Invertebrate community classification

The agglomerative cluster analysis of sites based on their invertebrate communities produced a dendrogram with five cluster groups, all supported by a simprof analysis, plus three sites that did not group with any others, at a uniform dissimilarity value of 0.30. PAM cluster analyses with 3 to 8 groups produced almost identical clustering, including separation of the same three individual sites at the 8 group level, so the hierarchical nature of the agglomerative analysis did not constrain optimisation of clustering. These groups also largely separated from one another in a two-dimensional ordination (Fig. 2a). Summary statistics for these communities are provided in Table 3 which shows that 127 species (about 60% of the total) only occurred in one of the cluster groups or in one of the three sites that didn't group with others. The highest level grouping in the cluster analysis separated the more saline wetlands (groups 1 and 2 plus Lake Thetis: tds 0.98 – 97 g/L, median 31) from fresh to subsaline wetlands (groups 3 to 5 plus Eatha Spring and northern Little Three Springs: TDS 0.66 – 16 g/L, median 4.8).

Table 3. Summary statistics for the invertebrate community groupings from the cluster analysis.

Group	Number of sites	Number of species in group	Number of species unique to group/site	Average richness	Salinity range (g/L)
1	6	38	4	14	24–71
2	4	52	5	21	(0.98) 27–34
3	5	89	18	38	3.3–12
4	2	79	26	50	0.66–2.3
5	7	127	60	42	0.76–5.7
site 7		20	5	–	4.8
site 15		10	5	–	50
site 16		27	4	–	16

Group 1. Six saline seasonally inundated playas (24 to 97 g/L) that were fringed with samphire but with little to no samphire across the bed, and mostly with substantial cover of submerged macrophytes (mostly *Ruppia*). Communities in these wetlands were more likely than those of other wetlands to include a number of halophilic ostracods (*Diacypris compacta*, *Reticypris clava*, *Platycypris baueri* and *Australocypris insularis*) and the dipterans Dolichopodidae sp. and *Tanytarsus barbitarsus*.

***Lake Thetis* (site 15)**. The community from this permanent saline wetland included numerous species not found within the other surveyed wetlands, including *Capitella* polychaetes, the amphipod *Melita kauerti* and copepods Laophontidae sp. 1 and *Halicyclops spinifera*.

Group 2. Four moderately saline wetlands (0.98 to 34 g/L), including an open playa with *Ruppia*, two wetlands with extensive samphire communities on the bed and a freshwater spring. These wetlands tended to have finer sediments than those in group 1. The spring, site 25, was located in the middle of a samphire pan (site 11) and is only fresh once the pan dries. The fauna in this spring has to cope with the saline phase when the pan is flooded (tds of 8.5 when sampled but probably higher at times) so it is comprised of salt-tolerant species even when the fresh spring is the only water present. Compared to communities in other wetlands, group 2 had more frequent occurrence of the ostracod *Diacypris spinosa*, dipterans Stratiomyidae and Ephydridae sp. JCS2, *Coxiella* snails, the beetle *Berosus discolor* and copepod *Apocyclops dengizicus*.

Eatha Spring (site 16). Despite its relatively high salinity of 16 g/L, this site clustered with fresh to subsaline swamps, probably because it consists of a freshwater seepage flowing into a salt lake. This is reflected in the invertebrate fauna including both halophilic species such as the midge *Tanytarsus barbitarsus* and cladoceran *Daphnia truncata*, euryhaline species such as the *Austrochiltonia subtenuis*, and species more usually associated with freshwater. The dual nature of this site would have contributed to it clustering separately to other sites. It was also the only site with oribatid mite sp. JCS1, darwinulid ostracods and gilgies (*Cherax quinquecarinatus*).

Group 3. Communities inhabiting five subsaline to mildly saline wetlands (3.3 – 12 g/L) including three samphire flats and three sedge swamps, mostly with >50% emergent vegetation and some with extensive growth of submerged macrophytes. These wetlands tended to have higher nitrogen concentrations than other fresh to subsaline wetlands. These communities were characterized by more frequent occurrence of many species, most notably the ostracod *Cyprinotus cingalensis*, haliplid and scirtid beetles, mesostigmatid mites, chironomids *Tanytarsus semibarbitarsus* and *Corynoneura* sp. V49 and the copepod *Boeckella triarticulata*.

Group 4. Communities from two of the three more isolated inland springs: Diamond of the Desert Spring (site 10) and northern Little Three Springs (site 26). The other inland spring (the southern occurrence of Little Three Springs) clustered away from all other sites. These springs were both fresh and had little macrophyte growth, probably due to the canopy cover of the woodland in which they were situated which also contributed to relatively high amounts of decomposing leaf litter. A third of species occurring in one or both of these two wetlands did not occur in any other sites. These were the only communities with *Necterosoma darwini* and two of only three communities with the mosquito *Aedes alboannulatus* and non-biting midge *Forcypomia* sp.

Group 5. Communities from seven fresh to subsaline wetlands (0.76 to 5.7 g/L), including most of the remaining springs, sedge swamps, seasonal lakes and Wealacutta Pool (site 23). Many of these wetlands had relatively high $\%Ca^{2+}$ and $\%HCO_3^{-1}+CO_3^{2-}$, reflecting their association with groundwater discharge from the Tamala limestone, and all but one had ≥ 60% submerged macrophyte cover. Nearly half of the species collected from these wetlands were not found in wetlands of other cluster groups. These communities were distinguished from those in other groups by more frequent occurrence of the chironomids *Tanytarsus fuscithorax* and *Polypedilum nubifer*, the hemipteran *Anisops thienemanni* and copepod *Mesocyclops brooksi*.

Southern Little Three Springs. This community inhabited small, shallow, litter-filled pools on a woodland floor. It was the only community to have the oligochaete *Ainudrilus nharna*, pezid mites, the beetle *Enochrus maculiceps* and the cranefly Tipulidae type C.

Invertebrate – environment relationships

Grouping of the sites in the cluster analyses suggested that communities varied along salinity and vegetation gradients. Total dissolved solids and % submerged macrophytes were amongst the eight environmental variables correlated with axis scores of the nMDS ordination (p-value < 0.05, r^2 0.24 to 0.82): the others being % cover of litter, $\%Cl^-$, $\%HCO_3^-$, $\%SO_4^{2-}$ and $\%K^+$ and cover of silt+clay. These variables are shown as vectors reflecting the strength and direction of their correlations with the nMDS axes on Fig. 2b. These vectors show composition aligned along a salinity gradient, with saline sites to the left and the freshest sites to the right. The relationship between salinity and the biota is not entirely aligned with vectors for the relative concentrations of ions. The most saline sites (≥ 60 g/L) to the left and top left of the nMDS plot tended to have highest $\%Cl^-$ (>88%) but so did Lake Thetis (site 15, tds 50 g/L) and even the salt lake influenced Eatha Spring (site 16, tds 16 g/L), while some of the more moderate saline lakes in the bottom left to centre of the plot had highest $\%SO_4^{2-}$. Some of the fresher sites had particularly high $\%HCO_3^{2-}$ (> 10%), probably as a result of groundwater discharge from the Tamala limestone, but the more inland springs fed by discharge from the Lesueur Sandstone (sites 7, 10 and 26) and the lower salinity wetlands closer to the coast (such as sites 21 and 23), which may have a marine influence, did not. At the fresher end of the salinity gradient there was a separation of those wetlands with higher cover of litter (heavily shaded sites such as the Little Three Springs sites towards the top right of the plot) from wetlands with the most submerged macrophytes (which were more open wetlands). Wetlands with finer sediments tended to occur more towards the bottom of the ordination plot and included a salt lake, samphire flats and fresh springs in the middle of subsaline wetlands (where water levels receding to the springs may have led to accumulation of fine sediment).

Twelve environmental variables had significant individual correlations with invertebrate community composition in an initial db-RDA. Of these, $\%HCO_3^{2-}$ and total dissolved solids were strongly correlated (r^2 = 0.92). Further analyses excluded total dissolved solids because it had a slightly lower individual correlation with community composition than $\%HCO_3^{2-}$. A step-wise approach to variable selection using the remaining 11 variables produced a model with 9 variables explaining 60% of variation in composition, but four of these variables (cover of logs, depth, temperature and longitude) did not contribute significantly to the model. A final model with $\%HCO_3^{2-}$, $\%Cl^-$, colour, submerged macrophyte cover and litter, all with significant partial contributions, explained 46% of variation in community composition.

These analyses indicate that wetland position and geomorphology, through influences on water chemistry, hydrology, vegetation structure, organic inputs and sediment composition, are important in structuring invertebrate communities of the region's wetlands.

DISCUSSION

Invertebrate diversity and distributions

Species richness is about what would be expected considering the nature of the wetlands: predominantly saline wetlands or small springs with low habitat diversity. The average of 30 species per sample is lower than the average of 36 per sample recorded in 200 wetlands across the south-west agricultural zone sampled by Pinder *et al.* (2004) and the 39 per sample recorded in the Hutt catchments by Pinder *et al.* (2012). Fewer species (an average of 19 per sample) were recorded within the mostly saline Buntine Marchagee wetlands in the northern Wheatbelt sampled by Aquatic Research Laboratory (2004, 2006, 2009). All of these studies have used the same sampling and laboratory methods and all these figures exclude rotifers and protozoans, as in the present study.

Horwitz *et al.* (2009) suggest that local and regional endemism amongst Swan Coastal Plain aquatic invertebrates was relatively low compared to other regional assessments in WA. Our results suggest that this holds for the Jurien area which is near the plain's northern extent. However, while most of the invertebrates are common and widely distributed in south-western Australia or more widely, there are some exceptions. Although the leech *Goddardobdella elegans* is widely distributed in Australia there are few records of leeches from the mid-west of Western Australia (data from the Western Australian Museum and the Department of Parks and Wildlife), reflecting the generally saline and/or temporary nature of most of the region's wetlands, so its occurrence in the swamp north of Lake Thetis (site 22) is notable. However, subsequent collecting in 2014 resulted in new (but unidentified) leech records from three other wetlands in the area (Dept Parks and Wildlife, unpublished data). The polychaete *Manayunkia* n. sp. is widely distributed in naturally saline lakes of the south-west (Pinder *et al.* 2004) but the record from site 12 is the first north of about Dowerin. The *Recifella* water mite from Wealacutta Pool (site 23) has not been recorded in other Department of Parks and Wildlife invertebrate projects and may be new. Another mite, *Arrenurus* (*Truncaturus*) sp. 25, recorded from Deadhorse Soak (site 18) is otherwise known only from springs near the town of Three Springs (Pinder & Leung 2010) plus the groundwater fed Utcha Swamp near Hutt Lagoon (Pinder *et al.* 2012). The brine shrimp *Parartemia extracta* (from three of the saline playas) is known only from the central and northern Wheatbelt and these new records represent half of the known extant populations. Timms *et al.* (2009) suggest that this species is becoming less abundant in the northern Wheatbelt due to salinisation, with half of previously known populations possibly extinct and that it may be a threatened species. The relatively well protected playas along the Jurien coast may be an important refuge for this species and its distribution in the lakes should be further investigated. The harpacticoid copepod in the genus *Leptocaris* is similar to *Leptocaris brevicornis* (a widely distributed marine interstitial species also known from Fortescue Marsh in the Pilbara) but differs in sufficient detail to suggest that

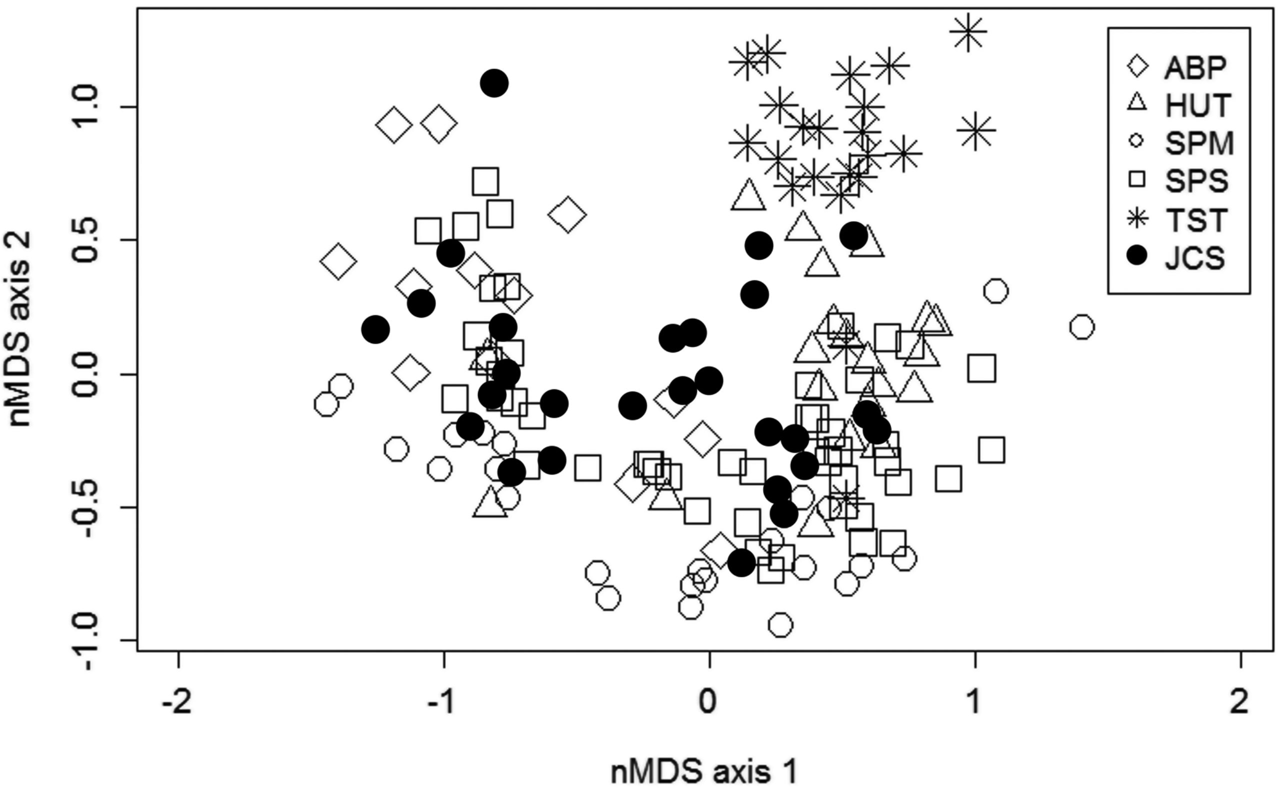

Figure 3. Axes 1 and 2 of a three dimensional ordination of aquatic invertebrate composition data from the present survey (JCS), northern Wheatbelt data from Pinder *et al.* (2004) (SPS), State Salinity Strategy wetland monitoring in the northern Wheatbelt by Cale et al. (2004 and unpublished data) (SPM), sites in the Hutt River/Hutt Lagoon catchments sampled by Pinder *et al.* (2012) (HUT), mound springs near the town of Three Springs at the headwaters of the Hill River sampled by Pinder and Leung (2010) (TST) and wetlands sampled in the northern Wheatbelt by Jones *et al.* (2009) (ABP). Stress = 0.15.

it may be a new species. It also differs from another new *Leptocaris* from Shark Bay (Jane McRae, Bennelongia Pty Ltd, pers. comm., 2 May 2012). A few other species have rarely been recorded in the mid-west and Wheatbelt, such as the water strider *Hydrometra strigosa* and *Hydrophilus* beetles. The occurrence of gilgies (*Cherax quinquecarinatus*) at Eatha Spring is the most northerly record known for this species (Pierre Horwitz, Edith Cowan University, pers. comm.).

Unlike the Hutt catchments, 200km further north, the Jurien fauna did not include a north-western element, although Pinder *et al.* (2004) collected a couple of such species from Lake Logue and Arro Lake just to the north-east of our study area. This fits with the notion that the northern element in the Western Australian aquatic invertebrate declines between the Murchison River and Eneabba (Pinder *et al.* 2004, 2012), excepting that a few such species do occasionally occur further south.

The composition of invertebrate communities in the Jurien wetlands is not distinct at a regional (northern Wheatbelt/southern Mid-west) scale. A three-dimensional ordination using data from other studies in the region with consistent taxonomy (Fig. 3) shows that there is considerable overlap in composition between Jurien communities and those in wetlands further inland and north. Axes 1 and 2 of the ordination are shown in Fig. 3 but other axis combinations did not show any greater separation of Jurien wetlands from others. This contrasts with the springs on the upper Hill River south of the town of Three Springs (TST sites in Fig. 3) which clearly support a distinctive assemblage of species, contributing to their status as threatened ecological communities. Jurien sites that were most separated in ordination space from other wetlands were Lake Thetis (top most Jurien site in Fig. 3) and three seepage fed vegetated swamps in the centre of the ordination (Eatha Spring, the sedge swamp near the mouth of Hill River and the seepage fed sedge swamp north of Jurien: sites 16, 21 and 4 respectively). Lake Thetis is a unique wetland type and freshwater sedge/rush dominated wetlands are rare in the broader region.

Geomorphic versus invertebrate classification

Table 1 lists the allocation of sites to the cluster groups based on invertebrate community composition and the geomorphic wetland class that they were assigned to by DEC (2012a). Seven of the 14 geomorphic wetland categories were represented in the sites reported here. Of these, only three were represented by more than one wetland: sumplands, springs and self-emergent wetlands. The latter were the saline moat wetland (site 20) and one of the freshwater Little Three Springs sites (site 26) but in the invertebrate analysis these sites clustered separately to one another within groups 2 and 4 respectively, reflecting differences in salinity. Fourteen sites were classified as sumpland (seasonally inundated basins) under the geomorphic system but these were spread over four of the invertebrate community groups. Most of these were salt lakes or samphire-dominated flats but there were also some freshwater swamps and springs. For the wetland mapping process, the two springs were evidently not sufficiently conspicuous (on aerial photographs and from other GIS data sources) to be distinguished from the larger wetlands within which they sit, so the issue was one of resolution rather than classification. These were Deadhorse Soak (site 18) within a large palusplain and the spring in the Dingo Swamp complex (site 11) within a small samphire filled sumpland. That site 5 was classified as a balkarra (intermittently inundated flat) by DEC (2012a) may also have been a resolution issue as the sampled site was a small area (<1 ha) of inundated samphire set within a larger non-flooded area, so was probably a sumpland lying within a balkarra. Our sites that were classed as springs in the geomorphic classification were certainly all areas of groundwater discharge but they were spread over invertebrate community groups 4 and 5 plus two of the sites that did not cluster with other sites (sites 7 and 16). The 'estuary-peripheral' site (site 21) was certainly on the edge of the Hill River mouth, but its invertebrate community grouped with other fresh to sub-saline vegetated swamps in group 5. Lake Thetis did not cluster with other wetlands in the invertebrate analysis and was the only site classed as a 'lake' by DEC (2012). Finally, Wealacutta Pool (site 23) was classed as a river in the geomorphic system but it grouped with other fresh to subsaline wetlands with emergent vegetation in invertebrate community group 5 above, reflecting its contemporary lentic nature. There was clearly little alignment between the cluster groups derived from the invertebrate community composition and the classification of the same sites based on the geomorphic system. Our analyses suggest that if the structure and cover of aquatic and fringing vegetation and some indication of salinity range were included in the classification system, as proposed in a newer expanded geomorphic system (Semeniuk & Semeniuk 2011), and as used in some other wetland classification systems (e.g. Duguid *et al.* 2005), then a better alignment with invertebrate biodiversity might be achieved.

Groundwater dependence

One of the aims of this study was to assess the degree to which the epigean aquatic invertebrate fauna is dependent on groundwater. The only invertebrates collected in this study that are known to be stygophilic are the unidentified darwinulid ostracods from Eatha Spring (site 16) which may be widespread in the underlying superficial aquifer. By comparison, springs in the upper Hill River north-east of the study area have darwinulid ostracods plus stygal candonid ostracods, bathynellids and phreodrilid oligochaetes which may also inhabit the associated groundwater (Pinder and Leung 2010). Nor was there a suite of epigean species known to be closely associated with spring habitats elsewhere, as is also the case in the Hill River springs. An exception might be the water mite *Arrenurus* sp. 25 from Deadhorse Soak, which is otherwise known only from the Hill River springs (Pinder and Leung 2010) and the groundwater-fed Utcha Swamp north of Hutt Lagoon (Pinder *et al.* 2012). Also unlike the Hill River springs and the springs in the Hutt River Catchments, the Jurien springs do not support south-west mesic-adapted species that are otherwise rare north of Perth, such as the dragonfly *Archaeosynthemis occidentalis* and trichopteran *Notoperata tenax*. Nonetheless, with at least some of the springs being permanent and fresh, they are likely to be acting as local drought refuges for many of the species collected in the study area. Some active dispersers such as the dragonfly *Orthetrum caledonicum*, beetle *Allodessus bistrigatus*, backswimmer *Anisops theinemanni* and chironomid *Tanytarsus fuscithorax* were present in most of the springs and probably disperse from these to the less permanent wetlands following dry periods. These and other species, such as many of the water mites, may also occur preferentially in the springs because of the reliably fresh water whereas many other wetlands are saline much of the time. Despite their lack of a characteristic spring associated fauna, these sites are likely to be critical for maintaining the regional diversity of aquatic invertebrates, with the eight springs collectively supporting 147 species, which is nearly as many as the other 19 sites combined (154).

Salt lake faunas

The other main driver of this survey was the need to understand the diversity and distribution of invertebrates in the saline playas that may be subject to expansion of gypsum mining in the future. These playas (sites 1,6,8,9,12,17 and 26) supported a total of 45 species, with 8 to 21 species per wetland. Several of those taxa could not be resolved to species level so their conservation status couldn't be assessed (e.g. *Coxiella* snails and mesostigmatid mites). Most of the rest are halophilic species, such as the copepod *Apocyclops dengizicus* and beetle *Necterosoma pennicilatus*, that are very widespread in south-western Australia (and beyond for some species). Two species were of note: the polychaete *Manayunkia* n. sp. and the brine shrimp *Parartemia extracta*, both discussed above. Previous records of *Manayunkia* have been from wetlands with salinities ranging from 17 to 120 g/L (Pinder *et al.* 2004 and Department of Parks and Wildlife unpublished data), but with a median salinity of 46 g/L. In the Jurien area it was collected from site 12 (27 g/L) whereas four of the remaining salt lakes (lacking *Manayunkia*) had salinity >54 g/L. *Parartemia extracta* was also recorded only at the lower end of the salinity range of these wetlands (27 to 55 g/L) which is within the previously known salinity occurrence range of the species: 27 to 100 g/L (Timms *et al.* 2009). That no more than half of the salt lake fauna occurred in any one of the playas indicates that these wetlands have heterogeneous faunas and that preservation of multiple representatives is required to ensure the persistence of the full salt lake fauna of the region.

SUMMARY

Wetlands are a prominent feature of the Jurien coastal landscape and one of only a few such wetland complexes along the western coast of Australia. This study has surveyed the dominant faunal group inhabiting these wetlands, finding that the region has about average diversity for the types of wetlands present and compositions not dissimilar to those of wetlands elsewhere in the northern Wheatbelt and mid-west coast. Most species were common and widespread, but some rare and/or restricted species were present. While there were very few species closely associated with groundwater or with springs, the springs are undoubtedly important in maintaining aquatic invertebrate diversity in the study area by providing a freshwater drought refuge for much of the fauna. The salt lakes may be particularly important for the brine shrimp *Parartemia extracta*, but further survey for this species in the region and in the broader northern Wheatbelt is required to determine its conservation status.

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Appendix 1. Presence of invertebrate species across the 27 samples collected in this study or by Pinder *et al*. (2004).

Higher taxonomy			Lowest level of identification	Site number 1	2	3	4	5	6	7	08 (99)	08 (11)	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Nematoda			Nematoda				1	1									1			1							1			1
Tardigrada			Tardigrada																											1
Gastropoda	Basommatophora	Planorbidae	*Glyptophysa* sp														1	1					1							
			Gyraulus sp.																			1								
	Neotaeniglossa	Pomatiopsidae	*Coxiella* sp.	1	1			1	1				1		1	1								1					1	
Annelida	Clitellata	Naididae	Naidinae sp.																											1
			Pristina longiseta																				1							
			Tubificinae sp.																											1
			Potamothrix bavaricus															1								1		1	1	
			Ainudrilus nr *nharna*							1																				
		Enchytraeidae	Enchytraeidae								1		1		1	1	1									1				1
			Enchytraeidae JCS2			1														1										
			Enchytraeidae JCS3			1																								
			Enchytraeidae JCS4			1	1																							
			Enchytraeidae JCS1				1			1																				
		Hirudinidae	*Goddardobdella elegans*																							1				
	Polychaeta	Sabellidae	*Manayunkia* n. sp.													1														
		Aeolosomatidae	*Aeolosoma* sp.																1											
			Polychaeta sp.																1											
Acariformes		Hydrachnidae	*Hydrachna* sp.																									1		
		Eylaidae	*Eylais* sp.																											1
		Oxidae	*Oxus australicus*																				1							
		Limnesiidae	*Limnesia dentifera*																				1							
			Limnesia sp.												1															1
		Unionicolidae	*Koenikea* sp.																			1								
			Recifella sp. JCS																								1			
		Pionidae	Pionidae																			1								
		Arrenuridae	*Arrenurus* sp.												1								1							1
			Arrenurus (*Micruracarus*) sp. 1																							1		1		
			Arrenurus (*Truncaturus*) sp. 25																			1								
		Pezidae	Pezidae							1																				
			Oribatida sp.														1						1	1		1	1			
			Trombidioidea				1			1				1											1					1
			Oribatida sp. JCS1																	1										
	Parasitiformes		Mesostigmata		1	1				1	1				1		1					1			1					

Higher taxonomy			Lowest level of identification	Site number 1	2	3	4	5	6	7	08 (99)	08 (11)	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Crustacea	Anostraca	Branchiopodidae	*Parartemia extracta*	1									1			1														
	Cladocera	Sididae	*Latonopsis brehmi*														1													
		Chydoridae	*Alona rigidicaudis*																				1							1
			Dunhevedia crassa															1					1							
			Leberis cf. *diaphanus*																				1							
			Pleuroxus inermis														1													
		Daphniidae	*Daphnia* cf. *carinata* (SAP)				1																							
			Daphnia truncata	1									1			1				1	1									
			Daphnia wardi		1			1																1						
			Simocephalus elizabethae														1	1				1	1		1	1				
		Macrotrichidae	*Macrothrix breviseta*																											1
			Macrothrix sp.			1	1								1		1													
	Ostracoda	Limnocytheridae	*Limnocythere mowbrayensis*														1													1
			Limnocythere sp.																	1										
		Cytherideidae	*Cyprideis australiensis*																1	1					1	1				
		Darwinulidae	Darwinulidae sp.																	1										
		Candonidae	*Candonopsis tenuis*																				1							
		Cyprididae	*Alboa worooa*			1	1			1					1		1			1		1	1		1	1	1	1		
			Australocypris insularis	1							1	1	1			1					1									
			Bennelongia barangaroo																											1
			Bennelongia sp.		1	1	1																							
			Candonocypris novaezelandiae							1							1	1				1						1		1
			Cypretta baylyi																											1
			Cyprinotus cingalensi		1	1	1								1	1														
			Ilyocypris australiensis																											1
			Diacypris spinosa					1							1	1			1			1	1	1						
			Diacypris compacta	1	1		1		1		1	1	1								1									
			Mytilocypris ambiguosa		1	1			1						1		1						1			1				1
			Mytilocypris mytiloides					1																1						
			Reticypris clava	1					1		1		1								1									
			Reticypris sp.																	1										
			Caboncypris nunkeri																			1								
			Caboncypris kondininensis		1																									
			Platycypris baueri	1					1		1	1	1								1			1						
		Cypridopsidae	*Sarscypridopsis aculeata*				1			1				1			1	1				1						1		1
			Sarscypridopsis sp. 165																						1					
		Notodromadidae	*Kennethia cristata*			1	1	1																						
			Kennethia sp.												1					1			1							
	Copepoda	Centropagidae	*Boeckella triarticulata*	1	1	1	1								1		1									1	1	1		
			Calamoecia clitellata	1									1			1					1		1							
			Calanoida sp.																						1					
		Cyclopidae	*Microcyclops varicans*															1												
			Metacyclops sp. 442													1														1

			Metacyclops sp. 434																										1
			Metacyclops sp. 1																					1					
			Australocyclops australis																										1
			Halicyclops spinifera															1											
			Halicyclops sp. 1 (nr *ambiguus*)							1									1										
			Mesocyclops brooksi		1	1								1		1	1		1		1	1		1	1	1	1		1
			Eucyclops australiensis														1												
			Apocyclops dengizicus		1		1			1		1							1				1					1	
			Meridiecyclops baylyi	1		1														1									
			Cyclopoida sp.								1						1												
		Canthocamptidae	*Mesochra baylyi*	1			1			1																			
			Mesochra nr *flava*									1		1	1														
			Mesochra parva																										1
			Cletocamptus dietersi														1		1		1				1		1		
		Laophontidae	*Onychocamptus bengalensis*																			1			1				
			Laophontidae sp. 2															1											
		Ameiridae	*Nitocra reducta*																							1			
			Nitocra sp. 4															1											
			Nitocra sp. 5 (nr *reducta*)																1					1					
			Nitocra sp.													1													
		Darcythompsoniidae	*Leptocaris* nr *brevicornis*																1				1		1				
	Amphipoda	Ceinidae	*Austrochiltonia subtenuis*	1			1			1				1		1	1		1		1	1	1	1	1	1	1	1	1
		Melitidae	*Melita kauerti*															1											
	Isopoda	Oniscidae	*Haloniscus searlei*	1			1	1		1				1	1								1						1
			Haloniscus sp.																		1								
	Decapoda	Palaemonidae	*Palaemonetes australis*																					1					
		Parastacidae	*Cherax quinquecarinatus*																1										
Insecta	Coleoptera	Haliplidae	*Haliplus fuscatus*		1																			1			1		
			Haliplus sp.	1										1		1						1							1
		Dytiscidae	*Hyphydrus elegans*										1			1									1				1
			Hyphydrus sp.																		1								
			Uvarus pictipes																			1							
			Hydroglyphus leai																			1							
			Limbodessus shuckhardi											1			1		1		1								
			Limbodessus inornatus			1																							1
			Limbodessus sp.														1												
			Allodessus bistrigatus										1				1				1						1	1	1
			Paroster niger	1									1				1												1
			Paroster sp.		1	1																							
			Antiporus gilberti																										1
			Sternopriscus sp.																										1
			Sternopriscus multimaculatus																								1		
			Necterosoma penicillatus							1		1				1					1		1	1			1	1	1
			Necterosoma darwini										1																
			Necterosoma regulare																							1			
			Necterosoma sp.	1			1					1		1	1				1										
			Megaporus howitti																								1		1
			Megaporus ruficeps																		1								

Higher taxonomy		Lowest level of identification	Site number																										
			1	2	3	4	5	6	7	08 (99)	08 (11)	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
		Megaporus solidus																				1							
		Megaporus sp.												1		1									1				
		Rhantus suturalis											1						1		1				1				1
		Rhantus sp.				1																		1					
		Lancetes lanceolatus														1					1				1				
		Hyderodes sp.			1	1								1															
		Eretes australis																											1
		Spencerhydrus pulchellus																				1							
		Onychohydrus sp.			1											1						1							
		Dytiscidae sp.							1																				
		Bidessini sp.				1								1		1					1	1		1					
	Gyrinidae	*Macrogyrus* sp.																			1								
		Dineutus australis																			1								1
	Hydrophilidae	*Berosus australiae*																									1		
		Berosus approximans																						1					
		Berosus discolor												1	1								1					1	
		Berosus macumbensis			1																								
		Berosus majusculus																							1				
		Berosus nutans																										1	
		Berosus sp.		1								1	1	1							1	1				1			1
		Enochrus elongatus																			1								
		Enochrus maculiceps							1																				
		Limnoxenus zelandicus				1																							
		Limnoxenus sp.		1	1								1								1								
		Paracymus pygmaeus																											1
		Hydrophilus sp.																								1			
		Hydrophilidae				1																							
	Staphylinidae	Staphylinidae				1			1																				
	Scirtidae	Scirtidae sp.		1	1	1							1	1					1										1
	Curculionidae	Curculionidae			1								1		1						1								1
Diptera	Tipulidae	Tipulidae type C							1																				
		Tipulidae type E																									1		
	Culicidae	*Anopheles annulipes* s.l.				1			1				1				1		1		1			1					1
		Anopheles sp.			1									1															
		Aedes alboannulotus				1			1				1																1
		Aedes camptorhynchus		1			1		1			1							1				1						
		Aedes sp.			1				1																				
		Culex globocoxitus				1			1				1																
		Culex australicus				1			1																				
		Culex sp.												1					1		1								1
		Coquillettidia linealis																				1							
	Ceratopogonidae	*Bezzia* sp.												1										1	1				
		Bezzia sp. 2															1												1
		Culicoides sp.	1					1		1	1	1	1	1			1	1			1						1	1	1

		Monohelea sp. 1		1											1				1		1				1			1	
		Nilobezzia sp. 1														1					1				1		1		
		Forcypomyia sp.											1									1							1
		Dasyhelea sp.				1			1			1		1								1	1						
		Ceratopogonidae							1																				
	Psychodidae	Psychodinae sp. 2							1				1																
		Psychodinae sp. 3							1																			1	
		Scatopsidae sp.								1																			
	Tabanidae	Tabanidae sp.		1	1		1			1			1	1		1	1								1	1	1		
	Stratiomyidae	Stratiomyidae sp.		1	1	1	1			1				1	1						1		1					1	1
	Dolichopodidae	Dolichopodidae sp.	1	1		1	1				1	1		1	1					1									
	Ephydridae	Ephydridae sp.									1					1						1					1		
		Ephydridae sp. 3			1		1		1			1			1						1		1	1				1	
		Ephydridae sp. 4																										1	
		Ephydridae sp. 6				1	1				1							1						1				1	
		Ephydridae sp. 20																						1					
	Muscidae	Muscidae sp. A					1					1		1										1				1	
		Diptera sp. 1											1				1					1		1			1		
	Chironomidae	*Procladius paludicola*	1	1	1					1		1		1	1	1	1		1		1	1			1	1	1	1	1
		Procladius villosimanus														1	1										1		
		Alotanypus dalyupensis																			1								
		Paramerina levidensis				1							1				1				1	1			1				1
		Larsia albiceps																							1	1			
		Tanypodinae												1															
		Corynoneura sp. (V49)			1	1								1							1	1		1	1				1
		Paralimnophyes pullulus																											1
		Limnophyes vestitus																											1
		Cladotanytarsus sp. A																								1			
		Tanytarsus barbitarsis						1		1	1	1						1	1	1			1						
		Tanytarsus fuscithorax											1			1	1				1	1			1	1		1	
		Tanytarsus semibarbitarsus	1	1	1		1							1		1	1				1			1					
		Tanytarsus sp. E														1													
		Tanytarsus fuscithorax/ semibarbitarsus				1																							1
		Chironomus occidentalis														1					1								
		Chironomus tepperi				1																		1					
		Chironomus sp.																								1			
		Chironomus aff. *alternans* (V24)			1	1			1				1	1		1	1		1		1			1				1	1
		Dicrotendipes pseudoconjunctus			1									1		1					1	1		1	1				
		Kiefferulus intertinctus			1											1						1			1		1		1
		Polypedilum nubifer			1					1				1		1	1				1	1					1	1	1
		Cryptochironomus griseidorsum																											1
		Microchironomus sp. P1															1												
		Cladopelma curtivalva												1	1										1	1			
Ephemeroptera	Baetidae	*Cloeon* sp.															1												
		Baetidae sp.																											1
	Caenidae	*Tasmanocoenis tillyardi*															1												1
Hemiptera	Mesoveliidae	*Mesovelia hungerfordi*															1												
		Mesovelia sp.											1																

Higher taxonomy		Lowest level of identification	Site number 1	2	3	4	5	6	7	08 (99)	08 (11)	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Hebridae	*Hebrus axillaris*																				1							
	Hydrometridae	*Hydrometra strigosa*																						1					
	Veliidae	*Microvelia* (*Pacificovelia*) *oceanica*															1		1		1								1
		Microvelia (*Austromicrovelia*) *peramoena*																								1			
		Microvelia sp.											1						1		1	1							
		Veliidae				1																							
	Corixidae	*Sigara mullaka*																									1		
		Agraptocorixa eurynome																			1				1		1		
		Agraptocorixa parvipunctata																											1
		Micronecta robusta															1								1		1	1	1
		Micronecta gracilis																										1	
		Corixidae sp.			1								1			1	1							1					
	Notonectidae	*Anisops thienemanni*					1									1	1				1				1	1	1	1	1
		Anisops hyperion																											1
		Anisops gratus																											1
		Anisops nasuta																			1								
		Anisops stali																			1								
		Anisops tahitiensis												1															
		Anisops baylii																							1		1		
		Anisops sp.		1	1																								
		Notonectidae		1		1																							
Lepidoptera		Lepidoptera (non-pyralid)											1	1		1						1							1
		Pyralidae nr. sp. 39/40								1																			
		Ischnura aurora aurora																											1
Odonata	Coenagrionidae	*Ischnura heterosticta heterosticta*																				1			1	1		1	
		Xanthagrion erythroneurum															1												
		Austrolestes analis																											1
		Coenagrionidae sp.															1												
	Lestidae	*Austrolestes annulosus*		1	1					1				1	1	1					1	1	1	1	1	1			
		Austrolestes psyche															1												
	Aeshnidae	*Adversaeschna brevistyla*		1	1																	1			1	1	1		
		Hemianax papuensis												1		1	1				1				1				
		Aeshnidae sp.				1																							
	Corduliidae	Corduliidae sp.																									1		
	Libellulidae	*Orthetrum caledonicum*											1			1	1		1		1				1		1		
	Hemicorduliidae	*Hemicordulia tau*								1			1			1						1			1				1
		Zygoptera sp.				1													1										
		Epiproctophora sp.																			1								
Trichoptera	Hydroptilidae	*Acritoptila* sp.																				1							
		Hellyethira litua														1	1												
	Leptoceridae	*Notalina spira*												1															
		Oecetis sp.												1												1			1
		Triplectides australis												1							1	1				1			1