

Aquatic invertebrate communities of selected springs in the Jurien (Cervantes to Coolimba) region

Interim report to Department of Water

January 2012

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Department of
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Our environment, our future



EXECUTIVE SUMMARY

- A survey of aquatic invertebrates in the Cervantes to Coolimba region of Western Australia was undertaken in September 2011. The primary aims of the survey were to describe the region's aquatic invertebrate diversity and assess its conservation significance to assist with environmental impact assessment. The Department of Water (DoW), which co-funded the project with the Department of Environment and Conservation (DEC), was particularly seeking knowledge of the diversity, significance and groundwater dependence of invertebrates inhabiting the region's springs.
- In this interim report to DoW we 1) describe the aquatic invertebrate communities present in the five springs sampled in 2011 and one spring (Little Three Springs) sampled in 1999 by Pinder *et al.* (2004), 2) assess the distributions and conservation significance of the species and communities and 3) assess the degree to which the spring invertebrates rely on groundwater discharge.
- Twenty five wetlands (Figure 1 and Table 1) were selected for inclusion in the survey after conducting a reconnaissance trip in spring 2010, consulting with officers from DoW and DEC's Mid-west region and examining results of a recent wetland mapping exercise (DEC unpublished). Seven of these wetlands were springs and five were sampled in September 2011: Eatha Spring, Deadhorse Soak, Diamond in the Desert Spring, an unnamed spring in a salt pan south-west of Cervantes ('Thetis Spring') and an unnamed spring south of Little Three Springs ('South Little Three Spring'). Two other springs will be sampled in late summer once the associated salt lakes have dried.
- The six springs differ from one another in their physical and chemical characteristics, reflected in highly heterogeneous invertebrate communities. Factors likely to be associated with invertebrate community composition include salinity, macrophytes, organic debris, area and depth of surface water and proximity to other wetlands.
- At least 129 species of aquatic invertebrates were collected from the six spring sites (Appendix 2). Average richness per spring was 41 and the range was 23 (at South Little Three Springs) to 69 (at Little Three Springs in 1999). This is comparable to the Hutt River catchment where an average of 40 species occurred in four springs (range 29 to 53) (Quinlan *et al.* 2009). Mound springs on the upper Arrowsmith River had an average of 31 species per sampling occasion and a range of 10 to 49 (Pinder & Leung 2010).
- The invertebrate faunas of the springs were primarily composed of species that are widespread in the lower Mid-west/northern Wheatbelt or even more broadly. Exceptions are an undescribed *Arrenurus* water mite (which is rare and restricted to groundwater fed wetlands in the northern Wheatbelt), the ostracod *Caboncypris nunkeri* (endemic to south-western Australia but uncommon) and *Megaporus ruficeps* (a northern Australian beetle). The presence of gilgies (*Cherax quinquecarinatus*) at Eatha Spring may represent a short extension to its known range.
- The spring's invertebrate communities are quite similar to those in the Hutt River catchment surveyed by Quinlan *et al.* (2009) but are very dissimilar to those on the upper Arrowsmith River sampled by Pinder & Leung (2010).
- Springs on the upper Arrowsmith River, and to a lesser extent those in the Hutt River catchment, are refugia for northern outlier populations of primarily mesic adapted species otherwise restricted to the higher rainfall south-west (Pinder & Leung 2010; Quinlan *et al.* 2009). The same is not true for the springs sampled for this survey. Few of the collected species are associated with permanent water, with most being widespread insects (capable of dispersal away from drying wetlands) or microcrustaceans with drought resistant propagules. The exceptions are known from temporary wetlands elsewhere and have other strategies for surviving temporary dry periods.

- Nonetheless, the springs are very likely to be drought refuges in a local context, as even the actively dispersing insects may have nowhere else to disperse to locally if the springs dry, although aquatic insect dispersal is poorly understood. Most other wetlands in (or near) the study area are saline and/or seasonally dry. The springs are most likely support source populations that disperse to more temporary wetlands during wet periods, rather than the reverse.
- Groundwater is important for maintaining the range of habitats present at these springs, including permanent(?) fresh and subsaline water, open water pools, litter-filled hollows and macrophyte communities. The stands of tall trees present at some springs are undoubtedly dependent on shallow groundwater tables and these also influence aquatic habitats; providing organic matter, shade and possibly preferred flow pathways. Management of groundwater should therefore be directed at maintaining the diversity of habitats present across the suite of springs.

INTRODUCTION

Groundwater is a critical component of the hydrology and ecology of a large proportion of Western Australian aquatic systems, primarily through maintaining base-flows in rivers and minimum water levels in wetlands and by prolonging intermittent filling and flow events (Hatton & Evans 1998). At the same time, groundwater is an essential water resource in many parts of the State with few surface supply options. Planning for management of groundwater in the Northern Perth Basin, which has significant areas of groundwater dependant ecosystems (Rutherford *et al.* 2005) and an expanding population, is being undertaken by the Western Australian Department of Water (DoW). As part of this process, DoW are addressing a need for greater understanding of the values and ecological water requirements of the region's groundwater dependant ecosystems, as identified by Department of Water (2009). These investigations are being carried out with the aid of funding from the Groundwater Dependent Ecosystem Vulnerability in the Mid West project (funded by the National Water Commission's Groundwater Action Plan). One project component involves understanding the values and water requirements of invertebrates in the region's springs.

There have been some previous studies of invertebrate communities of springs in the northern Perth Basin. The aquatic invertebrate communities of springs on the upper Arrowsmith River are already well described (Pinder & Leung 2010) and recognised as a threatened ecological community (Rees & Broun 2005). Aquatic invertebrates in springs in the Hutt River catchment, sampled by Quinlan *et al.* (2009), are located north of the area of interest to DoW, but provide useful comparative data. In this report, we present some interim results of a survey of aquatic invertebrates in wetlands along the coast between Cervantes and Coolimba, focusing on the springs. The impetuses for the survey were 1) a need by DEC to better understand biodiversity patterning in the region's wetlands (especially salt lakes) for impact assessment purposes and 2) a need by the DoW to understand the diversity, conservation significance and groundwater dependence of invertebrates inhabiting the region's springs. Funding for the survey therefore came from both DoW and DEC (the latter using funds provided by CSR Gypsum Pty Ltd as an offset for being licensed to mine gypsum in a salt lake in Beekeepers Nature Reserve). The project also addresses one of the data gaps for the Geraldton Sandplains IBRA subregion identified by Desmond and Chant (2002): Systematic Fauna Survey.

In this report we 1) describe the aquatic invertebrate communities present in the five springs sampled in 2011 and one (Little Three Springs) sampled in 1999 by Pinder *et al.* (2004), 2) assess the distributions and conservation significance of the species and communities and 3) assess the degree to which the populations, species and communities rely on groundwater discharge.

Other studies of aquatic invertebrate communities in the northern Wheatbelt include: the First National Assessment of River Health, which identified riverine invertebrates to family level (Halse *et al.* 2002); a survey of the South-west Agricultural Zone (Pinder *et al.* 2004) which sampled invertebrates at 65 northern Wheatbelt wetlands in 1999; a program monitoring aquatic biodiversity at 28 wetlands throughout the South-west Agricultural Zone, including 6 in the northern Wheatbelt (Cale *et al.* 2004);

surveys at a number of springs on the upper Arrowsmith River that support threatened ecological communities (Pinder & Leung 2010; Rees & Broun 2005); monitoring at 44 wetlands in the Buntine-Marchagee Recovery Catchment over several years (Aquatic Research Laboratory 2009); sampling of two claypans in Drummond Nature Reserve (Cale 2005; Pinder 2011); a survey of aquatic invertebrates in the Hutt River and Hutt Lagoon catchments (Quinlan *et al.* 2009) and a statewide baseline wetland condition project that included three northern Wheatbelt wetlands (Nowicki *et al.* 2008a, b; Nowicki *et al.* 2009; Susac *et al.* 2008).

Study area

The project area was designed to coincide with the area in which wetlands are being mapped and evaluated by the Wetlands Group in DEC's Species and Communities Branch (Shanahan 2011). It is located in DEC's Moora District and occupies about 100000 ha of the Shires of Dandaragan, Coorow and Carnamah, spanning the coastal strip from just south of the Cervantes north to Coolimba. The project area overlaps two Interim Bioregionalisation of Australia (IBRA) subregions: the northern extent of the Perth (SWA2) subregion of the Swan Coastal Plain IBRA region and the southern extent of the Lesueur Sandplain (GS3) subregion of the Geraldton Sandplain IBRA region. Geologically, the area is part of the Northern Perth Basin and consists of Jurassic/Triassic sandstones and siltstones overlain by Quaternary deposits of coastal and lacustrine/lagoonal/estuarine origin (Geological Survey of Western Australia 1990; Kern 1997; Myers & Hocking 1998).

There is only one exorheic creek (Hill River) with a small, semi-open estuary between Cervantes and Jurien. A few other creeks (such as Cockleshell Gully, Stockyard Gully) terminate at lake systems before reaching the coast. What appear to be remnants of creek systems run behind the primary dunes between Cervantes and Jurien. Also in the dunes are a few small dampland areas that would rarely (and probably only briefly) have surface water. The chains of semi-connected, mostly seasonal, salt lakes and associated samphire dominated flats are the dominant surface water features. There are also numerous springs in the study area, many of them on the edge of the salt lakes. Lake Thetis, immediately south of Cervantes, is a unique permanent lake in the region containing stromatolites (Grey *et al.*). A significant proportion of the region's wetlands are partly or wholly groundwater dependent (Rutherford *et al.* 2005).

METHODS

Site selection

Twenty five wetlands (Figure 1 and Table 1) were selected for inclusion in the survey after conducting a reconnaissance trip in spring 2010, consulting with officers from DoW and DEC's Mid-west region and examining results of a wetland mapping exercise in the region (DEC unpublished).

Factors influencing site selection were the need to:

1. include a range of salt lakes spanning across the study area to provide data for assessment of potential impacts of mining in salt lakes.
2. include a range of springs to provide information to DoW on the diversity, composition, conservation status and groundwater dependence of their faunas.
3. include a selection of other wetlands representative of wetland types in the region, such as sedge swamps and samphire flats.

Most wetlands were sampled in September 2011. However, two of the springs were in the middle of inundated salt lakes and will not be sampled until after the salt lakes dry over summer.

Physico-chemical measurements

Conductivity, pH and turbidity were measured in the field with a calibrated meter. Maximum depth was measured or estimated. Water samples were collected for laboratory analysis of total dissolved solids (TDS), colour, total and total filterable persulphate nitrogen and phosphorus and total nitrate/nitrite. Total dissolved solids is the concentration of dissolved substances calculated by evaporating off the water from a sample. Where ions are the dominant dissolved substances TDS should be close to the sum of the concentrations of major ions (SOI) and so is often used as a measure of salinity. Salinity measured in the field with a meter is an approximation of salinity calculated from electrical conductivity. The two laboratory methods of determining salinity (TDS and SOI) matched fairly well, with ratios of TDS: SOI averaging 1.03 (range 0.89 to 1.24). However, these values for salinity were an average of 24% higher than recorded by the conductivity meter (ratio of TDS:meter measurement varied between 0.84 and 2.08). All three measures of salinity are presented but major discrepancies are noted in the text.

Samples for nutrient analyses were passed through a filter paper of pore size 0.45 µm and frozen in the field, except for highly turbid samples, which were frozen unfiltered and centrifuged prior to analysis. Chlorophyll 'a', 'b', 'c' and phaeophytin 'a' were measured from phytoplankton retained on glass-fibre paper after filtering at least 500 ml of water (normally 900 ml). Chlorophyll fractions were combined for analysis.

Percentage cover of emergent and submerged plants was estimated for the area sampled for invertebrates. Percentage cover (at the bed surface) of seven substrate classes was estimated in the field (bedrock, boulder, cobble, pebble, sand, gravel and silt+clay) using size classes defined in Brakensiek *et al.* (1979).

Table 1. List of wetlands sampled in 2011, plus Little Three Springs sampled in 1999 (Pinder *et al.* 2004). Spring highlighted in red.

Site code	Site name	Wetland type	Date sampled	Latitude	Longitude
JCS 01	Salt lake 9km north of Jurien	Salt lake (non-permanent)	12/09/2011	- 30° 12.403'	115° 02.251'
JCS 02	Samphire flat north of JCS001	Samphire flat	12/09/2011	- 30° 12.124'	115° 01.863'
JCS 03	Samphire flat south of JCS 001	Samphire flat	13/09/2011	- 30° 13.377'	115° 03.056'
JCS 04	Sedge swamp near JCS003	Sedge swamp	13/09/2011	- 30° 13.717'	115° 03.259'
JCS 05	Flats North of Coorow-Greenhead Road	Samphire flat	13/09/2011	- 30° 01.301'	115° 00.801'
JCS 06	Salt lake near Leeman (= site sampled by Susac <i>et al.</i> 2009)	Salt lake (non-permanent)	13/09/2011	- 29° 55.766'	114° 59.319'
JCS 07	South Little Three Spring	Spring	14/09/2011	- 29° 59.398'	115° 05.196'
JCS 08	Salt lake east of Coolimba	Salt lake (non-permanent)	14/09/2011	- 29° 51.915'	115° 00.294'
JCS 09	Salt lake 2km south of Leeman airstrip	Salt lake (non-permanent)	14/09/2011	- 29° 59.245'	114° 59.394'
JCS 10	Diamond in the Desert Spring	Spring	15/09/2011	- 30° 06.947'	115° 05.317'
JCS 11	Samphire flat 5km north-east of Cervantes	Samphire flat	16/09/2011	- 30° 27.812'	115° 05.479'
JCS 12	Salt Lake 4.5 km north-east of Cervantes	Salt lake (non-permanent)	16/09/2011	- 30° 27.920'	115° 05.404'
JCS 13	Thetis Claypan	Hyposaline lake	19/09/2011	- 30° 31.090'	115° 06.193'
JCS 14	Thetis Spring	Spring	19/09/2011	- 30° 30.974'	115° 06.234'
JCS 15	Lake Thetis	Salt lake (permanent)	19/09/2011	- 30° 30.494'	115° 04.896'
JCS 16	Eatha Spring	Spring	20/09/2011	- 30° 06.31'	115° 02.683'
JCS 17	Eatha Salt Lake	Salt lake (non-permanent)	20/09/2011	- 30° 06.290'	115° 02.477'
JCS 18	Deadhorse Soak	Spring	21/09/2011	- 29° 54.147'	115° 01.228'
JCS 19	Sedge Swamps W of Deadhorse Soak	Sedge swamp	21/09/2011	- 29° 54.229'	115° 00.720'
JCS 20	Roman Hill Fort	Inundated moat around mound	22/09/2011	- 30° 13.076'	115° 01.004'
JCS 21	Hill River Sedge Swamps	Sedge swamp	22/09/2011	- 30° 23.510'	115° 03.173'
JCS 22	Lake Thetis Sedge Swamp	Rehabilitated gravel pit	22/09/2011	- 30° 30.279'	115° 04.828'
JCS 23	South Cervantes palaeo creek	Endorheic creekline	23/09/2011	- 30° 28.812'	115° 04.560'
JCS 24	Oil Rig Track Spring	Spring	-	- 30° 08.864'	115° 02.411'
JCS 25	Spring within JCS011	Spring	-	- 30° 27.812'	115° 05.479'
SPS202	Little Three Springs	Spring	24/09/1999	- 29° 59.017'	115° 5.167'

Aquatic invertebrate sampling

Aquatic invertebrates were sampled using standard methods employed by DEC for many other survey projects (see list in Introduction). Two invertebrate samples were collected at each wetland: one benthic sample, using a 250 µm mesh net to sample all habitats (e.g. open water, sediments, detritus, submerged vegetation and streambed of flowing areas, where present), and a plankton sample using a 50 µm mesh net to sample the water column and submerged vegetation. For larger wetlands, each sample involved sweeping for a total of 50 m (not usually contiguous) where possible. Most of the springs (with the exception of Eatha Spring and Deadhorse Soak) had very small areas of water and samples were usually more in the order of 10 to 15 metres of sampling (or as was felt adequate to represent the spring without damaging the site).

Invertebrate sample processing

Invertebrates from the benthic and plankton samples were combined prior to being identified to species level where possible. Morphospecies names were assigned to undescribed species or to species that were represented only by immature stages that could not be associated with described adults. All identifications are consistent with previous DEC projects including those listed in the introduction.

Consistency of identification was achieved by the use of a voucher collection consisting of specimens whose identity was verified or determined by specialists, with the notable exception of dipterans. Unlike most previous DEC aquatic invertebrate projects, rotifers and protozoans have not been removed from samples due to time and funding constraints.

Data analysis

Data for these springs and other wetlands in the region sampled with comparable effort and with invertebrates identified using an identical taxonomic framework were combined into a single matrix for some analyses. The other datasets were as described in the introduction. For multivariate analyses, protozoans and rotifers were excluded since they have not been picked from the Jurien samples. Other groups of lower invertebrates, such as nematodes and flatworms, were excluded because they undoubtedly represent multiple species. Most records of partially identified species were also excluded (e.g. larvae of species that require adults for identification). The combined matrix was 566 taxa by 144 samples (from 89 streams and wetlands).

Ordinations (non-hybrid multi-dimensional scaling = nMDS) and hierarchical cluster analyses (using the group averaging linkage method) were performed on presence/absence data using Primer (Primer-E Ltd 2008) on Sorenson similarity matrices with singleton species (those occurring in only one sample) removed.

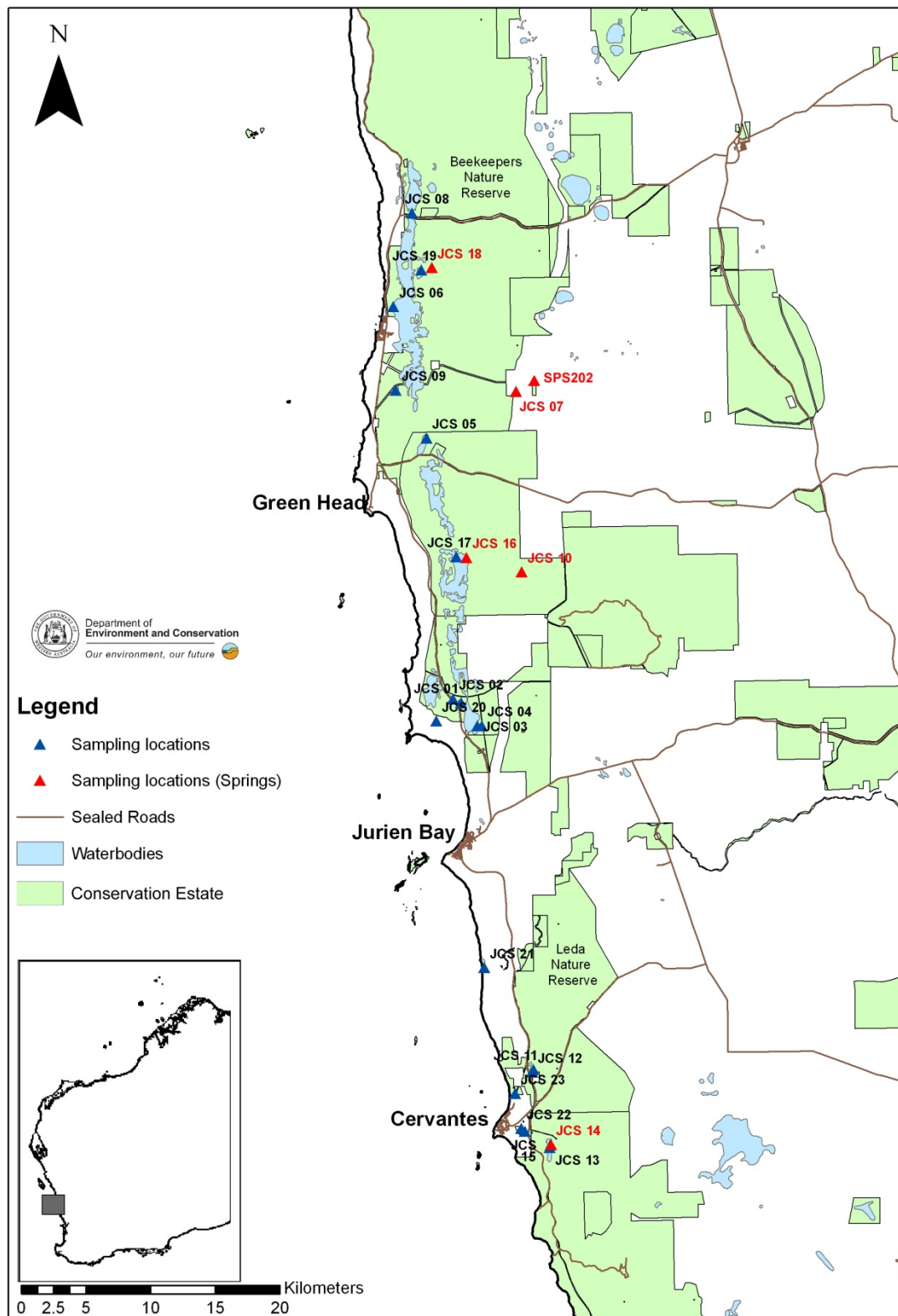


Figure 1. Map of Jurien to Coolimba region showing location of all 23 sampling locations sampled in September 2011 and SPS202 sampled by Pinder et al. (2004). The six springs are labelled in red.

RESULTS AND DISCUSSION

Habitats and water chemistry

Appendix 2 contains all physical and chemical habitat data for all 23 sampled wetlands in 2011 and for Little Three Springs sampled in 1999, but only results for the six springs (highlighted in green) are discussed below. These springs varied greatly in the physical, chemical and habitat characteristics.

Maximum depth when visited varied by only 7 cm across four of the springs (range 34 to 41 cm). Eatha Spring was shallower, with depth ≤ 15 cm. At South Little Three Springs average depth would have been much lower (< 5 cm). The area of inundated habitat varied greatly between springs. South Little Three Springs had numerous small puddles (1 to 5 cm deep), a single pool of about 2 m² and 34 cm depth and small trickling seeps. The adjacent Little Three Springs had a series of large boggy pools, one of which appeared to have been excavated and which fed a flowing creek that disappeared underground after a short distance. Thetis Spring had a single round static pool about 10 m in diameter. Diamond in the Desert Spring had a static pool about 20 m by 3 m fed by a flowing seep at one end and overflowing down a short bank into a limestone ridge at the other. Deadhorse Soak had a large static pool about 15 m in diameter which narrowed to a long (~ 100 m x 2 m) channel. Eatha Spring was much more extensive, with the diffuse inflow of water extending over about 2 ha of sedges and flowing out onto a salt lake.

South Little Three Springs had no aquatic vegetation and Diamond in the Desert Spring had little (about 20% cover of *Chara* and a few scattered sedge stems). Deadhorse Soak had abundant *Chara* covering about 95% of the bed and Thetis Spring had high (60%) cover of *Chara* and *Ruppia*. Eatha Spring lacked submerged macrophytes but was mostly covered by *Typha*. Little Three Springs had dense *Typha* growing in the creekline and patches of macrophytes.

The substrate at Deadhorse Soak was mostly bedrock, with areas of sandy clay and stones. The other springs had substrates dominated by sand and finer sediments. At Diamond in the Desert Spring and South Little Three Springs the substrate was inorganic but was covered by a layer of fine organic material and plant debris. At Eatha Spring the substrate itself was highly organic, probably a result of decaying *Typha*.

Four of the springs (Little Three Springs, Diamond in the Desert, Thetis Spring and Deadhorse Soak) were fresh, although the latter had slightly elevated salinity at 2 g/L. South Little Three Springs was subsaline (TDS = 4.8 g/L) and Eatha Spring was mildly saline (TDS = 16 g/L). The salinity value from the conductivity meter at Eatha Spring (8.99) was much lower than either the TDS value (16 g/L) or the sum of ions (15.89 g/L). The occurrence of *Typha* and the gilgie at this spring (see below) suggests the lower field measurement might be more correct in this case. All six springs were NaCl dominated, but the Thetis Spring had much higher proportions of Ca²⁺ and HCO₃²⁻ (31 and 28%) than the other four sites (all $> 17\%$ and 19%). The claypan within which the Thetis Spring is located was dry, but an adjacent (and similar) inundated pan (JCS13) had only 6.2% Ca²⁺ and 1.7% HCO₃²⁻. This suggests different sources of water for the spring and the claypan.

All six springs were slightly alkaline (7.17 to 7.99) and were clear (turbidity < 20 NTU). Thetis Spring, Eatha Spring and Deadhorse Soak all had very low colour (< 30 TCU) but Little Three Spring, South Little Three Spring and Diamond in the Desert Spring were slightly coloured with TCU values of 100 to 280, probably reflecting the larger amounts of particulate organic matter and plant debris in these springs.

Total phosphorus (TP) concentrations were close to or below detectable limits at five of the springs. At South Little Three Springs TP was 0.61 mg/L, about half of which was in soluble form. However, no chlorophyll was detected in the main pool of this spring, probably because the site was very shaded. Total nitrogen (TN) concentrations were generally low, with the highest values recorded at Thetis Spring (2.3 mg/L) and Eatha Spring (2 mg/L). Most of this nitrogen was in the form nitrate/nitrites. Chlorophyll was near or below detectable limits at all six springs but Thetis Spring and Deadhorse Soak had extensive growth of filamentous algae.

Site descriptions

South Little Three Springs (JCS07 Figure 2) is a raised area of groundwater discharge under a dense canopy of trees (mostly eucalypts). Aquatic habitats were a number of small (mostly < 1 m²), shallow (mostly < 5 cm, maximum 35 cm) water filled hollows and short flowing seepages. The largest pools had slightly coloured water (280 NTU) and most pools had abundant coarse organic matter overlying sandy inorganic sediments. The water in the largest pool was subsaline. There is some ferricrete outcropping on the edges of the spring area.



Figure 2. South Little Three Springs (site JCS07). A) *Eucalyptus* woodland with shallow areas of seepage, B) One of the smaller pools of water and C) Area of groundwater discharge flowing downhill to the right of the photo.

Diamond in the Desert Spring (JCS10 Figure 3) consists of areas of fresh groundwater seepage flowing into small hollows in the base of a limestone ridge. The sampled seepage filled a pool (approximately 3 m x 20 m x up to 34 cm deep) before flowing into the ridge. The pool had patches of *Chara* and abundant particulate organic matter and leaf litter overlying the sand and silt/clay sediments. The water was slightly coloured but clear with a pH of 7.81. The vicinity of the springs is highly disturbed and weed infested.



Figure 3. Diamond in the Desert Spring (site JCS10). A) Pool fed by groundwater discharging at a break in slope (not shown - to the left of the photo) and B) Pool narrowing where water flowed down to the base of the limestone ridge.

Thetis Spring (site JCS14 Figure 4) consists of an inorganic mound in the centre of an extensive samphire flat. The mound is surrounded by sedges which are more extensive on the south side. Also on the south side is a small (about 10 metres across) shallow (41 cm) pool with sedges and patches of *Chara* and filamentous algae. The pool was fresh (with higher than average Ca^{2+} and HCO_3^{2-}) and clear with soft fine sediments. We sampled the northern half of the pool.

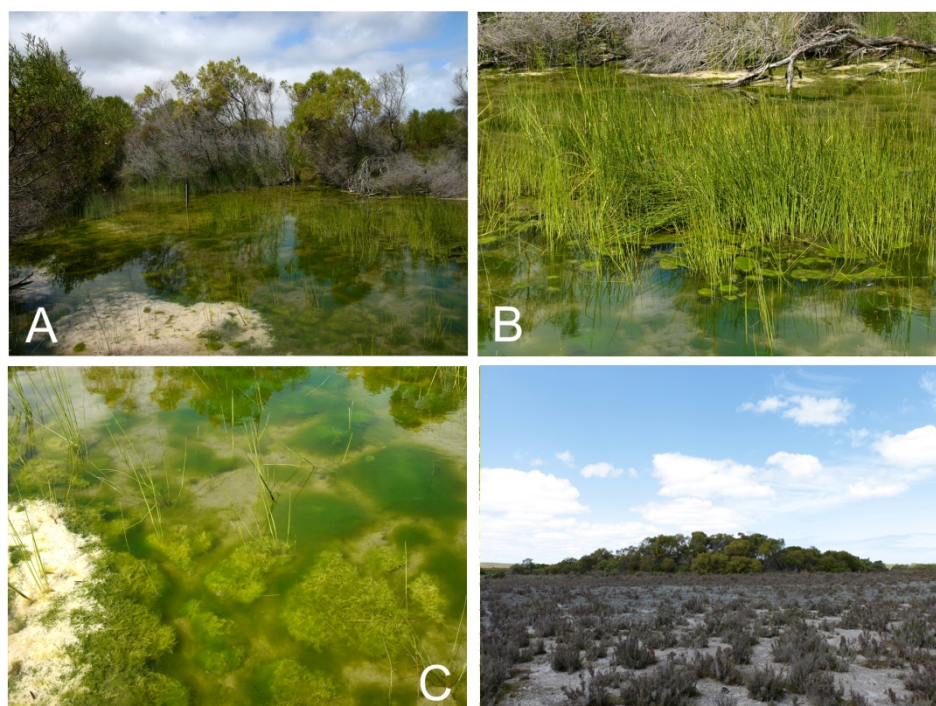


Figure 4. Thetis claypan mound spring (JCS14). A) View of the pool, B) Sedges, C) Chara and filamentous algae and D) The mound in the middle of the north-eastern Thetis claypan.

Eatha Spring (site JCS16 Figure 5) is an area of saline groundwater discharging from the base of a limestone ridge on the eastern shore of a salt lake north of Oil Rig Track. Further out onto the lake bed the water becomes more saline and the *Typha* gives way to salt-tolerant sedges. When sampled, water was flowing slowly through the sedges into the flooded lake at a rate of about 3 cm/s. We sampled the lowest salinity landward part of the spring amongst the *Typha*.



Figure 5. Eatha Spring (JCS14). A) open water around edges of *Typha*, B) Collecting the plankton sample.

Deadhorse Soak (site JCS18 Figure 6) is an area of fresh groundwater discharging from within a limestone pool and then into a short sandy channel. In wet years the channel is contiguous with extensive flooded fresh to subsaline sedgeland to the west. Both the pool and channel were included in the area sampled. A skeleton of a dead horse was present in the pool.

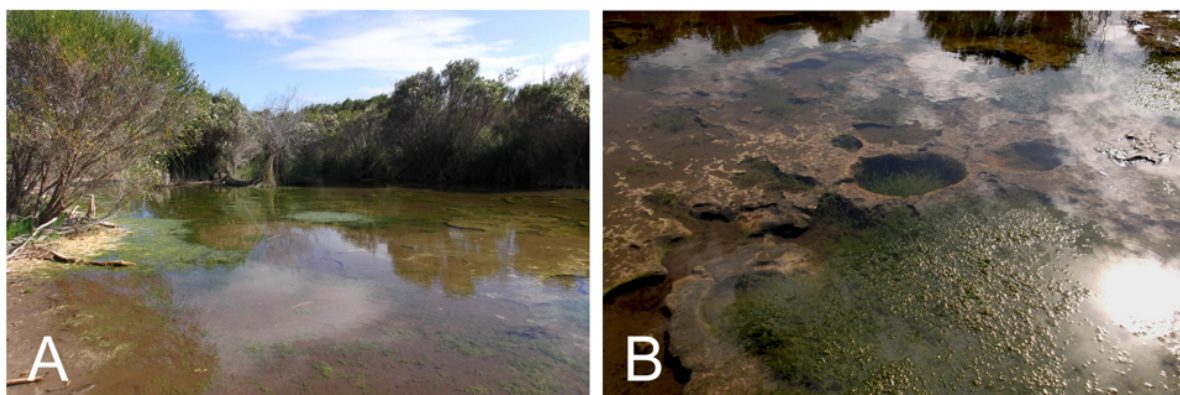


Figure 6. Deadhorse Soak (JCS18). A) View of pool, B) Limestone formations and beds of Chara in pool.

Little Three Springs (SPS202 of Pinder *et al.* 2004, Figure 7). A low mound with *Eucalyptus* and *Melaleuca* woodland overlying swampy soils with interconnected shallow pools and a short channel flowing from a small excavated pool. Water in the pools was marginally fresh (2.3 g/L) and coloured. Macrophytes were mostly associated with the excavated pool and channel.



Figure 7. Little Three Springs (SPS202) photographed in September 1999.

Invertebrate diversity

At least 101 species of aquatic invertebrates were collected from the five spring sites sampled in September 2011. An additional 28 species were collected from Little Three Springs (just north of South Little Three Springs = JCS07) by Pinder *et al.* (2004), bringing the total number of invertebrate species known from the Jurien springs to 129 (Appendix 2). About 70% of these were collected at just one of the six springs, only thirteen occurred in more than half of the six springs and only two species occurred in them all.

The total number of species (other than rotifers and protozoans) collected from wetlands in the northern Wheatbelt is roughly 800, so about 16% have been found in these six springs. Average richness per spring was 41 and the range was 23 to 69 (at South Little Three Springs and Little Three Springs respectively). This is comparable to the Hutt River catchment where an average of 40 species occurred in four springs (range 29 to 53) (Quinlan *et al.* 2009). The upper Arrowsmith River mound springs had an average of 31 species per sampling occasion and a range of 10 to 49 (Pinder & Leung 2010).

Most of the species collected from the Jurien springs are common in the northern Wheatbelt or more widely distributed. Exceptions are as follows:

***Arrenurus* sp. 25** was first collected from Utcha Swamp in the Hutt Catchment (Pinder *et al.* 2004), then in two springs on the upper Arrowsmith River south-west of Three Springs (Pinder & Leung 2010) and now at Deadhorse Soak (JCS18). All four of these locations are groundwater fed wetlands in the northern Wheatbelt and it may be a regional endemic.

A single specimen of a Darcythompsoniid copepod from Eatha Spring was female so the species identification is tentative, but it appears to be ***Leptocaris brevicornis***. Darcythompsoniids are primarily marine, but a few, including *L. brevicornis*, inhabit brackish and fresh waters. This species is a globally widespread species, inhabiting muddy substrates in “brackish, sometimes hypersaline coastal lagoons and continental fresh waters” (Young 1998). It has been found in the North and South Atlantic and Pacific Oceans, the Mediterranean Sea, Iran, the South African coast, El Salvador (inland fresh waters), and Brazil (Boxshall & Defaye 2008). Despite its apparently widespread global distribution, the single record at Eatha Spring is significant because it represents the second known record of the family from Australian waters.

Gilgies, ***Cherax quinquecarinatus***, were abundant at Eatha Spring (JCS16). There are records of this species from the Hill River (about 30km south) but the Eatha Spring record may be at or near the northern limit of the species' distribution (P. Horwitz, Edith Cowan University and S. Beatty, Murdoch University pers. comm. and Jasinska *et al.* (1993)). Austin & Knott (1996) recorded gilgies in waters with salinity up to 4 g/L and Pinder *et al.* (2004) recorded it at up to 7.7 g/L, but the salinity (at least 9 g/L) at Eatha spring would be close to its ecological tolerance.

Caboncypris nunkeri is a relatively rare ostracod and a south-western endemic, with DEC records from just seven other wetlands in Western Australia (plus the type locality near Forrestdale Lake). It primarily inhabits temporary freshwaters, such as Goonapping and Dobaderry swamps in the wandoo forest and Lake Logue west of Eneabba. In this project it has so far only been collected from Deadhorse Soak.

The dytiscid beetle ***Limbodessus shuckhardi*** (= *L. dispar*) occurs widely in Australia but in Western Australia it appears to be primarily a species of the higher rainfall south-west. The only records from north of Perth are from a saline wetland in the Buntine-Marchagee catchment (Aquatic Research Laboratory 2009) and the new records from JCS14, 16 and 18. The new records are of female specimens and males would be required to confirm the identification.

Megaporus ruficeps is a northern Australian dytiscid beetle that is common in the Kimberley and Pilbara regions (e.g. Daniel *et al.* 2009; Pinder *et al.* 2010). It was not recorded in the Carnarvon Basin by Halse *et al.* (2000) but was collected in the Hutt River by Quinlan *et al.* (2009). The record of this species from Deadhorse Soak fits with the concept that the coastal areas of the northern Wheatbelt are a zone of overlap between northern and south-western aquatic invertebrate faunas (Quinlan *et al.* 2009).

Rotifers have not been considered in this survey due to time and budget constraints, but they generally comprise about 15 to 20% of regional aquatic invertebrate faunas, although at springs with little open water the proportion is likely to be lower. Thirteen rotifer species were identified from the sample collected at Little Three Springs in 1999. Of these, two (a *Lecane* and a *Lepadella*) were new to science and are still not known from any other wetlands.

Stygobiont and crenobiont species

The only invertebrates collected that are strongly associated with groundwater (stygophiles) are the darwinulid ostracods from Eatha Spring (site 16). A few other species, such as the copepods *Mesocyclops brooksi* and *Apocyclops dengizicus* are regularly found in groundwater (Karanovic 2004) but do not show any preference for subterranean waters. In other northern Wheatbelt springs candonid ostracods and bathynellid syncarids have also been collected and considered to be stygophiles (Pinder & Leung 2010; Quinlan *et al.* 2009). There are few, if any, aquatic invertebrates in the northern Wheatbelt that could be said to be spring specialists (crenobionts). As mentioned above, the undescribed water mite *Arrenurus* sp. 25 has only been collected at springs (on the upper Arrowsmith and Deadhorse Soak) and at the groundwater maintained Utcha Swamp north of Hutt Lagoon. It may have a requirement for permanent freshwater but nothing is known about its biology.

Mesic adapted species associated with other springs in the northern Wheatbelt

Springs on the upper Arrowsmith River and, to a lesser extent, those in the Hutt River catchment, support northern outlier populations of numerous mesic adapted species otherwise found only much further south (Pinder & Leung 2010; Quinlan *et al.* 2009). These are not closely associated with springs across their range, but springs in the northern Wheatbelt provide permanent freshwater refugia in an otherwise dry region. These include the dragonflies *Archaeosynthemis occidentalis* and *Archargiolestes pusillus*, mosquitoes *Culiseta atra*, *Anopheles atratipes*, *Culex latus* and *Coquillettia* nr *linealis*, oligochaetes *Antarctodrilus horwiti*, *Antarctodrilus* WA3 and *Pristina sima*, several non-biting midges (Chironomidae) and the caddisfly *Notoperata tenax*. The Jurien springs seem to lack such species, suggesting that they do not provide sufficiently reliable surface water (or haven't in the past) or are otherwise unsuitable. Jurien springs associated with salt lakes, such as Eatha spring, would be too saline for most of these species. Also, these and other springs, such as Diamond in the Desert Spring, Little Three Springs and South Little Three Springs, may be (or may have been) too disconnected from source populations.

Descriptions of invertebrate communities in each spring

Composition amongst the springs was highly variable, to the extent that there is little biological redundancy amongst the six sampled springs and none of them could be lost without significantly affecting their combined biodiversity. This suggests that additional diversity would be found in the springs that have not been sampled, such as the other springs in the Thetis claypans.

South Little Three Springs (JCS07). This site had the lowest richness of invertebrates (23 species), probably reflecting the very small areas of surface water. Snails were absent and while annelids and water mites were not diverse this spring had the only record of *Ainudrilus* nr *nharna*, a sediment dwelling oligochaete, and pezid mites (which occur in fresh to brackish wetlands and in groundwater). This site (and site 10) had particularly depauperate microcrustacean faunas, probably associated with the fact that there was only one small pool with water > 5cm. The rest of the fauna were common insects and, while diversity of these was also very low, there were more mosquito species than at any of the other springs. Most of the species are detritivores which reflects the high degree of shading and large amounts of organic matter. The ostracods, some of the mosquitoes, moth flies (psychodids) and the only non-biting midge (*Chironomus* aff. *alternans*) were most abundant.

Diamond in the Desert Spring (JCS10). The fauna in this spring was almost entirely insect dominated, with the only non-insects being two species of enchytraeid oligochaetes, trombidiods (velvet mites) and the very widespread ostracod *Sarocypridopsis aculeata*. The 30 species included a much wider range of ecological groups compared to South Little Three Springs, including numerous predatory dytiscid beetles, corixid water bugs and dragonflies. Detritivores (oligochaetes, hydrophilid

beetles) and filter feeders (mosquitoes) were also present. Two of the detritivores, the ostracod *Sarsypridopsis aculeata* and non-biting midge *Chironomus* aff. *alternans*, were numerically dominant. The only invertebrates found only at this spring were lepidopteran larvae and these may have been terrestrial.

Thetis Spring (JCS14). This site had more species (37) than either of the above two springs and a greater range of feeding groups. The *Glyptophysa* snails, baetid mayflies (*Cloeon*) hydroptilid caddisflies (*Hellyethira*) water fleas and copepods are all grazers or algal filter-feeders, reflecting the greater light availability for plant and algal growth in the open pool of this spring. *Chara* and filamentous algae were abundant (Figure 4) and presumably so was attached microalgae, though low chlorophyll concentration indicates that there was not much algae in the water column. There was also a large range of predators (dytiscid beetles, dragonflies and damselflies, water bugs (*Micronecta* and *Anisops*) and predatory midges (*Procladius* spp.). Most of the detritivores were sediment dwelling animals such as the cosmopolitan oligochaete *Potamothrix bavaricus* and numerous chironomids, but crawling *Austrochiltonia* amphipods (also detritivores) were the most abundant species. Other abundant species were some of the copepods, *Potamothrix bavaricus* and *Procladius* chironomids.

Eatha Spring (JCS16). Despite the large area of open water, richness at Eatha Spring was fairly low at just 30 species. This would mostly have been because salinity was high enough at this spring (8 g/L) to reduce richness of freshwater species, with only partial compensation by salt tolerant and halophilic species (Pinder *et al.* 2005). In addition, *Typha* dominated swamps tend to have low richness compared to other vegetated swamps. The high diversity of microcrustaceans (13 species = 40% of the fauna) is typical of brackish to hyposaline waters. Many of these are well known salt tolerant species or halophiles, including *Reticypriis* ostracods, *Halicyclops* copepods, the water flea *Daphnia truncata*, *Austrochiltonia* amphipods, *Haloniscus* isopods and the chironomid *Tanytarsus barbitarsus*. Feeding groups were predators (including *Procladius* chironomids, *Microvelia* water striders, dytiscid beetles and the dragonfly *Orthetrum caledonicum*), detritivores/scavengers (e.g. enchytraeid oligochaetes, oribatid mites, ostracods, the glgie and amphipods) and filter feeders (some copepods, *Daphnia* and mosquito larvae). *Austrochiltonioa* amphipods and some of the microcrustaceans were the most abundant species, but the gilgie *Cherax quinquecarinatus* were quite abundant and would have dominated biomass. There were no macrophytes and macroalgae and no detectable chlorophyll in the water so grazer diversity would not have been expected to be high.

Deadhorse Soak (JCS018). This spring had a large area of inundation, high cover of submerged macrophytes, some emergent macrophytes, bedrock and fine sediments. This high habitat diversity, together with the proximity of this spring to other freshwater wetlands, probably contributed to the high invertebrate richness (52 species). The salinity (2 g/L) is high enough to influence community composition but not overall species richness (Pinder *et al.* 2005). Annelids were (unusually) absent, but water mite diversity was relatively high. There was a moderately high diversity of microcrustacea (8 species), including the halophilic ostracod *Diacypris spinosa* in high abundance. *Diacypris* rarely occur below 5 g/L and its presence suggests the spring has higher salinities at times (which may explain the absence of oligochaetes). The presence of other salt tolerant species (e.g. the damselfly *Austrolestes annulosus* and beetle *Necterosoma penicillatus*) may be incidental as these regularly occur in waters ranging from fresh to saline. Insect diversity was particularly high at this spring (39 species = 75%), perhaps due to its proximity to (and occasional continuity with) extensive areas of freshwater sedge wetlands. Despite high abundance of macrophytes there were few herbivores: just *Gyraulus* snails in low abundance and probably some of the chironomids and ostracods feeding on benthic microalgae. Most species were predators (water mites, dytiscid and gyrrinid beetles, damselflies, dragonflies and water bugs). The main non-predators were amphipods, isopods, chironomids and ostracods (primarily detritivores and benthic grazers) and mosquitoes and cladocerans (filter feeders). The most abundant species were amphipods, some of the ostracods and chironomids, *Anisops* backswimmers and *Agraptocorixa* water boatmen. This was the only spring with *Gyraulus* snails, unionicolid and pionid water mites, the ostracod *Caboncypris nunkeri* and a number of beetles.

Little Three Springs (SPS202). The total of 69 species collected at this site in 1999 was much more than was collected at any of the springs sampled in 2011. Several groups, especially beetles, chironomids and water bugs, contributed to the higher richness. This spring had a wide variety of habitats, from flowing water in *Typha*, extensive shaded and shallow pools with dense leaf litter, to exposed sandy pools and this habitat diversity probably promoted higher invertebrate richness. While most species were predators and detritivores (as at other springs), a number of grazers were present including haliplid beetle larvae, ephydrid larvae and cloeon mayflies. Some of the ostracods and the chironomid *Polypedilum nubifer* were numerically dominant. This spring had several genera of water mites, ostracods, copepods, cladocerans and insects absent from the other five springs.

Comparisons with other areas of the northern Wheatbelt/lower mid-west

An nMDS ordination of all samples collected from springs by DEC in the northern Wheatbelt is shown in Figure 8. Springs from three regions and projects are shown: five samples from four springs in the Hutt River catchment, springs from the upper Arrowsmith River and the six Jurien springs. This ordination suggests that invertebrate communities inhabiting the Jurien springs are more like those in the Hutt River catchment than those on the upper Arrowsmith River. In a cluster analysis (Figure 9) most of the upper Arrowsmith spring samples grouped separately to the rest, but the Hutt and Jurien were intermingled. Such comparisons between springs must be viewed with some caution as sample size is determined by available habitat, although communities present would have been fairly well sampled irrespective of sample size.

To put the Jurien springs into a broader regional wetland context, an nMDS ordination of all aquatic invertebrate communities sampled for this and other DEC projects in the northern Wheatbelt area is shown in Figure 10. This ordination clearly separated most of the lentic wetlands (represented by blue crosses) from most of the rivers, creeks and springs (represented by circles). Furthermore, the rivers and creeks were mostly separate from the springs. The Jurien springs (red solid circles) were placed in a position somewhat intermediate between the lotic and lentic wetlands. Most of the other springs (open orange circles) formed a separate group, with those placed nearest the Jurien springs being those of the Hutt River catchment. The ordination indicates that the Jurien region springs did not have invertebrate communities that are unique in composition compared to other wetlands in the northern Wheatbelt.

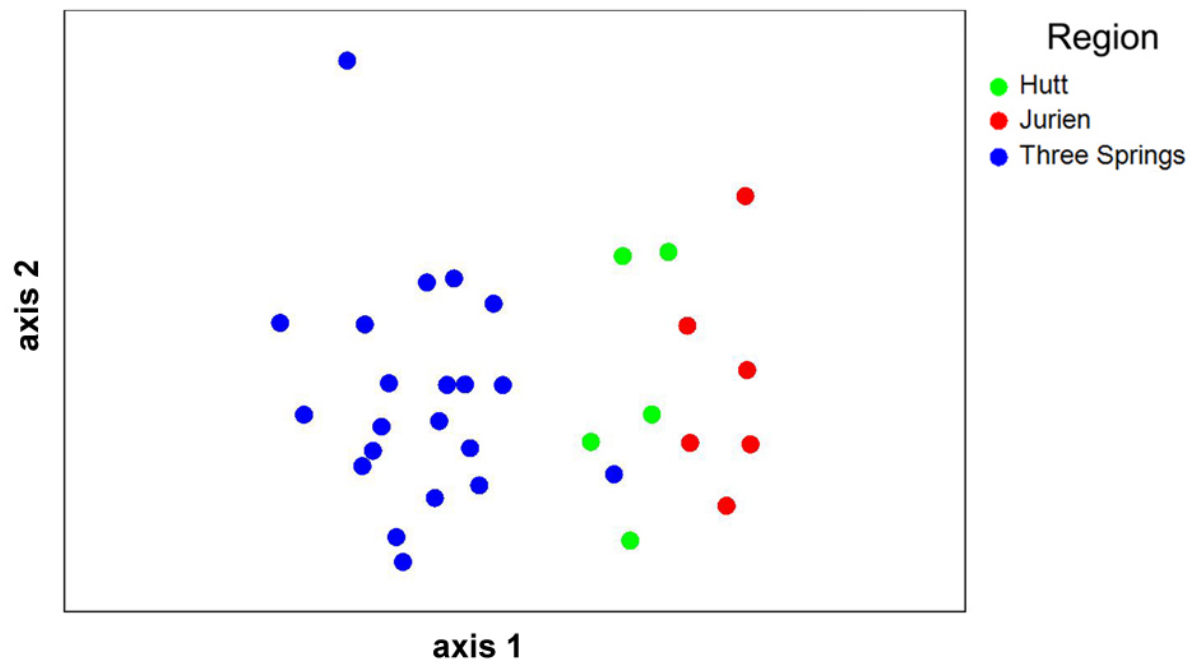


Figure 8. Two-dimensional nMDS ordination of invertebrate samples collected from springs in the northern Wheatbelt. Stress = 0.2. Numbers are site codes for the six Jurien springs.

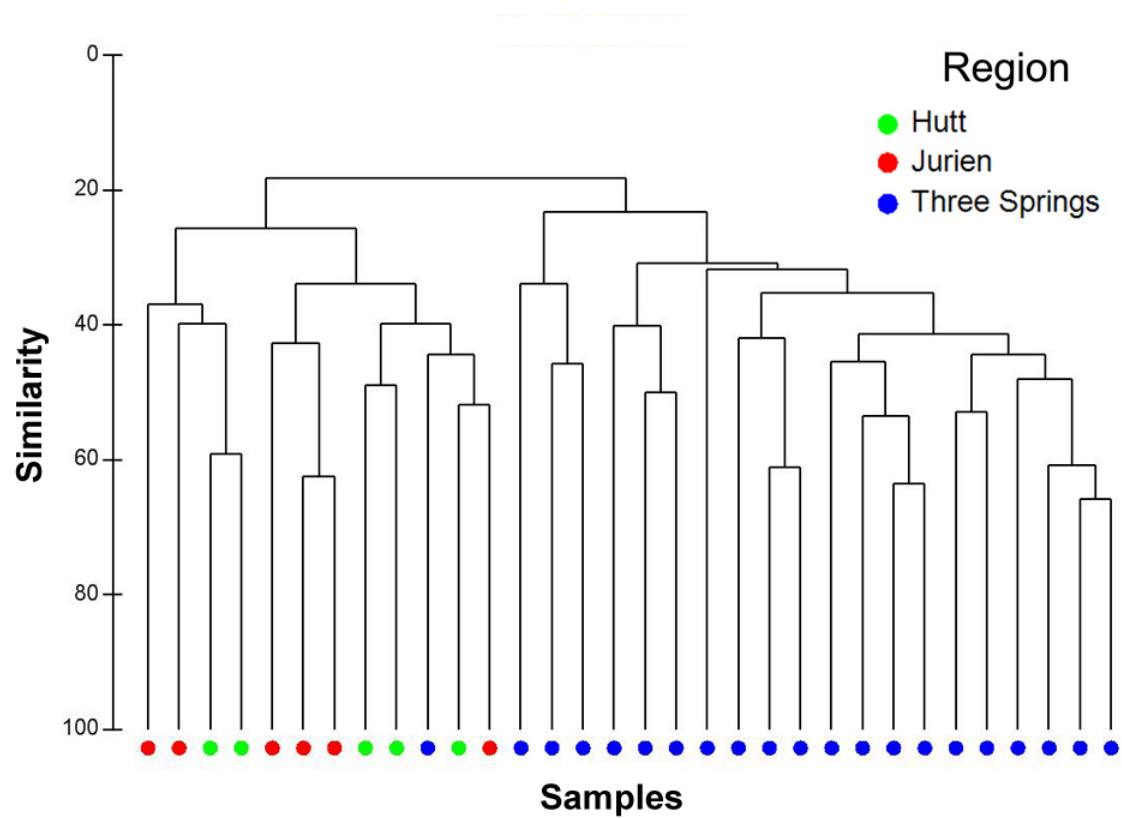


Figure 9. Cluster analysis of all invertebrate samples collected from springs in the northern Wheatbelt.

Figure 11 is a dendrogram resulting from a cluster analysis of the same invertebrate samples as were included in the ordination. In this analysis, the Jurien springs all fell within one of the larger cluster groups (on the right of Figure 11) comprised mainly of creeks, rivers and other springs, mostly from the Hutt River and Hutt Lagoon catchments, but also a few lentic wetlands. All of the samples from Hutt River catchment springs are in this group whereas almost all of the upper Arrowsmith springs formed a separate group to the left of Figure 11. Within the cluster containing the Jurien sites, sites 14 (Thetis Spring), 16 (Eatha Spring) and 18 (Deadhorse Soak) grouped with the Hutt Lagoon catchment swamps (such as Utcha Swamp) plus Lake Wannamal near New Norcia and one of the upper Arrowsmith springs that had been excavated to form a farm dam. By contrast, Jurien sites 7 (South Little Three Springs) and 10 (Diamond in the Desert Spring) grouped with a sample from the Hutt River, and two Hutt River springs. Little Three Springs (SPS202 of Pinder et al. 2004) grouped with another of the Hutt springs (Yerina Spring), plus a spring fed tributary of the Arrowsmith (One Tree Hill Creek) and another groundwater-fed creek (Skelton Gully near Northampton).

While the Jurien springs may not support particularly distinctive invertebrate communities and most of the component species are widely occurring, the springs may support invertebrate species not found in other wetlands within the study area. The springs may also act as local drought refugia and thus act as sources of colonisation for other less permanent wetlands. These questions can be addressed once the rest of the samples have been processed.

It is difficult to make much of the fact that sites 14, 16 and 18 grouped with lentic wetlands whereas sites 7, 10 and SPS202 grouped with creeks and other springs. The latter three sites certainly had some flow (albeit just trickling water at 7 and 10) whereas the others did not (other than slow sheet drift at site 16). However, there were no species present that tend to be strongly associated with flowing water or even with spring habitats. Possible exceptions are the *Arrenurus* water mite and the mosquito *Culex globocoxitus*, which is mostly collected in spring habitats in the northern Wheatbelt, but the latter occurs in a wide range of other fresh to subsaline wetlands across its broad Australian distribution. Only two species were present in sites 7, 10 and SPS202 but not in the other three sites. Sites 7, 10 and SPS202 are also more isolated from other wetlands compared to the other three sites and had little macrophyte. By contrast, sites 14, 16 and 18 are located close to, or are contiguous with, lentic wetlands and have more abundant emergent and/or submerged macrophytes. Thetis Spring is within (but elevated slightly above) a salt pan, Eatha Spring is hydrologically contiguous with a large salt lake and was subsaline when sampled and Deadhorse Soak is also part of a complex of wetlands that, at times, would be connected to the large salt lake south of Coolimba Road. These features may have given these three springs a more strongly lentic element to their fauna. Certainly a few species (such as the dragonfly *Hemianax papuensis* and backswimmer *Anisops thienemanni*) that are common in a broad range of lentic wetlands were present at these springs but absent in others (Table 2).

Sites 14, 16 and 18 also supported a number of salt tolerant or halophilic species (such as the ostracods *Diacypsis spinosa* and *Reticypsis* sp., copepod *Halicyclops* nr *ambiguous* and *Austrochiltonia* amphipods) that would have colonised the springs from the adjacent salt lakes. Some of these (e.g. the copepod *Cletocamptus dietersi* and ostracod *Diacypsis spinosa*) were also present in some of the Hutt Lagoon catchment swamps with which these Jurien springs grouped. Eatha Spring had a particularly high richness of salt tolerant and halophilic species. During major flood events Eatha Spring would be inundated by the salt lake and halophilic species would then reach the spring. Some of these would not survive at the spring (e.g. there were many dead *Coxiella* snails) but others, such as the ostracods and copepods, clearly do.

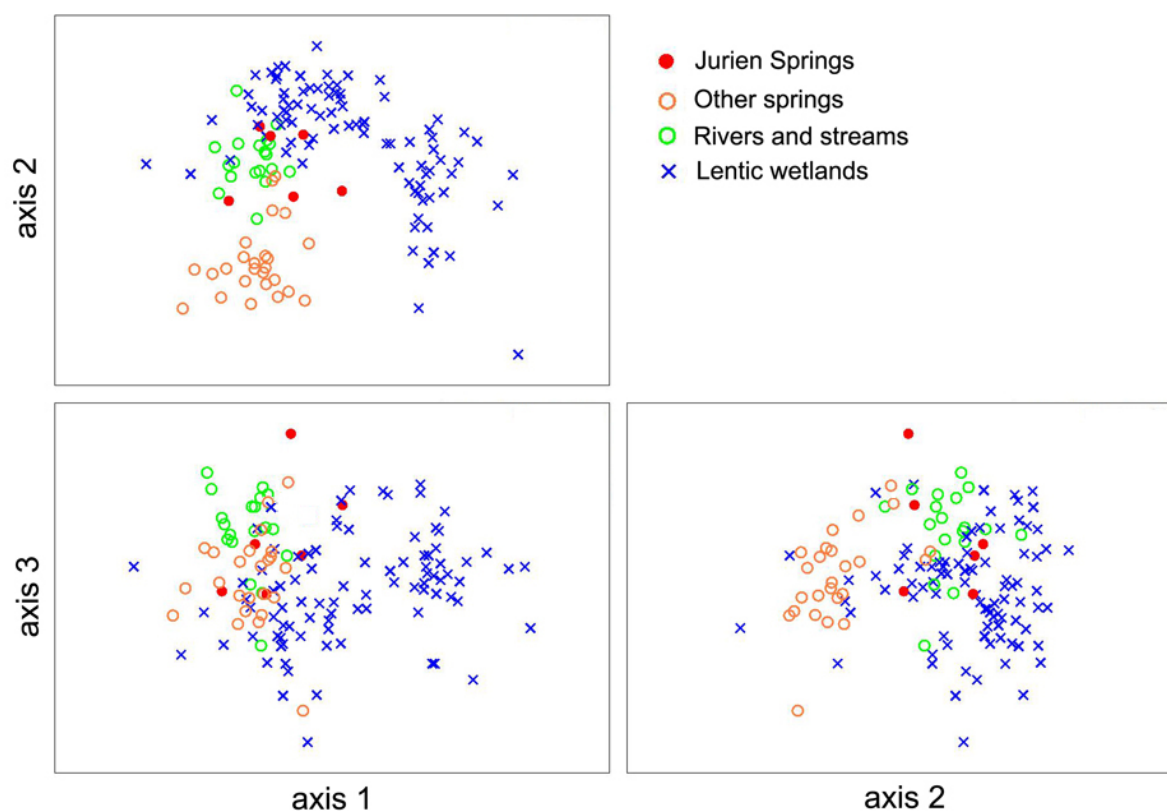


Figure 10. Three-dimensional nMDS ordination of all samples collected by DEC in the northern Wheatbelt since 1997. Stress = 0.15.

Table 2. Species restricted to at least two of sites 7, 10 and SPS202 or at least two of sites 14, 16 and 18.

	Site 7	Site 10	SPS202	Site 14	Site 16	Site 18
Trombidoid water mites						
<i>Aedes alboannulatus</i> (mosquito)						
<i>Culex globocoxitus</i> (mosquito)						
Psychodid sp. 2 (Moth fly)						
<i>Cletocamptus dietersi</i> (copepod)						
<i>Limbodessus schuckhardi</i> (beetle)						
<i>Procladius paludicola</i> (non-biting midge)						
<i>Simocephalus elizabethae</i> (cladoceran)						
<i>Monohelea</i> sp. 1 (biting midge)						
<i>Hemianax papuensis</i> (dragonfly)						

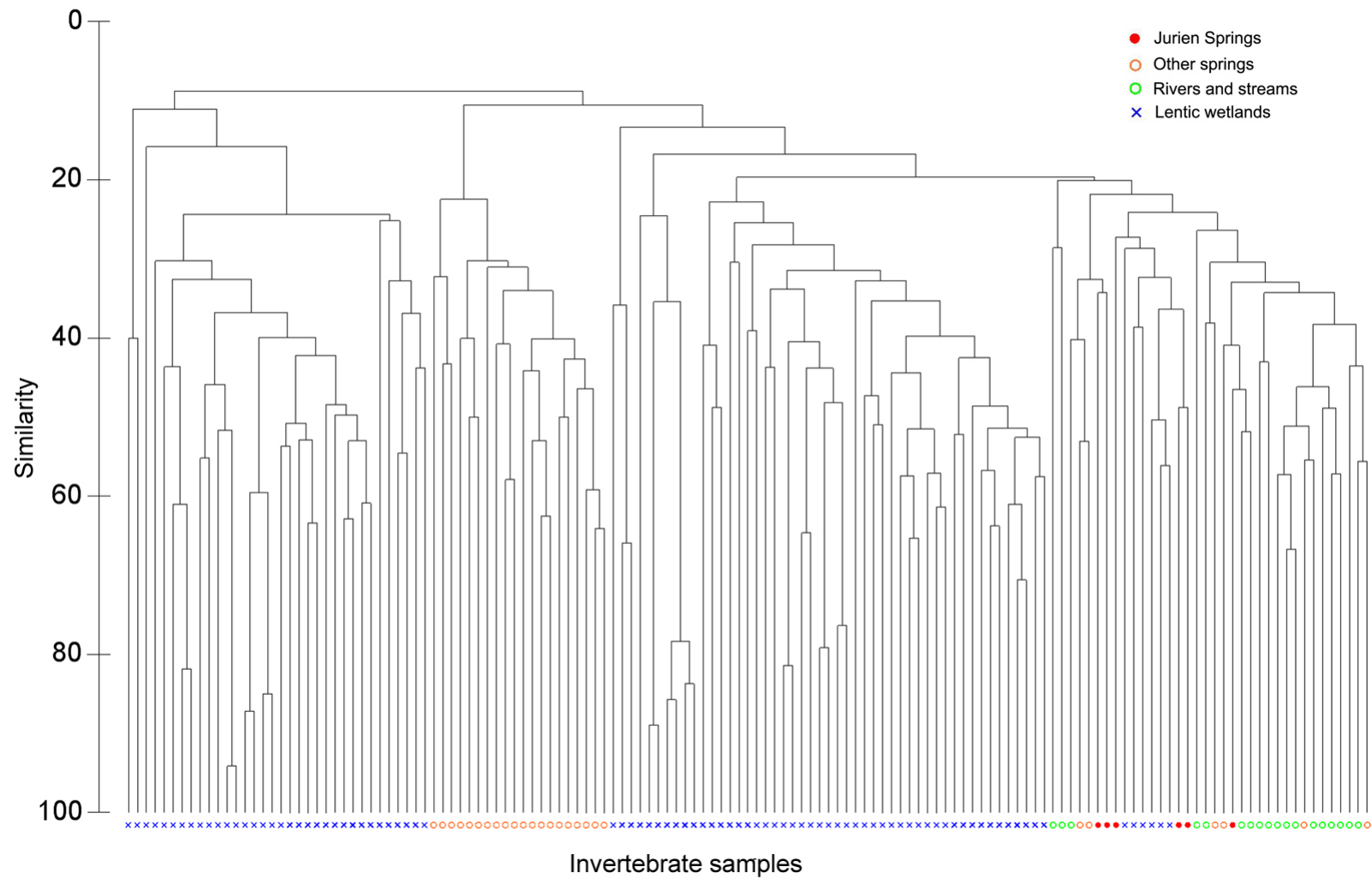


Figure 11. Hierarchical cluster analysis showing grouping of northern Wheatbelt aquatic samples according to their invertebrate community composition. Wetlands are coded according to whether they were springs, rivers/creeks or lentic wetlands.

Groundwater dependence

The aquatic invertebrates in Appendix 2 can be allocated to a number of groups reflecting their degree of dependence on groundwater at the springs.

Stygofauna. Stygophilic invertebrates preferentially occur in subterranean waters but will occasionally or regularly occur in associated surface discharge habitats. Western Australia appears to have a particularly diverse stygofauna by world standards (Eberhard *et al.* in press) and many of these species have been found in groundwater-fed surface wetlands. The groundwater fauna of the Mid-west and northern Wheatbelt has not been well surveyed. The fauna of springs on the upper Arrowsmith River included only two stygal species (the darwinulid ostracod *Penthesilenula brasiliensis* and bathynellid syncarids) (Pinder & Leung 2010) and none were collected from the springs in the Hutt catchment by (Quinlan *et al.* 2009). In the present survey, the only stygofaunal species was an unidentified darwinulid from Eatha Spring. These are almost certainly either *Vestalenula marmonieri* or *Penthesilenula brasiliensis*, both of which are globally widespread species. However, there is likely to be a range of other stygophilic species in the aquifers feeding these springs.

While stygophiles are reliant on groundwater, they are almost certainly not reliant on the groundwater discharging at springs. Downwelling and infiltration of water into aquifers is a much more important process for stygofauna as it brings nutrients and oxygen to aquifer ecosystems (Tomlinson & Boulton 2008). Lowered water tables can alter these surface-groundwater exchanges as well as aquifer chemical and biological (including microbial) processes and the extent and quality of aquifer habitats (e.g. porosity, flow and connectivity). Unfortunately, habitat requirements of stygofaunal invertebrates and the impacts of drawdown on groundwater processes of importance to stygofauna are still poorly understood. A survey of stygofauna in the study area, combined with investigations or review of aquifer habitats, would assist with an assessment of the conservation values of the region's aquifers for stygofauna and the potential impacts upon it by groundwater resource development.

Species associated with permanently moist surface habitats. Many surface dwelling species have a requirement for permanent moisture (at least subsurface moisture during short dry periods) and in some wetlands this permanency is provided by groundwater. Numerous such species inhabit the springs on the upper Arrowsmith River (Pinder & Leung 2010) and, to a lesser extent, in the Hutt River catchment (Quinlan *et al.* 2009). These are primarily species that mainly occur in the higher rainfall south-west but persist in the drier northern Wheatbelt because springs and spring-fed creeks provide permanent refugia. Examples include the dragonfly *Archaeosynthemis occidentalis*, oligochaetes *Antarctodrilus* WA3 and *Antarctodrilus horwiti*, the mosquito *Anopheles atratipes* and the caddisfly *Notoperata tenax*. The only species collected in the Jurien springs that might fit this category is the gilgie, *Cherax quinquecarinatus*, which appears to be at its northern limit at Eatha Spring. Gilgies require permanent moisture but will burrow down to shallow watertables to survive dry periods. Its persistence at Eatha Spring, on the edge of a seasonal salt lake, is certainly dependent upon groundwater discharge creating a moist and relatively low salinity refuge. The salinity at this spring is near the upper limit of the gilgie's tolerance and groundwater feeding the spring may be preventing higher salinity water below the salt lake intruding into the area under Eatha Spring.

There are other species that are widespread and common in the northern Wheatbelt/lower mid-West that also require permanent moisture for survival, though many of these can take temporary refuge in moist subsurface habitats (including in crayfish burrows). This particularly applies to the oligochaetes, the amphipod *Austrochiltonia subtenuis*, *Haloniscus* isopods and water mites, although some of the latter can disperse as parasitic larvae on flying insects.

Actively dispersing species. All of the insects are widespread species and are active dispersers, though some weakly so. The mayflies (*Tasmanocoenis tillyardi* and *Cloeon* sp.) are amongst the weakest flyers and, while they are widespread forms (an assumption for the *Cloeon*), their long-term persistence in the region may be reliant on permanent moisture at the two springs at which they

occurred (Thetis Spring and Little Three Springs). The same may be true for the caddisfly *Hellyethira litua*, also from Thetis Spring. This ability to disperse could be seen as a mechanism allowing tolerance by insects to temporary declines in water levels or drying in the springs. However, recolonisation requires source populations and for the Jurien region wetlands, the springs themselves are likely to be the primary drought refuges and to act as sources of colonisation for other wetlands, rather than the reverse. This is likely to be an important ecological service provided by these springs, so the ecological water requirements of these mobile invertebrates should be considered.

Drought tolerant species. Microcrustaceans (cladocerans, ostracods and copepods) accounted for about a fifth of the invertebrates occurring in the springs and these can generally survive drying as drought resistant propagules. Nonetheless, it is likely that the mix of species present is influenced by the fact that there is permanent moisture at the springs, together with the proximity of some of the springs to other wetlands. An exception may be the copepod *Leptocaris* nr *brevicornis*. This belongs to the mostly marine family Darcythompsoniidae and occurs in both marine and near coastal inland waters around the world. As a marine species it is unlikely to have drought resistant propagules and may be reliant on the groundwater maintained permanent moisture at Eatha Spring. Non-mobile species without drought resistant propagules (like gastropods and annelids) can also survive periods of drying as aestivating adults for short periods where subsurface sediments retain sufficient moisture.

Community composition and groundwater discharge. As well as physiological and ecological dependence of individual species on groundwater or the conditions it creates, the presence of groundwater discharge can also support unique combinations of species (i.e. unique communities). This is the case for the springs on the upper Arrowsmith River, where the presence of groundwater maintained permanent surface and subsurface habitats is critical to the occurrence of a unique and threatened combination of species (Pinder & Leung 2010). This community type is recognised as a Threatened Ecological Community (TEC) known as “Assemblages of Organic Mound Springs of the Three Springs Area” (Rees & Broun 2005). The springs described in this report do not appear to have similarly distinct communities. All of their component species are widespread in the northern Wheatbelt (and most are even more widely distributed) and their combinations appear not to be unique at this regional scale. However, within the Cervantes to Coolimba subregion covered by this study, the springs are likely to be very important in maintaining local aquatic invertebrate diversity. Most of the other wetlands in this area are more saline and far less persistent than the springs. These factors alone may mean that, at a local level, many of the species in Appendix 2 are dependent on the presence of permanent moisture and/or low salinity waters provided by groundwater discharge at these and other springs. Once the remaining samples have been processed, this question of local importance of the springs can be addressed.

Groundwater management and spring invertebrate communities

There is substantial heterogeneity in invertebrate community composition across the six sampled springs, reflecting the variety of habitats present. Preservation of this invertebrate diversity will largely be a question of maintaining the current mix of habitats and, to a large extent, the types of habitats present is determined by the quality and quantity of groundwater.

Water quality. Salinity is a major determinant of invertebrate community composition (Pinder et al. 2005). Even within the “freshwater” range of < 3 g/L, there can be substantial turnover in species composition. Four of the six springs were within this range, although we have no data on how variable salinity is over time. Most of the collected species would have a preference for salinities under 2 to 3 g/L (Pinder et al. 2005). Exceptions are the halophilic species, but those are salt lake species that would survive in dry sediments of adjacent salt lakes. Ionic composition is known to influence the composition of invertebrate communities, especially of crustaceans, but primarily in temporary saline waters where precipitation pathways can affect ion availability (Radke et al. 2003) during the drying

phase. Water was dominated by sodium and chloride at all springs, but ratios of subdominant ion species varied greatly. Thetis Spring stands out as having particularly high proportions of Ca^{2+} and HCO_3^{2-} , presumably associated with limestone aquifer geology, but that spring did not have crustacean species that were not also present in some of the other springs. High density of *Chara* and presence of the grazing snail *Glyptophysa* (both of which deposit calcium) at Thetis Spring, may be promoted by this ionic composition, but actual concentrations of Ca^{2+} were quite low so the high *Chara* density was most associated with high light availability.

All six springs were slightly alkaline. Effects of acidity on invertebrates are normally restricted to $\text{pH} < 5$ to 6, although this is modified by other factors such as metal concentrations (Morris & Taylor 1989). Unless there are potential acid sulphate soils, altered pH should not be a problem at these springs.

Water quantity. In the absence of time series data for water quantity it is difficult to comment on how permanent these springs are. At South Little Three Springs there was only saturated ground present when visited by A. Pinder in October 2010, after a very dry winter/spring period. All of the other springs had some surface water at that time. Deadhorse Soak had a much larger area of inundation in September 2011 than in October 2010, but area of inundation was about the same for Eatha Spring, Thetis Spring and Diamond in the Desert Spring. There are few elements of the fauna of these springs that would indicate that they have acted as long term (pre-historic) drought refugia, unlike the fauna of the upper Arrowsmith springs. This does not negate their current importance as local refugia in a generally dry region of high conservation value.

Depth at some of the springs was sufficient to support insects and other invertebrates, such as copepods, that require adequate water column for swimming behaviour associated with foraging and reproduction. For these species, saturated sediments and litter-filled puddles are inadequate, which is probably why there was so few insects at South Little Three Springs. Macrophyte communities, required by invertebrate grazers and as physical habitat for invertebrates such as damselflies, also require adequate depth in pools. Most springs had maximum depths of only 30 to 40 cm and maintenance of such depths is probably required for the submerged macrophyte and swimming invertebrate communities. Maintenance of these depths may also prevent encroachment of semi-aquatic vegetation into currently open water habitats.

Finally, some springs (Little Three Springs, South Little Three Springs and Diamond in the Desert Spring) have a canopy of tall trees, which stand out in the otherwise scrub-heath landscape. These stands of trees are undoubtedly supported by shallow depth to fresh groundwater. Tree cover provides shade, cooler water temperature, lower evaporation and large amounts of coarse organic matter, resulting in coloured water, food for detritivores and physical habitat for shelter and egg laying (e.g. for some mosquitoes). The leaf litter and shading may also influence the capacity of soils to retain moisture during dry periods. It is also possible that the trees influence spatial patterns of groundwater expression, e.g. through fallen trees forming hollows or through tree roots creating preferential flow paths. Discharge at springs often seems to occur around exposed roots of larger trees.

ACKNOWLEDGEMENTS

Funding for this project has come from 1) an environmental offset provided by CSR Gypsum Pty Ltd (via the DEC Geraldton Office) as part of the conditions of their approval to mine gypsum from a salt lake in Beekeepers Nature Reserve and 2) the Western Australian Department of Water's Groundwater Dependent Ecosystem (GDE) Vulnerability in the Mid West project funded by the National Water Commission. Thanks to Benson Todd (DEC) and Anya Lam (DoW) for assistance with location and selection of sites and to DEC Jurien staff for facilitating aspects of our field work. Site selection was made easier by familiarity with the region obtained during a reconnaissance trip

organised by Anne Shanahan (DEC) as part of the wetland mapping and evaluation project run in conjunction with the present survey. Russell Shiel (University of Adelaide) identified the cladocerans and Jane McRae (Bennelongia Pty Ltd) identified the darcythompsoniid copepod. Pierre Horwitz (Edith Cowan University) and Stephen Beatty (Murdoch University) provided advice about the identification, distribution and salinity tolerance of gilgies.

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Appendix 1. Physical and chemical data	JCS001	JCS002	JCS003	JCS004	JCS005	JCS006	JCS007	JCS008	JCS009	JCS010	JCS011	JCS012	JCS013	JCS014	JCS015	JCS016	JCS017	JCS018	JCS019	JCS020	JCS021	JCS022	JCS023	SPS202
							South Little Three Springs			Diamond in the Desert				Thetis Claypan Mound Spring		Eatha Spring		Deadhorse Soak						Little Three Springs
<u>Habitat</u>																								
Submerged macrophyte cover (%)	10	5	75	1	5	50	0	0	60	20	95	1	99	60	0	0	15	95	95	0.5	100	90	95	10
Emergent macrophyte cover (%)	0	50	20	95	80	0	0	0	1	1	5	50	5	15	0.5	90	0.5	1	50	1	90	90	1	10
Depth (cm)	15	12	28	21	70	26	35	10	10	34	45	14	110	41	120	15	20	37	15	36	50	25	45	40
<u>Water chemistry</u>																								
Field Conductivity (mS/cm)	319	12.7	12.04	7.3	46.8	90.6	8.82	113	43	1.296	12.6	34.9	9.09	1.533	62.7	14.54	81	3.84	3.69	0	6.23	4.35	8.95	4.07
Field measured salinity (g/L)	23.7	6.9	6.68	4.11	29	59.3	5.05	76.2	26.3	0.668	7.52	22.2	5.34	0.838	40.4	8.99	55.8	2.19	2.07	18.8	3.95	2.4	5.07	2.1
Total dissolved solids (g/L)	28	12	6.8	6.6	34	71	4.8	97	55	0.66	8.5	27	5.4	0.76	50	16	66	2	2.3	27	3.3	3	5.7	2.3
Sum major ions	26.71	11.96	6.94	6.85	32.00	71.48	5.48	92.91	54.33	0.75	8.18	24.34	5.84	0.94	49.40	15.89	68.33	2.28	2.49	24.00	3.30	3.18	6.03	2.53
pH	8.68	8.92	8.47	7.88	8.07	8.34	7.9	8.31	8.68	7.81	8.59	8.98	9.02	7.99	8.14	7.17	7.9	7.6	7.54	7.83	7.02	8.05	9.18	8.05
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	2	3.1	2.3	1.9	0.54	0.37	4.6	1.6	1	2.8	-
Total filterable nitrogen (mg/L)	1.1	2.4	3.3	1.9	3.2	1.3	1	3.2	2.7	0.43	1.2	1.5	1.4	2	2.9	2.3	1.6	0.54	0.29	4	0.76	1	1.8	0.77
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	0.03	1.7	0.01	1.8	<0.01	0.24	0.17	0.02	<0.01	<0.01	0.01	<0.02
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	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.07	0.01	0.01	-
Total filterable phosphorus (mg/L)	<0.01	<0.01	0.02	0.05	<0.01	<0.01	0.33	<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	<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	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.01
Temperature (°C)	26.4	27.4	17.9	16	30.4	27.6	17.5	29.9	28.1	24.5	18.9	20.2	19.2	23.2	20.6	21.8	25	21.2	21.2		19.5	20	13	18
Turbidity (NTU)	1.2	11.5	1.6	1.6	3	0.8	19.4	5.5	11.8	10.5	0	3.6	0.5	0	0	0	11.5	1	0	0.4	2.8	1.8	33	4.5
Colour (TCU)	5	46	220	310	180	5	280	6	9	120	100	22	82	6	2	3	4	26	11	190	190	100	27	100
Sodium (% millequivalents)	77.03	79.73	77.35	76.14	74.99	83.88	73.78	81.21	78.34	82.93	76.60	77.51	80.59	59.24	83.02	80.97	80.83	73.92	71.11	76.62	81.25	75.61	80.92	77.78
Calcium (% millequivalents)	4.41	4.93	6.69	8.08	15.32	5.70	10.18	6.45	7.03	6.21	8.32	8.55	6.22	30.55	3.26	6.46	6.72	16.61	19.40	9.00	5.54	9.86	1.52	4.89
Magnesium (% millequivalents)	16.75	13.34	14.26	14.11	8.00	8.44	10.95	9.56	12.65	9.43	12.66	12.01	11.34	8.81	11.32	10.93	10.01	7.66	8.08	12.40	11.20	12.70	15.63	14.29
Potassium (% millequivalents)	1.81	2.00	1.70	1.67	1.69	1.98	5.09	2.78	1.97	1.43	2.42	1.93	1.85	1.41	2.41	1.63	2.44	1.81	1.41	1.98	2.01	1.82	1.93	3.04
Chloride (% millequivalents)	80.58	86.74	83.65	83.55	86.22	90.94	79.11	90.95	86.64	85.20	81.87	83.30	88.09	66.41	91.57	89.67	89.25	82.08	80.27	86.41	87.73	80.45	85.48	81.72
Sulphate (% millequivalents)	18.87	11.15	10.25	9.72	12.80	8.86	2.76	8.93	13.17	5.59	15.06	16.35	9.17	5.47	7.79	8.44	10.55	4.13	5.19	11.54	7.72	8.42	6.22	3.47
Bicarbonate (% millequivalents)	0.35	2.09	6.08	6.72	0.98	0.13	18.11	0.09	0.08	9.08	2.42	0.18	1.77	28.00	0.50	1.88	0.19	13.74	14.50	2.04	4.52	11.10	4.83	14.73
Carbonate (% millequivalents)	0.20	0.01	0.01	0.01	0.00	0.07	0.02	0.04	0.10	0.13	0.65	0.17	0.98	0.11	0.14	0.01	0.02	0.05	0.04	0.00	0.03	0.03	3.47	0.08
Ionic balance	5.1	-0.3	-0.3	-5.1	2	-4.7	-3.9	-3.1	-4.5	-0.3	0.5	-1.5	-2.4	-1.7	-4.6	1	-6.1	2.6	2.6	-1.3	-1.1	2.3	0.4	1.2
<u>Substrate</u>																								
silt+clay	3	2	2	1	5	1	2	3	4	3	4	5	4	3	0	3	3	1	4	5	4	2	1	2
sand+gravel	3	4	5	5	1	5	4	3	2	3	2	2	3	2	1	1	3	1	2	1	3	5	5	5
pebble+cobble	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0
boulder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
bedrock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4	0	0	0	0	0	0
organic soil	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	-
benthic mats	1	1	5	0	5	1	0	5	4	0	4	0	0	0	0	0	0	0	0	5	1	0	0	-
particulate organic matter	0	1	0	2	0	0	5	0	0	5	0	0	1	0	0	0	0	0	0	1	0	0	5	-
litter (leafs and sticks)	0	1	0	2	1	0	4	0	1	5	0	0	1	1	0	1	0	1	1	1	1	1	1	2
logs	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	1
For substrate variables:	0 = none visible		1 = <20%		2 = 2 to <40%		3 = 40 to <60%		4 = 60 to <80%		5 = 80 to 100%													

Appendix 2. Invertebrates

			Spring					
Higher taxonomic group	Family	Identification	7	10	14	16	18	SPS202
			South Little Three Springs	Diamond in the Desert Spring	Thetis Mound Spring	Eatha Spring	Deedhorse Soak	Little Three Springs
Nematodes (roundworms)	-	Nematoda				1		1
Snails	Planorbidae	<i>Glyptophysa</i> sp.			2			
		<i>Gyraulus</i> sp.				1		
Bristle worms (Polychaeta)	Aeolosomatidae	<i>Aeolosoma</i> sp. 1				1		
Aquatic earthworms (Clitellata)	Naididae	<i>Potamothrix bavaricus</i>			3			
		<i>Ainudrilus</i> nr <i>nharna</i> (small form)	1					
		Naidinae sp. (ex Naididae)						1
		Naididae sp. (ex Tubificidae)						1
	Enchytraeidae	Enchytraeidae JCS1	3	2				
		Enchytraeidae JCS2		1		1		
Enchytraeidae sp.							1	
Water mites (Acarina)	Unionicolidae	<i>Koenikea</i> sp.					1	
	Pionidae	Pionidae					1	
	Eylaidae	<i>Eylais</i> sp.						1
	Limnesidae	<i>Limnesia</i> sp.						1
	Arrenuridae	<i>Arrenurus</i> (<i>Truncaturus</i>) sp. 25					1	
		<i>Arrenurus</i> sp.						1
	Pezidae	Pezidae	1					
	-	Mesostigmata	2				1	
	-	Trombidioidea	1	1				2
-	Oribatida sp.				1			
Cladocera	Chydoridae	<i>Dunhevedia crassa</i>			1			
		<i>Alona rigidicaudis</i>						2
	Macrothricidae	<i>Macrothrix breviseta</i>						2
	Daphniidae	<i>Daphnia truncata</i>				3		
<i>Simocephalus elizabethae</i>				2		3		
Ostracoda	Limnocytheridae	<i>Limnocythere</i> sp.				2		
		<i>Limnocythere mowbrayensis</i>						3
	Cytherideidae	<i>Cyprideis australiensis</i>				2		
	Darwinulidae	Darwinulidae				2		
	Ilyocyprididae	<i>Ilyocypris australiensis</i>						1
	Cyprididae	<i>Alboa worooa</i>	4			3	4	
		<i>Candonocypris novaezelandiae</i>	3		1		2	4
		<i>Bennelongia barangaroo</i>						2
		<i>Cypretta baylyi</i>						4
		<i>Mytilocypris ambiguosa</i>						2
		<i>Diacypris spinosa</i>					4	
		<i>Reticypriis</i> sp.				2		
		<i>Caboncypris nunkeri</i>					3	
Cypridopsidae		<i>Sarscypridopsis aculeata</i>	3	4	1		4	3
Notodromadidae	<i>Kennethia</i> sp.				3			
Copepoda	Cyclopidae	<i>Halicyclops</i> sp. 1 (nr <i>ambiguus</i>)				1		
		<i>Metacyclops</i> sp. 442						1
		<i>Metacyclops</i> sp. 434						2
		<i>Australocyclops australis</i>						1
		<i>Mesocyclops brooksi</i>			3	1	2	2
		<i>Eucyclops australiensis</i>			3			
		<i>Apocyclops dengizicus</i>				2		
	Canthocamptidae	<i>Cletocamptus dietersi</i>			1	2	1	
	Ameiridae	<i>Nitocra</i> sp. 5 (nr <i>reducta</i>)				2		
Darcythomsoniidae	<i>Leptocaris</i> ? <i>brevicornis</i>				1			
Amphipods	Ceinidae	<i>Austrochiltonia subtenuis</i>			4	4	4	1
Isopods	Oniscidae	<i>Oniscidae</i> sp.					1	1
Crayfish	Parastacidae	<i>Cherax quinquecarinatus</i>				1		
Beetles (Coleoptera)	Dytiscidae	<i>Hyphydrus elegans</i>		1				1
		<i>Hyphydrus</i> sp.					2	

Appendix 2. Invertebrates

Higher taxonomic group	Family	Identification	Spring					
			7	10	14	16	18	SPS202
			South Little Three Springs	Diamond in the Desert Spring	Thetis Mound Spring	Etha Spring	Deedhorse Soak	Little Three Springs
		<i>Limbodessus shuckhardi</i>			1	1	1	
		<i>Limbodessus inornatus</i>						2
		<i>Allodessus bistrigatus</i>		1	1		1	1
		<i>Paroster niger</i>		1	1			1
		<i>Antiporus gilberti</i>						1
		<i>Sternopriscus</i> sp. (larvae)						1
		<i>Necterosoma penicillatus</i>					2	
		<i>Necterosoma darwini</i>		1				1
		<i>Necterosoma</i> sp. (larvae)				1		
		<i>Megaporus ruficeps</i>					2	
		<i>Megaporus howitti</i>						1
		<i>Rhantus suturalis</i>		2		1	1	2
		<i>Eretes australis</i>						1
		<i>Lancetes lanceolatus</i>					1	
		Dytiscidae (early instar larvae)	1					
	Haliplidae	Halipus sp. (larvae)						1
	Gyrinidae	<i>Dineutus australis</i>					1	1
	Hydrophilidae	<i>Berosus</i> sp.		1			1	1
		<i>Enochrus elongatus</i>					1	
		<i>Enochrus maculiceps</i>	1					
		<i>Paracymus pygmaeus</i>						1
		<i>Limnoxenus</i> sp.		1			1	
	Staphylinidae	Staphylinidae	1					
	Scirtidae	Scirtidae sp.		1		1		1
	Curculionidae	Curculionidae		1			1	2
Diptera	Tipulidae	Tipulidae type C	1					
	Culicidae	<i>Anopheles annulipes</i> s.l.	1	1	1	2	2	2
		<i>Aedes alboannulotus</i>	2	2				1
		<i>Aedes camptorhynchus</i>	3			3		
		<i>Culex globocoxitus</i>	4	2				
		<i>Culex</i> (<i>Culex</i>) <i>australicus</i>	2					
		<i>Culex</i> sp. (early instar)				1	1	1
	Ceratopogonidae	<i>Bezzia</i> sp. 2			1			1
		<i>Culicoides</i> sp.		1	1		1	2
		<i>Monohelea</i> sp. 1				3	1	
		<i>Nilobezzia</i> sp. 1					1	
		<i>Forcypomyia</i> sp.		1				1
		<i>Ceratopogonidae</i> (early instar)	1					
		Dasyheleinae	1					
	Psychodidae	Psychodinae sp. 2	2	1				
		Psychodinae sp. 3	3					
	Tabanidae	Tabanidae		1	1			
	Stratiomyidae	Stratiomyidae					2	1
	Ephydriidae	Ephydriidae sp. 3	1				1	
	-	Diptera (unidentified)		1	1			
	Chironomidae	<i>Procladius paludicola</i>			3	2	3	
		<i>Procladius villosimanus</i>			2			
		<i>Alotanypus dalyupensis</i>					1	
		<i>Paramerina levidensis</i>		2	2		3	1
		<i>Corynoneura</i> sp. (V49)					3	1
		<i>Paralimnophyes pullulus</i>						1
		<i>Paralimnophyes vestitus</i>						1
		<i>Tanytarsus barbitarsis</i>				2		
		<i>Tanytarsus fuscithorax</i>		1	2		2	
		<i>Tanytarsus semibarbitarsus</i>			3		3	2
		<i>Chironomus occidentalis</i>					1	
		<i>Chironomus</i> aff. <i>alternans</i> (=V24)	4	4	1	1	3	2
		<i>Dicrotendipes pseudoconjunctus</i>					2	

Appendix 2. Invertebrates

Higher taxonomic group	Family	Identification	Spring					
			7	10	14	16	18	SPS202
			South Little Three Springs	Diamond in the Desert Spring	Thetis Mound Spring	Etha Spring	Deadhorse Soak	Little Three Springs
		<i>Kiefferulus intertinctus</i>						1
		<i>Polypedilum nubifer</i>			2		3	3
		<i>Cryptochironomus griseidorsum</i>						2
		<i>Cladopelma curtivalva</i>			2			
Mayflies	Baetidae	<i>Cloeon</i> sp.			1			1
	Caenidae	<i>Tasmanocoenis tillyardi</i>			2			1
Water bugs	Mesoveliidae	<i>Mesovelvia hungerfordi</i>			2			
		<i>Mesovelvia</i> sp.		1				
	Veliidae	<i>Microvelia</i> (<i>Pacificovelia</i>) <i>oceanica</i>			1	2	2	1
		<i>Microvelia</i> sp. (juveniles)		1				
	Corixidae	<i>Agraptocorixa eurynome</i>					3	
		<i>Agraptocorixa parvipunctata</i>						2
		<i>Micronecta robusta</i>			1			1
		Corixidae (juveniles)		1				
	Notonectidae	<i>Anisops thienemanni</i>			2		2	2
		<i>Anisops hyperion</i>						2
		<i>Anisops gratus</i>						1
		<i>Anisops stali</i>					3	
Moth larvae	-	Lepidoptera (non-pyralid) sp. 3						1
	-	Lepidoptera		1				
Damselflies (Zygoptera)	Coenagrionidae	<i>Xanthagrion erythroneurum</i>			1			
		<i>Ischnura aurora aurora</i>						1
	Lestidae	<i>Austrolestes psyche</i>			1			
		<i>Austrolestes annulosus</i>					2	
		<i>Austrolestes analis</i>						1
	-	Zygoptera (early instar)				1		
Dragonflies (Eiproctophora)	Aeshnidae	<i>Hemianax papuensis</i>			1		2	
	Libellulidae	<i>Orthetrum caledonicum</i>		1	1	1	1	
	Hemicorduliidae	<i>Hemicordulia tau</i>		2				2
Caddisflies	Hydroptilidae	<i>Hellyethira litua</i>			2			
	Leptoceridae	<i>Oecetis</i> sp.						1
		<i>Triplectides australis</i>					1	2
Total richness			23	30	37	33	52	69