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Halophile aquatic invertebrates in the wheatbelt region of south-western Australia

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Introduction

In the wheatbelt region of inland south-western Australia, extensive clearing of native vegetation for dryland agriculture has reduced evapotranspiration which, in turn, has caused ground water to rise. This has resulted in widespread secondary salinisation and waterlogging of aquatic and terrestrial environments (GEORGE et al. 1995). Despite the severity and extent of salinisation, the area still has significant conservation value. This was recognised in the State Salinity Strategy (ANONYMOUS 1996), which included a survey of the region's biodiversity to provide information for regional conservation planning. Aquatic invertebrates and waterbirds were censused at 230 wetlands. The survey is nearing completion and there are sufficient data to summarise some components of the biota, such as the aquatic invertebrates of granite outcrops (PINDER et al. 2000) and, in this study, the aquatic invertebrates that show a distinct optimisation under saline conditions.

Although salinity has negative connotations in a region severely affected by secondary salinisation, naturally saline playas, in extensive palaeodrainage flats, are a prominent feature of the wheatbelt landscape. Many of the rivers along the south coast are also naturally saline. There have been few studies of the fauna of these saline wetlands. Forty-two saline lakes from two areas of the wheatbelt were sampled by GEDDES et al. (1981), but only a limited suite of crustaceans was identified to species level. BROCK & SHIEL (1983) also included several wheatbelt sites in a study of saline lake plants and invertebrates of the south-west but the identification effort was concentrated on some microinvertebrate groups. A more intensive study of aquatic invertebrates, but from a smaller number of saline wetlands in the northern wheatbelt, was carried out by HALSE (1981), and two wetlands affected by secondary salinisation were studied by HALSE et al. (2000a).

Methods

The 230 wetlands surveyed (Fig. 1) were as evenly spread across the study area as possible and covered the full salinity range, from fresh (approx. 40% of sites) to extremely saline, and included both naturally and secondarily saline sites. Most sites were lentic but 15 lotic sites were included. Two samples were collected at each site: one benthic sample using a 250-µm mesh net and one plankton sample using a 50-µm mesh net. Each sample involved sweeping for a total of 50 m (not necessarily contiguous) and included all macrohabitats (major vegetation types, organic matter, etc.) within wadeable depth. Samples were sorted in the laboratory and the identities of vouchers were verified by taxonomists. Total dissolved solids (APHA method 2540C, APHA 1995) was used as a measure of salinity and is presented as parts per thousand (‰), and pH was measured in the field using a WTW Multiline P4 meter and probe. Some sorting and identification is still taking place and data were not available from all 230 sites for the present study. Macroinvertebrate data were available for 199 sites (lacking only for some of the northern wheatbelt sites), copepod data for 172 sites (mostly in the central and southern wheatbelt) and ostracod, rotifer and cladoceran data for 95 sites (mostly in the central wheatbelt). In the present study, saline water is defined as water with a salinity of more than 3‰, following recent convention reviewed by HAMMER (1986), and water with salinity between 3 and 10‰ is termed subsaline. A halophile is defined as a species occurring mostly or entirely in saline water. No attempt is made to separate halobiont species, as variously defined in the literature (e.g. TIMMS 1983, WILLIAMS 1985).

Study area

The wheatbelt is an area of mostly dryland agriculture approximately bounded by the 600-mm rainfall isohyet to the west and the extent of clearing to the east (Fig. 1), occupying a plateau of low relief, poor soils and poor drainage. This region has been extensively cleared of native vegetation, which was mostly eucalypt woodlands, grading to mallee inland and

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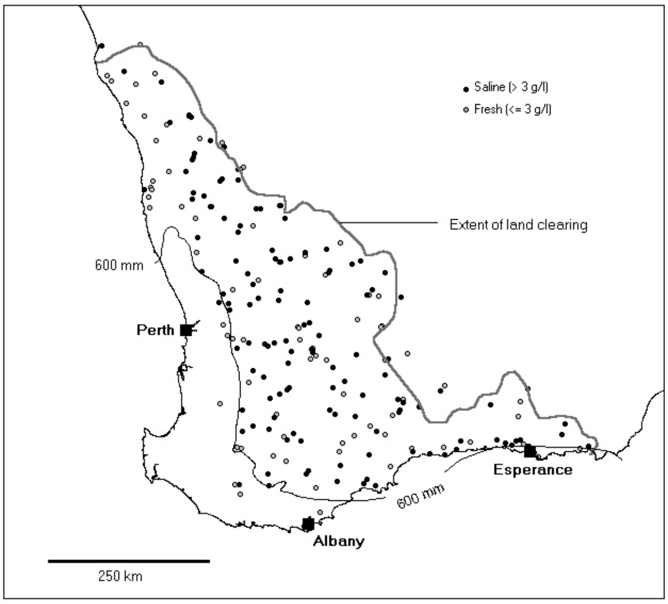

Fig. 1. Map of south-western Australia showing the saline and freshwater survey sites in the wheatbelt region.

scrub-heath to the south and west coasts. As already mentioned, this clearing has resulted in dryland salinity, which currently affects about 10% of the wheatbelt but is expected to affect up to 30% (ANONYMOUS 1996). The extensive inland catchments of the largest rivers (such as the Avon, Blackwood and Moore Rivers) are broad, low-gradient palaeodrainage flats which rarely flow. These palaeodrainage flats largely consist of hundreds of naturally saline playa lakes, most of which dry seasonally. By contrast, most coastal salt lakes have a marine origin. Freshwater wetlands include shallow seasonal claypans and more substantial lakes in upland areas or in areas with fresh ground water or higher rainfall.

Results

Approximately 730 invertebrate taxa have been identified in the survey to date, of which 680 have been identified to species or morphospecies level. Of the latter, 311 species were recorded only from fresh water, leaving 369 species that occurred at least once at or above 3‰. Of these, 84 could be considered halophilic and the rest were halotolerant freshwater species. The halophile species are listed in Table 1, along with the salinity range within which they were collected. Some invertebrates (such as nematodes and most dipteran families) could not be identified to species level, but are included in Table 1 because they contain halophilic species.

Of the new species in Table 1, *Australocypris* sp. nov. has been recorded in previous studies (unpublished data) but several others were collected for the first time in this survey. The sabellid polychaete *Manayunkia* sp. nov. appears to be widespread but uncommon, occurring in seasonal, naturally saline playas except for one record in a broad saline drainage line. The new copepods and ostracods were also restricted to seasonal, naturally saline playa lakes but there are only single records of these and little can be said about their habitat preferences and distribution in the absence of further data. The new *Paroster* is notable, within an otherwise freshwater genus, for occurring in two secondarily saline lakes in the southern wheatbelt. All of the new *Parartemia* were collected from seasonal playas, but one also occurred in a semi-permanent lake. *Parartemia*

Table 1. List of halophilic invertebrates collected during the biological survey of wheatbelt wetlands.

	Taxon	Salinity range (outliers) ‰			Number of records
Cnidaria	*Australomedusa ?baylii* (Russel)		21.0		1
Rotifera	*Ptygura ?melicerta* (Ehrenberg)		55.7		1
	Hexarthra ?oxyuris Sernov		6.4–45.7		3
	Hexarthra fennica (Levander)		4.2–81.2	(240.2)	10
	Brachionus plicatilis (Müller)		4.2–53.0		6
	Brachionus quadridentatus cluniorbicularis (Skorikov)		0.4–4.9	(40.5)	5
	Brachionus rotundiformis Tschugunoff		5.3–10.9		4
Mollusca	*Coxiella exsposita* (Iredale)		3.1–31.0	(126.9)	5
	Coxiella glabra Macpherson		6.0–126.9		11
	Coxiella glauerti Macpherson		88.0		1
	Coxiella striatula (Reeve)		3.4–27.0	(120.0)	9
	Coxiella gilesi (Angas)		22.0–60.0		3
	Coxiella sp. 1		49.0–88.0		2
	Coxiella sp. 2		25.0		1
Oligochaeta	Tubificidae sp. WA10		5.5		1
	Paranais litoralis (Muller)		3.8–7.6		8
Polychaeta	*Manayunkia* sp. nov.		20.0–49.0	(120.0)	6
Anostraca	*Artemia parthenogenetica*		104.8–218.5		3
	Parartemia contracta		84.0–240.2		3
	Parartemia serventii		60.0–74.0		3
	Parartemia cylindifera		20.0–49.0		2
	Parartemia informis Linder		52.0–88.0		2
	Parartemia sp. nov. 1		226.2		1
	Parartemia sp. nov. 2		49.0		1
	Parartemia sp. nov. 3		41.0–130.0		2
	Parartemia sp. nov. 4		33.0		1
	Parartemia sp. nov. 5		110.0		1
	Parartemia sp. nov. 6		92.0–300.0		6
Cladocera	*Daphniopsis pusilla* Serventy		40.9–81.2		5
	Daphniopsis queenslandensis Sergeev	(1.4)	10.7–24.1	(68.0)	6
	Daphniopsis australis Sergeev and Williams		21.0		1
Ostracoda	*Cyprideis australiensis* Hartmann		6.7–37.1		2
	Australocypris insularis (Chapman)		21.0–126.9		16
	Australocypris sp. nov.		33.0–240.2		6
	Cyprinotus edwardi McKenzie		4.2–40.5		12
	Diacypris dictyote De Deckker		30.0–81.2		4
	Diacypris spinosa De Deckker		1.4–45.7	(126.9)	14
	Diacypris compacta (Herbst)		20.6–146.8		11
	Diacypris whitei (Herbst)		92.0–146.8		2
	Diacypris sp. nov. 523		55.7		1
	Diacypris sp. nov. 562		21.0		1
	Mytilocypris ambiguosa		1.4–24.2		8
	Mytilocypris tasmanica chapmani		4.9–60.0	(126.9)	20
	Reticypris clava De Dekker	(1.4)	6.7–63.0		6
	Reticypris sp. nov. 556		60.0–240.2		4
	Reticypris sp. nov. 640		33.0		1
	Platycypris baueri Herbst		15.0–120.0		12

Table 1 *contd.*

	Taxon	Salinity range (outliers) ‰			Number of records
	Leptocythere lacustris De Dekker		6.7–37.1		3
Copepoda	*Calamoecia clitellata* Bayly	(o.4, 1.6)	3.2–126.9		26
	Calamoecia salina (Nicholls)		37.0–110.0		2
	Calamoecia trilobata Halse & McRae		33.0–240.2		6
	Gladioferens imparipes Thomson		5.5–21.0		8
	Sulcanus conflictus Nicholls		3.9–10.9		3
	Metacyclops arnaudi (sensu Kieffer)		6.0–240.2		26
	Metacyclops sp. nov. 3		63.0		1
	Metacyclops sp. nov. 6		49.0		1
	Halicyclops sp. 1		3.8–37.1		10
	Apocyclops dengizicus (Lepeschkin)		4.2–81.2		30
	Mesochra baylyi Hamond	(0.2)	3.2–37.1		10
	Mesochra parva Thomson		6.7		1
	Mesochra ?flava Lang	(0.4, 0.5)	3.2–130.0		24
	Cletocamptus deitersi (Richard)		1.4–6.7		5
	Onychocamptus bengalensis (Sewell)		0.7–20.0		13
	Schizopera clandestina (Klie)		53.0		1
	Schizopera sp. 1		74.0–110.0		3
	Nitocra ?reducta (Schafer)		2.5–24.2		13
	Harpacticoida sp. 1		5.3–42.0		6
Malacostraca	*Haloniscus searlei* Chilten		0.2–126.9		29
Coleoptera	*Paroster* sp. nov. 2		8.4–85.0		2
	Necterosoma penicillatum (Clark) (adults)		0.0–130.0		71
	Necterosoma penicillatum (Clark) (larvae)		77.0		
	Berosus munitipennis Blackburn (adults)		0.8–60.0		18
	Berosus munitipennis Blackburn (larvae)		60.0		
Diptera	*Aedes camptorhynchus* (Thomson)		0.2–63.0		14
	?Monohelea sp. 3		1.0–110.0		14
	Forcypomyia sp. 6		17.0–63.0		2
	?Compterosmittia sp. 2		120.0		1
	Orthocladiinae sp. 7		3.4–63.0	(130.0)	11
	Orthocladiinae sp. 16		6.9–20.0		2
	Orthocladiinae sp. S03C		55.7–68.0		2
	Tanytarsus barbitarsis Freeman	(0.04)	3.4–209.5		37
	Polypedilum nr *vespertinus* (sp. M2)		20.0–21.0		2
Trichoptera	*Symphitoneuria wheeleri* Banks		3.4–42.0		9
Lepidoptera	Pyralidae sp. 4	(0.1)	4.1–53.0		16
Taxa not identified to species level but likely to include halobiontic species					
Nematoda	Nematoda		0.03–300.0		122
Diptera	Culicoides		0.03–300.0		96
	Muscidae		0.03–300.0		40
	Tabanaidae		0.08–300.0		61
	Stratiomyidae		0.08–300.0		56
	Ephydridae		0.04–300.0		80
	Enchytraeidae		0.04–300.0		60

sp. 4 was the only new species to occur in an acidic lake (pH 3.87). No two *Parartemia* were recorded in the same lake.

Several taxa in Table 1 have not previously been recorded from Western Australian inland waters. The first record of *Australomedusa ?baylii* (previously known only from coastal lakes on the South Australian coastline) is from a naturally saline south coast river. The naidid oligochaete *Paranais litoralis* was collected mostly from secondarily subsaline rivers and associated wetlands, but also from a naturally subsaline lake on the south coast. This cosmopolitan species has previously been collected from marine/estuarine localities on the southern Australian coast (e.g. Erséus 1990) but not from inland sites. Enchytraeid oligochaetes occur in most aquatic habitats but have not previously been recorded from inland saline wetlands in Western Australia. They were collected in fresh to saline (up to 300‰) lentic and lotic habitats in the present survey and occurred in saline lakes in south-eastern Australia (Timms 1983). The records of the cosmopolitan rotifers *Brachionus rotundiformis* and *Brachionus quadridentatus cluniorbicularis*, mostly from subsaline sites, are the first for Western Australia but both species are already known from south-eastern Australia.

Discussion

That about half of the species in this survey were recorded in both fresh and saline water reflects the findings of Kay et al. (2001) that riverine invertebrates of the south-west agricultural zone are reasonably tolerant of salinity. Table 1 shows that the number of species that have a propensity for, rather than simply a tolerance to, salinity is also high in this region. This list is provisional and may expand, though probably not greatly, once remaining samples are processed. The number of halophiles recorded in the present survey is larger than the combined total of Geddes et al. (1981), Halse (1981) and Brock & Shiel (1983). However, this is largely because of the greater taxonomic resolution of *Coxiella* (however tentative), harpacticoids and insects in the present survey, and the more intensive sampling of benthic invertebrates. Described microinvertebrates listed in Table 1 but not recorded by previous studies of the inland south-west include the new records for Western Australia (see Results section) and six other species (*Cyprideis australiensis*, *Reticypris clava*, *Diacypris dictyote*, *Onychocamptus bengalensis*, *Leptocythere lacustris* and *Schizopera clandestina*), which have been recorded from other regions of Western Australia (Edward 1983, Storey et al. 1993, Halse et. al. 2000a,b and unpublished data). Conversely, species listed by Geddes et al. (1981) and Brock & Shiel (1981) but not collected in the present study are *Diacypris fodiens*, *Australocypris robusta*, *Parartemia extracta* and *P. longicaudata*. In addition, *Diacypris deitzi* and *Quinquelaophonte wellsi* are known from south-eastern Australian salt lakes (Hamond 1973) and from coastal saline birradas of the Carnarvon Basin on the mid-west coast of WA (Halse et al. 2000b) but are yet to be recorded from the wheatbelt.

Most of the species recorded in wheatbelt saline lakes are Australian endemics, with a few more widely distributed species, such as the naidid oligochaete *Paranais litoralis*, *Brachionus* spp., *Hexarthra fennica* (and *H. oxyuris*, if this is the correct identification), *Apocyclops dengizicus* and the brine shrimp *Artemia ?parthenogenetica*. *Artemia* were recorded from a large coastal lagoon (used for salt extraction) in the northern wheatbelt and two small wetlands in the central wheatbelt (one secondarily saline site and one saline wetland that has arisen only since clearing). *Artemia* appears to have been introduced to Australia (Geddes 1983) but is now widespread, with previous Western Australian records from saline lakes on Rottnest Island (off the coast near Perth), coastal salt lakes in the north-west used for salt extraction and some coastal saline lakes south of Perth (Geddes 1980, unpublished data). The two records from the central wheatbelt are unusually far from the coast. While neither of these sites is naturally saline, there is another recent record of *Artemia ?franciscana* Kellogg from a naturally saline playa, Lake Koorkoodine, even further inland, and it appears that *Artemia* are spreading.

Most of the described Australian endemics occurring in the wheatbelt, particularly the microinvertebrates and insects, have also been recorded from one or more of the various saline lake systems in south-eastern Australia studied by BAYLY & WILLIAMS (1966), BAYLY (1970, 1976), DE DECKKER & GEDDES (1980), WILLIAMS (1981, 1984), WILLIAMS & KOKKIN (1988) and TIMMS (1983, 1993). It remains to be seen whether the undescribed ostracods and copepods (and *Calamoecia trilobata*, a new species described from material collected in this survey) are restricted to Western Australia, or whether, as appears to be the rule for halophile microinvertebrates in Australia, they will be found to have broader distributions. GEDDES et al. (1981) listed the same number of undescribed *Australocypris*, *Diacypris* and *Reticypris* ostracods and *Metacyclops* (as *Microcyclops* spp.) copepods as this survey has revealed to date, but noted that some of these had also been collected from the south-east. There are a few described species, e.g. the ostracod *Reticypris herbsti* and the brine shrimp *Paratemia zietziana* known from south-eastern Australia that have not yet been recorded in Western Australia. As noted before (e.g. WILLIAMS 1984) the most distinctive features of the south-west salt lake fauna are the diversity of *Coxiella* gastropods and *Parartemia* brine shrimps. These must have accounted for most of the dissimilarity between the halophile faunas of south-western and south-eastern Australia calculated by WILLIAMS (1984).

Unfortunately, the taxonomy of *Coxiella*, which appears to have multiple species restricted to southern Western Australia, is in need of revision (WILLIAMS & MELLOR 1991). Although the *Coxiella* in Table 1 have been separated into morphospecies by the present authors and W. PONDER (Australian Museum), the identifications are tentative and only serve to indicate the possible diversity within this group. Several authors (e.g. DE DECKKER & GEDDES 1980) have commented on the ecophenotypic plasticity of the characters used to separate species in the only review of *Coxiella* (MACPHERSON 1957). The genus was collected from approximately 25% of saline sites. All but one of these sites was alkaline, the exception being an acidic playa with a single fragile (calcium deficient?) individual that may have been washed in from upstream. The salinity ranges given in Table 1 are for live, though not necessarily active, specimens.

Available data provide scant evidence of localised patterns in the distribution of halophile taxa within the wheatbelt. While many species are currently known only from particular subregions, there is little corroboration between taxa to suggest substantial regionality of the fauna. Although the study area is large and contains thousands of saline lakes that vary in their morphology, chemistry and hydrology, there are few geographic trends in the variation, other than the increasing seasonality from south to north. Possible differences between the fauna of the wheatbelt region and drier areas further inland were mentioned by GEDDES et al. (1981), and the occurrence of several undescribed ostracod species in playas east of the wheatbelt (unpublished data) provides some additional evidence that faunal differences may exist.

The strongest biogeographic pattern observed within the wheatbelt was that some species (Tubificid sp. WA10, *Australomedusa ?baylii*, *Gladioferens imparipes*, *Onychocamptus bengalensis*, *Leptocythere lacustris*, *Cyprideis australiensis*, *Halicyclops* sp. 1, *Polypedilum* cf. *vespertinus* and *Symphitoneuria wheeleri*) do not penetrate very far inland. All are athalassic species (but, except for the insects, belong to groups with a recent marine/estuarine origin). They all occurred in sites with permanent water (including river pools, closed inlets of south coast rivers or seepages), which may help to explain their essentially coastal distribution. All of the described species are otherwise known only from coastal wetlands in eastern Australia (e.g. BAYLY & WILLIAMS 1966, BAYLY 1970, DE DECKKER & GEDDES 1980) and Western Australia (ANONYMOUS 1992, STOREY et al. 1993, HALSE et al. 2000b and unpublished data).

Generally, described species were collected within, or only slightly outside, salinity ranges in the literature. There were, however, large differences between species in their salinity range, and salinity is a major determinant of the distribution of halophilic taxa. Very few species were restricted to subsaline conditions, and even these have been recorded at higher salinities in other studies. About half of the halophile species in the wheatbelt extended from fresh or subsaline water to maximum salinity records of 10–80‰, with some species, such as *Tanytarsus barbitarsus*, *Haloniscus searlei*, *Necterosoma penicillatum*, *Calamoecia clitellata* and *Mesochra ?flava* occurring over particularly wide salinity ranges. Relatively few species are known to be restricted to higher salinities (virtually never occurring in subsaline conditions). Even some of the ostracods recorded only above 20–30‰ to date in the present survey have been recorded at lower salinities in studies reviewed by HAMMER (1986). Species restricted to high salinities include *Diacypris whitei*, *Calamoecia salina*, *Calamoecia trilobata*, *Artemia*, *Parartemia* and, possibly some *Coxiella*.

Given the increasing amount of secondary salinisation in Western Australia, which affects the hydrology of naturally saline, as well as fresh wetlands (GEORGE et al. 1995), it is significant that the majority of halophilic species were recorded from seasonal, naturally saline, rather than waterlogged secondarily saline, wetlands. Species that occurred in secondarily saline wetlands include *Coxiella*, *Daphniopsis* spp., *Mytilocypris* spp., *Diacypris* spp. (though not the new species), *P. baueri*, *C. clitellata*, *M. arnaudi*, *A. dengizcus*, *Mesochra* spp., *N. ?reducta*, *N. penicillatum*, *B. munitipennis* and *T. barbitarsus*. Virtually all other species were restricted to naturally saline wetlands and it is likely that their distribution in Western Australia will contract as secondary salinisation becomes more widespread.

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