

The biogeography and conservation status of the Australian endemic brine shrimp *Parartemia* (Crustacea, Anostraca, Parartemiidae)

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ABSTRACT

Australia has more species of halophilic Anostraca than any other continent and most belong to the endemic genus *Parartemia*. The distributions of twelve described and 10 undescribed species of *Parartemia* have been mapped, based on 367 records. Western Australia (WA) has 13 species, South Australia (SA) seven, Victoria two and the remaining states and the Northern Territory (NT) have one each.

Some species are widespread, including *P. minuta* in the inland of the eastern states, new species 'g' in northern and inland WA and the NT and *P. cylindrifera* and *P. acidiphila* in southern SA and southern WA. Many species are widespread in the Wheatbelt and/or Goldfields of WA (e.g. *P. informis*, *P. longicaudata*, *P. serventyi*, *P. acidiphila* and species 'a'). Eight species are known from six or fewer sites each in WA or SA.

It is recommended that *P. extracta* and species 'c' should be assessed against IUCN categories and criteria as a threatened species. They are likely to be consistent with category "Vulnerable" due to secondary salinisation severely affecting their habitat and the declining number of populations. *Parartemia* species 'b', 'e' and 'x' should be assessed against the Western Australian Department of Environment and Conservation's criteria for listing as Priority species (Priority 1: Taxa with few, poorly known populations on threatened lands), due to the threat posed by secondary salinisation and/or few known locations. *Parartemia contracta* is already listed as a Priority 1 species, but is perhaps not as threatened as previously believed and so this should be reassessed. Others, particularly those in the WA Wheatbelt, are losing populations to salinisation, but are probably safe in smaller lakes in the upper catchments. In most cases of population extinction we believe that some combination of salinity change, pH decrease, and change to water permanency is involved.

In order to provide a more suitable base for assessment of conservation significance and environmental requirements we recommend further surveys and monitoring of natural saline lakes and research on the ecophysiology of *Parartemia* species in Western Australia.

Keywords: Brine shrimp, *Parartemia*, salt lakes, salinisation

INTRODUCTION

By world standards anostracan diversity is relatively low in Australia (Brendonck *et al.* 2008), but Australia has a relatively high proportion of its fauna (24 out of about 55 species) inhabiting saline waters (Timms 2009a). While a few species of the Australian fairy shrimp genus *Branchinella* live in saline and subsaline waters, special interest centres on the endemic brine shrimp genus *Parartemia* whose ecology and physiology mirrors that of *Artemia* in the northern hemisphere (Geddes 1981; Clegg & Campagna

2006). Most *Parartemia* inhabit intermittent saline lakes, although some are known from permanent lakes and some from slow flowing saline creeks, the latter especially where these are part of larger saline wetland complexes (as in the Wheatbelt region of Western Australia: shaded area on Figure 1). The first species was described in 1903 (*Parartemia zietziana* Sayce), six more from Western Australia (WA) were added by Linder (1941), Geddes described *P. minuta* in 1973 and Timms & Hudson (2009) have described three new species from South Australia (SA) and one from WA. It is now believed that there are 19 species, comprising these 12 described species and seven undescribed species in Western Australia (Timms & Savage 2004; Timms *et al.* 2006; Timms & Hudson 2009).

Parartemia is thus more speciose than *Artemia* which has only nine species (Timms & Savage 2004). The undescribed species are herein denoted by letter codes consistent with those in Timms & Savage (2004).

Australia's inland waters are stressed and many, including saline waters in Western Australia, are changing rapidly (Davis *et al.* 2003; Halse *et al.* 2003; Nielsen *et al.* 2003; Timms 2005). Brine shrimp are a quintessential component of saline lake ecosystems, yet little is known of their distribution, abundance and habitat requirements. This review has been prompted by apparent extinctions of several *Parartemia* populations in the Wheatbelt and concerns about the long term persistence of some species. While it is too late to be cognisant of the pre-European distribution of brine shrimp, enough unaltered or partly altered habitats are available to establish a broad picture. Geddes (1981) tried, but had few records and mentioned only the eight described species of the time. More data are now available in the unpublished records of various institutions and researchers and there have been a few recent studies in regions where *Parartemia* are common. It is the aim of this study to assemble these data, compose distribution maps and assess the biogeography and conservation status of each species. Unfortunately the detailed studies of *P. zietziana* by Geddes (1975a, 1975b, 1975c, 1976) and Marchant & Williams (1977a, 1977b, 1977c) have not been repeated in other situations or expanded to other species and nothing can be added to knowledge of the habitat requirements of the various species, as reviewed in Timms (2009a).

METHODS

Besides the earlier sources used by Geddes (1981), such as Bayly & Williams (1966), Geddes (1976) and Geddes *et al.* (1981), many records were sourced from regional studies by De Deckker & Geddes (1980), Timms (1993, 2007, 2009b, 2009c), Timms *et al.* (2006) and a few isolated occurrences were gleaned from Conte & Geddes (1988), Timms (2004), Williams (1984, 1990), Williams & Kokkin (1988), Williams *et al.* (1998) and Pinder *et al.* (2002, 2004). However the majority of records are based on, in numerical order, the collections of the senior author, the Western Australian Department of Environment and Conservation (DEC), Western Australian Museum, South Australian Museum, Veronica Campagna (Outback Ecology in WA), Actis Environmental Services (WA), Alan Savage, Museum Victoria (formerly National Museum of Victoria), Australian Museum, Centre for Excellence in Natural Resource Management, University of Western Australia, Peter Hudson (South Australian Museum) and Joanne O'Conner (Murdoch University). A few records are based on hatching of eggs from dried mud: an under utilised resource for distribution records (Campagna 2007).

Altogether, 367 records of the 19 species were available. Most collections were made after 2000, but some are 20 to 30 years old, and a few date back to the 1930s. The senior author holds the master file and a copy is kept by DEC's Science Division.

RESULTS

Known distributions of the 12 described and seven undescribed species of *Parartemia* are shown in Figures 1–4. Not all of the 367 records appear on the maps because some sites have been visited a few times and many have been combined on the maps because they are too close together to show individually. For some species (e.g. *P. cylindrifera*, *P. longicaudata*, *P. zietziana*) there are many known sites and collections, others are less common (e.g. *P. informis*, *P. contracta*) and many are uncommon or even rare (e.g. *triquetra*, *P. auriciforma* and species 'b', 'c', 'e' and 'x' (see Table 1).

Eastern Australia (Figure 1) has just two species, *P. minuta* in inland Queensland, northwestern New South Wales, northwestern Victoria and eastern SA, and *P. zietziana* in central lowland Tasmania, western Victoria, and southern SA, including the far southeast, Riverland, Adelaide and southern Yorke and Eyre Peninsulas. Both species have disjunct distributions with populations separated by large tracts of land without saline lakes. The southern and northern distributions of these species overlap slightly in northern Victoria and northern Eyre Peninsula (Figure 1). Two species (*P. cylindrifera* and *P. acidiphila*) are shared between SA and WA. The former occurs in near coastal regions of SA and in a band across the southern Wheatbelt from near Esperance in WA (Figure 2). By contrast, *P. acidiphila* is less widespread, being found only in the southern Gawler Ranges of SA and in the Esperance hinterland of WA (Figure 3). *Parartemia* species 'g' is sparsely distributed in northern and inland WA and inland Northern Territory (Figure 1) but it is not known whether it penetrates into northwestern SA. Three species are known only from SA (*P. triquetra*, *P. auriciforma* and *P. yarleensis*). *Parartemia yarleensis* is widespread through the southern inland of SA but the other two are each known from a single locality.

The remaining 14 species are endemic to WA. Some are known from only one or a few lakes; these include species 'e' and 'x' in the northern Goldfields (Figures 2 and 4), species 'c' near Wubin to Cunderin, northeast of Perth (Figure 3), and species 'b' southeast of Hyden and Lake King (Figure 4). Species 'a' has a restricted range in the Esperance hinterland (in almost the same area as WA populations of *P. acidiphila*) (Figure 4), while species 'd' occurs sparsely across the Goldfields (Figure 3). The remaining species are more common or widespread. *Parartemia serventyi* is known from the central Wheatbelt and southern Goldfields (Figure 2), *P. longicaudata* from the southern and central Wheatbelt (Figure 3), *P. contracta* from the southern Wheatbelt and adjacent area of the northern Wheatbelt (Figure 4), *P. informis* in the northern and central Wheatbelt (Figure 1) and finally *P. extracta* in the Wheatbelt and Mid-west regions from near Lake Grace to Lake Moore and coastal lakes near Jurien (Figure 2).

A summary map (Figure 5) shows the number of species in each one degree latitude and longitude cell. This reveals that diversity is greatest at 3 to 5 species per cell in a curved band through the inland of south-western Australia, from northeast of Perth through to the

Esperance hinterland, although there are other groupings of cells with two species. Despite these concentrations of diversity and substantial overlaps in distribution for many species it is rare for species of *Parartemia* to co-occur. *Parartemia minuta* co-occurs with *P. yarleensis* in Ironstone Lagoon in the Gawler Ranges, SA (Timms & Hudson 2009) and *P. serventyi* and species 'd' sometimes co-occur in the Lake Johnson area east of Norseman in WA (A. Savage, pers. comm.¹). In Lake Carey species 'g' is sometimes washed into the main lake from adjacent saline pans and temporarily lives with Lake Carey's resident species 'x' (B. Datson, pers. comm.²). Some species live in close proximity but are separated by barriers and/or habitat differences. For example, in Lake Way (near Wiluna) *Parartemia* species 'd' and 'g' can be separated by a causeway, or species 'g' is found in pools in inflowing creeks while species 'd' occurs in pools on the lake bed (data from V. Campagna). In the Esperance hinterland habitat differences can contribute to species living close to each other, but separated by a sandbar 5 m wide (Timms 2009b).

It appears that *Parartemia* have become extinct in some lakes, although how long egg banks remain viable under conditions unsuitable for adults is unknown. In 1978 Geddes *et al.* (1981) collected *P. extracta* in a lake near Dowerin, *P. informis* in Cowcowing Lake (via Wyalchatchem), and *P. longicaudata* in Lake Warden (a Ramsar wetland near Esperance), Lake King, Lake Grace, Lake Stubbs (near Newdegate) and Lake Burkett (near Newdegate). Repeated attempts by the senior author to find *Parartemia* in these lakes over 2004–08 have failed. Some of these lakes (lake near Dowerin, Cowcowing Lakes, Lake Stubbs, Lake Burkett) appear in the meantime to have been affected by salinisation, while Lake Warden has become less saline and more permanent (Halse & Massenbauer 2005).

On the other hand, some *Parartemia* have appeared in lakes where they were previously not recorded. In Victoria's Lake Corangamite brine shrimp were not recorded throughout much of the 1900s when its salinity was mesosaline to hyposaline and fish were present. Notably, when the lake was hypersaline and lacked fish in 1918, *P. zietziana* was common (Shephard *et al.* 1918). However, with steadily increasing salinity and death of the fish population in the late 1900s, *P. zietziana* reappeared in the last decade (Timms 2004). Another marked change in recent years is the bloom of *P. zietziana* in the lower Coorong in response to increasing salinity (M. Geddes, pers. comm.³). In both of these cases, the high numbers of shrimp have attracted feeding associations of water birds, especially of the Black-winged Stilt.

Table 2 shows the recorded salinity ranges for *Parartemia* species (where known). Most species have been recorded from a very wide range of salinities and most have recorded salinities in the 150 to 250 g/L range.

Where this is not the case it may be due to the small number of measurements, although *P. cylindrifera* is likely to be an exception with 130 of 131 records below 135 g/L. Most species have only been recorded from alkaline lakes but *P. contracta*, *P. acidiphila* and species 'b' are acidophiles and *P. serventyi* has been recorded in both alkaline and acidic waters.

Body size also varies between species (Table 2) and there may be a geographic pattern in body size which has not been noted before. The largest species (*P. contracta*, *P. cylindrifera*, *P. informis*, *P. longicaudata*, *P. serventyi* and species 'c') occur primarily in lakes of the Western Australian Wheatbelt (Table 2). These lakes tend to be reliably inundated for many months of the year, though a drying climate may be creating more variability. Reliably longer hydroperiods accommodate slower growth and no urgency to attain sexual maturity. By contrast, the smallest species (*P. minuta*, *P. triquetra*, *P. auriciforma*, *P. yarleensis*, *P. acidiphila* and species 'a', 'b', 'd' and 'g'—Table 2) occur in areas of less reliable rain and shorter hydroperiods (although larger lakes can episodically fill for extended periods). In these species, small body size confers an advantage by allowing early maturity. Alternatively, or in addition, the size relationship may be mediated more by food availability than hydrology; regularly filled lakes that retain surface water for longer periods accumulate more organic matter and benthic algal mats than lakes that fill unpredictably and ephemerally, other factors being equal. *Parartemia* species 'x' is a contradiction to this relationship between aridity and body size, as it is a large species occurring in an arid zone (Lake Carey). However, this lake collects water from a large catchment and consequently the lake holds some water for many weeks in most years (Timms, *et al.* 2006; Gregory *et al.* 2009).

DISCUSSION

Diversity and distributions

Parartemia appears to have undergone a rapid radiation, especially compared to freshwater anostracans in Australia (Hebert *et al.* 2002; Remigio *et al.* 2001), and is far more speciose in Western Australia than elsewhere. Similar high diversity and endemism is known for some other invertebrates inhabiting lentic wetlands of the south-west, especially in the arid and semi arid interior. This applies to *Branchinella* (Timms 2002), *Daphniopsis* (Hebert & Wilson 2000) and many other cladocerans (R. Shiel, pers. comm.⁴), mytilocyprinid ostracods (Halse & McRae 2004), phreodrilid oligochaetes (Pinder, 2001) plus some elements of the fauna of rock pools (Pinder *et al.* 2000; Timms 2006). The ancient, largely stable landscape with

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an enormous number saline lakes in Western Australia and middle South Australia (Van de Graaf *et al.* 1977; Pilgrim 1979; Twidale & Campbell 1993; Beard 1997, 1999), combined with climatic fluctuations and periodic isolation of the west from the east (Williams *et al.* 1993), have probably promoted speciation of these groups in the west and to a lesser extent in southern middle Australia. For *Parartemia*, speciation is probably also promoted by their resting eggs being heavy and sticky and hence easily bound to the clays that characterise salt lake sediments, inhibiting dispersal by wind and floods. In an interesting contrast, many invertebrate groups in streams of the more temperate south-west are depauperate in comparison with eastern Australia and entire families of stoneflies, mayflies and caddisflies, common in the east, are absent from otherwise suitable habitat in WA (Bunn & Davies 1990).

A range of occurrence patterns are evident within the genus, including common but restricted (e.g. species 'a'), common and widespread (e.g. *P. cylindrifera*), rare and restricted (e.g. species 'e' and 'x') and rare but widespread (species 'g'). In the more arid regions some species (*P. triquetra*, *P. auriciforma* and species 'e' and 'x') appear to have particularly small ranges and most are known from only one or a few populations. Low dispersal ability, the episodic nature of filling events (which limits opportunities for successful colonisation) and sparse distribution of salt lakes may have contributed to such patterns. However, survey effort in the arid zones has been low compared to the more semi-arid and temperate regions and some arid zone species (*P. acidiphila* and species 'd' and 'g') do have their few populations distributed over very wide ranges. Where lakes are more densely aggregated, as in the Wheatbelt, there is likely to be more opportunity for dispersal (e.g. *Parartemia* are occasionally recorded in the region's saline creeks) and patterns of occurrence are more likely to reflect ecophysiological tolerances to variables such as salinity and pH. For example, *P. contracta* and species 'b' largely occupy acid waters (Conte & Geddes 1988; Timms 2009b) whereas most others occupy alkaline waters. Lower salinities are important for *P. cylindrifera* (Timms 2009c) and possibly some other species. Known range size is nonetheless also variable even for these more south-western species (e.g. *P. serventyi* and *P. longicaudata* have large ranges whereas species 'c' and 'a' have smaller ones).

Threats

For some *Parartemia* the number of extant populations may have been reduced since European settlement. This is especially so in the Wheatbelt region where secondary salinisation is a major problem (George *et al.* 1995; Clarke *et al.* 2002; Halse *et al.* 2003). The lakes where *Parartemia* have been lost include those listed above but most likely an unknown number of additional localities. Certainly in recent years there have been numerous failed attempts to collect *Parartemia* from Wheatbelt lakes in which they were known to have occurred in the past. Surveying for uncommon invertebrates has some well-known difficulties, including false absences (New 1998).

However, we believe our data indicate genuine absence of viable populations from such lakes because in typical pristine saline lakes multivoltine *Parartemia* live through almost the whole period the lake holds water (e.g. Geddes 1976; De Deckker & Geddes 1980). Viable eggs may still be present, but with little hope of ever hatching in the changed milieu.

It is not known which component (or combination thereof) of the salinisation process is responsible for the declines. Rising groundwater has increased (sometimes decreased) salinity and extended the hydroperiod of many wetlands. In some areas rising groundwater, and the drainage schemes designed to reduce the impact of salinity on agriculture, have dramatically reduced pH. As far as is known most, and probably all, *Parartemia* produce both non-resting eggs (for maintenance of populations during a filling event) and drought resistant resting eggs (for surviving between filling events). The latter require a period of drying before they will hatch. These strategies mean that *Parartemia* should be able to maintain populations in permanent wetlands (as evidenced presently in the Coorong and in Lake Corangamite), but if a population dies out for some other reason then it will not be able to re-establish from the egg bank if the wetland does not dry.

Increased acidity could be an important threat as most *Parartemia* are restricted to alkaline waters. Agricultural drainage schemes are moving acid water around the landscape and affecting some naturally saline systems in the Wheatbelt (Stewart *et al.* 2009). There is no evidence that the common acidophile *P. contracta* is colonising such waters within its range but *Parartemia serventyi* (id confirmed by B. Timms) has been recorded in secondarily acidic (pH > 3.7) reaches of the Salt River in the Wheatbelt (G. Janicke, pers. comm.⁵)

It is possible that salinities in many salinised lakes (even those that were always saline) may have increased beyond the known upper salinity tolerance of many *Parartemia* and certainly beyond thresholds for hatching of their eggs. On the other hand, just as many secondarily saline lakes (i.e. lakes that were once fresh) have salinities in the 50–150 g/L band but very few have been colonised by *Parartemia*, even though such salinities are within the known field range for most species (Table 2). Colonisation of these may occur over time and it is notable, in this respect, that *Parartemia zietziana* lives in secondarily salinised lakes of high salinity on the Eyre Peninsula (Timms 2009c). What is clear is that there is no simple explanation for the loss of *Parartemia* populations and that this is a priority area for future brine shrimp research.

The dewatering of mines into saline lakes is also a vexed question. Lake Carey in the northern Goldfields has received mine waste water for many years. The lake is normally dry but *Parartemia* species 'x', plus other invertebrates and diatoms, still live in the lake when it holds water (Timms *et al.* 2006; Gregory *et al.* 2009; B. Datson, pers. comm.²). In this case the lake is very large

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and only a small area is affected by salt accumulation from the waste water. When mining ceases, much of the salt is expected to dissipate within decades (M. Coleman, pers. comm.⁶). The same is true of Lake Hope North (L. Hill, pers. comm.⁷). Should the receiving lake be small or the salt load large in relation to the natural salt in the lake, then there may be more of an impact. Hatching trials on *Parartemia* species 'd' found that increased sediment salinity negatively affected emergence of nauplii, despite adults showing sufficient osmoregulatory capability (Campagna 2007). The matter would be of greater concern if the waste water was acid or contained significant concentrations of heavy metals. There are no species of *Parartemia* in the Goldfields resistant to acid waters and hence any local species would succumb to lowered pH.

While the effects of heavy metals on *Artemia* species are well documented, no published information is available for *Parartemia*. The ultrastructure of the resting eggs of two *Parartemia* species ('d' and 'g') is identical to those of *Artemia franciscana* (Campagna 2007) and, moreover, contain the stress proteins p26, artemin and hsp70, which enable the encysted embryo to tolerate severe desiccation, previously known only for *Artemia* (Clegg & Campagna 2006). Given these physiological similarities, the effects that heavy metals have on *Artemia* may and *Parartemia* may be similar. While *Artemia* have been found to accumulate and tolerate high levels of metals in their tissue (Blust *et al.* 1987), the emerging pre-larval stages were found to be more sensitive to heavy metals than the larvae and adults (MacRae & Pandey 1991), with hatching from the egg also inhibited (Brix *et al.* 2006; Go *et al.* 1990). With this in mind, the discharge of mine dewatering high in heavy metals may have an adverse effect on *Parartemia*, particularly on the hatching of the resting eggs from the sediment.

At least two species of the northern hemisphere genus *Artemia* (*A. parthenogenetica* and *A. franciscana*) have been introduced to Australia, though there may have been some pre-European occurrences of *A. parthenogenetica*, such as in the lakes of Rottneest Island (McMaster *et al.* 2007), perhaps as a result of translocation by migratory birds. The distribution of *Artemia parthenogenetica* is certainly now expanding into *Parartemia* ranges, though they are largely occurring in disturbed wetlands. Examples include a small lake 7 km east of Quairading, Lake Ninan 20 km east of Wubin (B. Timms, unpublished data), many in the Fitzgerald River area (G. Janicke, pers. comm.⁵) and some in the Esperance area (Timms 2009a). It is not known whether *Parartemia* used to live in these lakes, but data on lakes in their districts suggest *Parartemia* probably lived in them before they salinised. *Artemia* has also colonised the naturally saline Lake Boonderoo in the eastern Goldfields. There is little to suggest the two genera are in competition; indeed habitat change to a more saline and permanent environment is implicated in the spread of *Artemia*.

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Conservation status

Although information is limited for many *Parartemia* it is opportune to provide an overview of the conservation status of the various species (Table 1). This is rarely done for aquatic invertebrates in Australia (Yen & Butcher 1997).

Parartemia contracta is listed as a Priority Species (Priority 1: taxa with few, poorly known populations on threatened lands) by the Western Australian Department of Conservation. The 1995 listing was made on the basis that it was known from only two wetlands in the Wheatbelt. There are now many more records (Table 1, Figure 4) and, although some of the known populations may have been lost in recent years, this listing should be reassessed. Other species are of greater concern.

Recent targeted surveys by the senior author for *P. extracta* have failed to find most of the six previously known populations in the northern Wheatbelt and coastal Mid-west, although two new populations have been discovered recently in the southern Wheatbelt (DEC unpublished data). Most localities are within the Wheatbelt (Figure 2) rather than the rangelands so this species may be under particular threat.

There are only four known populations of species 'c' (Figure 3) but recent targeted surveys by the senior author have failed to confirm the persistence of these. However, two of these locations, Lake Moore and Lake De Courcey, are very large lakes and mostly in the rangelands, the former 50 km long, and it is likely that populations persist in these relatively undisturbed lakes. Nonetheless, some of this species' range is within the intensive agricultural zone and it does seem that the number of populations may be declining.

We suggest that both *P. extracta* and species 'c' may meet the criteria for Vulnerable species under IUCN (2001) criteria A2(c) and B2(a) & (c), and should be assessed as such by the WA Threatened Species Scientific Committee.

Three other undescribed species ('b', 'e' and 'x') are each known only from one to three localities. The acid tolerant species 'b' is known only from the Lake King to Hyden region (Figure 4) and two of its three known locations are subject to salinisation. However, all three populations were extant in October 2008. Species 'e' is known only from Lake Barlee, a very large playa northwest of Kalgoorlie (Figure 2) and species 'x' is known only from the extensive Lake Carey north-east of Kalgoorlie (Figure 4), though it is known to be widespread across the lake. Excess water from mining operations is discharged onto the bed of Lake Carey, but see above for details and expected degree of impact of this. We suggest that these three species may meet criteria for listing as Priority One species by DEC.

Remaining species occurring in the Wheatbelt (*P. cylindrifera*, *P. informis*, *P. longicaudata* and *P. serventyi*) are widespread and relatively common, some with populations also in the Goldfields. Some of these species have lost populations but we think that they are likely to survive the widespread salinisation, especially in small

naturally saline lakes in catchment headwaters. Such lakes should therefore be considered critical habitats for the long-term persistence of these species. Other species with distributions mostly or entirely outside of the Wheatbelt (*P. acidiphila* and *Parartemia* species 'a' and 'd') appear to be secure.

Parartemia is secure in the other states. Except for new species in South Australia, all have wide distributions and their habitats generally are in pristine condition. Exceptions apply short term to some sites affected by drought (e.g. *P. minuta* in northern parts of its range; *P. zietziana* in many lakes in Western Victoria) and to some lakes on Eyre Peninsula. The latter have increased in salinity over recent decades probably due to clearing of vegetation. In time many will exceed the upper salinity tolerance of *P. cylindrifera* so it will be locally threatened (Timms 2009c) and perhaps replaced by the very salt tolerant *P. zietziana*.

RECOMMENDATIONS

- 1 Describe the undescribed species.
- 2 Further surveys of naturally saline lakes should be undertaken to confirm the restricted distribution and limited occurrences of any species that are listed as threatened or priority fauna. This would help to more accurately determine their conservation status and provide more data on their habitat requirements. This must be opportunistic to coincide with major rainfall events that inundate inland lakes, or be achieved by sampling sediments and then hatching the eggs and rearing to maturity.
- 3 Regular monitoring of these same species should be established so that their persistence through time can be confirmed. This would also provide information on the occurrence of *Parartemia* over time under different wetland hydrological and salinity conditions.
- 4 Research into the ecophysiological and habitat requirements of Western Australian *Parartemia* needs to be undertaken to better understand their decline and inform potential conservation initiatives.

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Table 1Distribution of *Parartemia* species and their suggested conservation status in Western Australia.

Species	Number of records in database	Comments	Suggested conservation status in Western Australia
<i>P. acidiphila</i>	22	Common in suitable lakes in Esperance hinterland and on Eyre Peninsula	Not threatened
<i>P. auriciforma</i>	1	Remote 'safe' site, but only one known	Not known in WA
<i>P. contracta</i>	23	Some losses in inner Wheatbelt, but still common, especially east of Hyden	Not threatened
<i>P. cylindrifera</i>	66	Widespread and common. Increasing salinity in Eyre Peninsula lakes threatens this species of lower salinities (Timms, 2009b)	Not threatened
<i>P. extracta</i>	6	Restricted distribution. Most of known sites salinised and now without shrimps (lakes near Perenjori, Moora, Minnivale, Dowerin)	To be assessed as potentially Vulnerable
<i>P. informis</i>	29	Widespread and common. Some sites now salinised and now lack <i>Parartemia</i>	Not threatened
<i>P. longicaudata</i>	53	Widespread and common. Some sites lost due to salinisation or waterlogging. Persists in type locality of Pink Lake at Esperance despite hydrological changes.	Not threatened
<i>P. minuta</i>	16	Wide distribution. None of its sites subject to secondary salinisation	Not known in WA
<i>P. serventyi</i>	35	Persistent in Lakes Cowan and Gilmore from 1937 when first found by D. Serventy. Not lost yet from any old site, possibly because salinisation is not so severe in the eastern Wheatbelt	Not threatened
<i>P. triquetra</i>	1	Remote 'safe' site, but only one known	Not known in WA
<i>P. yarleensis</i>	6	Remote sites, none degraded	Not known in WA
<i>P. zietziana</i>	47	Most Victorian collections are pre-1980 and have not been checked recently, but some sites known to be persistently dry (R. Missen, pers.comm.) Re-occurrence in Lake Corangamite. Lives in secondarily salinised lakes on Eyre Peninsula	Not known in WA
P. new sp. a*	18	Common in suitable lakes in Esperance hinterland	Not threatened
P. new sp. b*	6	Narrow distribution. Two of three known sites salinised as of October 2008.	To be assessed as a potential Priority One species
P. new sp. c*	4	Has not been found recently in any known site (Lakes Cowcowing, De Courcey, Moore, Wubin)	To be assessed as potentially Vulnerable
P. new sp. d*	6	Common within its known distribution in the rangelands	Not threatened
P. new sp. e*	1	Known only from one remote site.	To be assessed as a potential Priority One species
P. new sp. g*	16	Wide distribution and sites largely undisturbed	Not threatened
P. new sp. x+	9	All sites in one large lake subject to salt disposal from mining, but species surviving well at present	To be assessed as a potential Priority One species

* Defined in Timms and Savage (2004); + Defined in Timms et al. (2006).

Table 2Known field salinity range for *Parartemia* species.

Species	Recorded salinity range (g/L) ¹	Number of records for salinity range	Average length of males in mm ²
<i>Parartemia acidiphila</i>	35-210	42	12.1
<i>Parartemia auriciforma</i>	unknown	0	11.5
<i>P. contracta</i>	84-240	4	20.1
<i>P. cylindrifera</i>	3-123 (240) ³	131	22.3
<i>P. extracta</i>	27 - 100	3	17.0
<i>P. informis</i>	30-186	13	26.7
<i>P. longicaudata</i>	41-240	29	25.4
<i>P. minuta</i>	2-255	143	14.2
<i>P. serventyi</i>	15-262	21	21.2
<i>Parartemia triquetra</i>	unknown	0	19.5
<i>Parartemia yarleensis</i>	unknown	0	18.0
<i>P. zietziana</i>	22-353	148+	19.3
<i>Parartemia</i> n. sp. a	20-235	42	18.1
<i>Parartemia</i> n. sp. b	33-95	5	10.5
<i>Parartemia</i> n. sp. c	50-120	2	21.8
<i>Parartemia</i> n. sp. d	74-225 ⁴	6+	13.6
<i>Parartemia</i> n. sp. e	unknown	0	unknown
<i>Parartemia</i> n. sp. g	8-141	10	17.5
<i>Parartemia</i> n. sp. x	22-105	15	21.6
<i>Artemia parthenogenetica</i>			7.9
<i>Artemia franciscana</i>			13

¹ Condensed from Timms 2009a, plus unpublished data.² One male chosen randomly from each of five collections by B. Timms, except for *Parartemia* sp 'd' where V. Campagna measured 10 males raised from dried mud. Lengths of shrimp are variable depending on nutrition, stage of development and salinity, among many factors.³ 240 g/L is an outlier and seems incorrect.⁴ from Chaplin 1998.

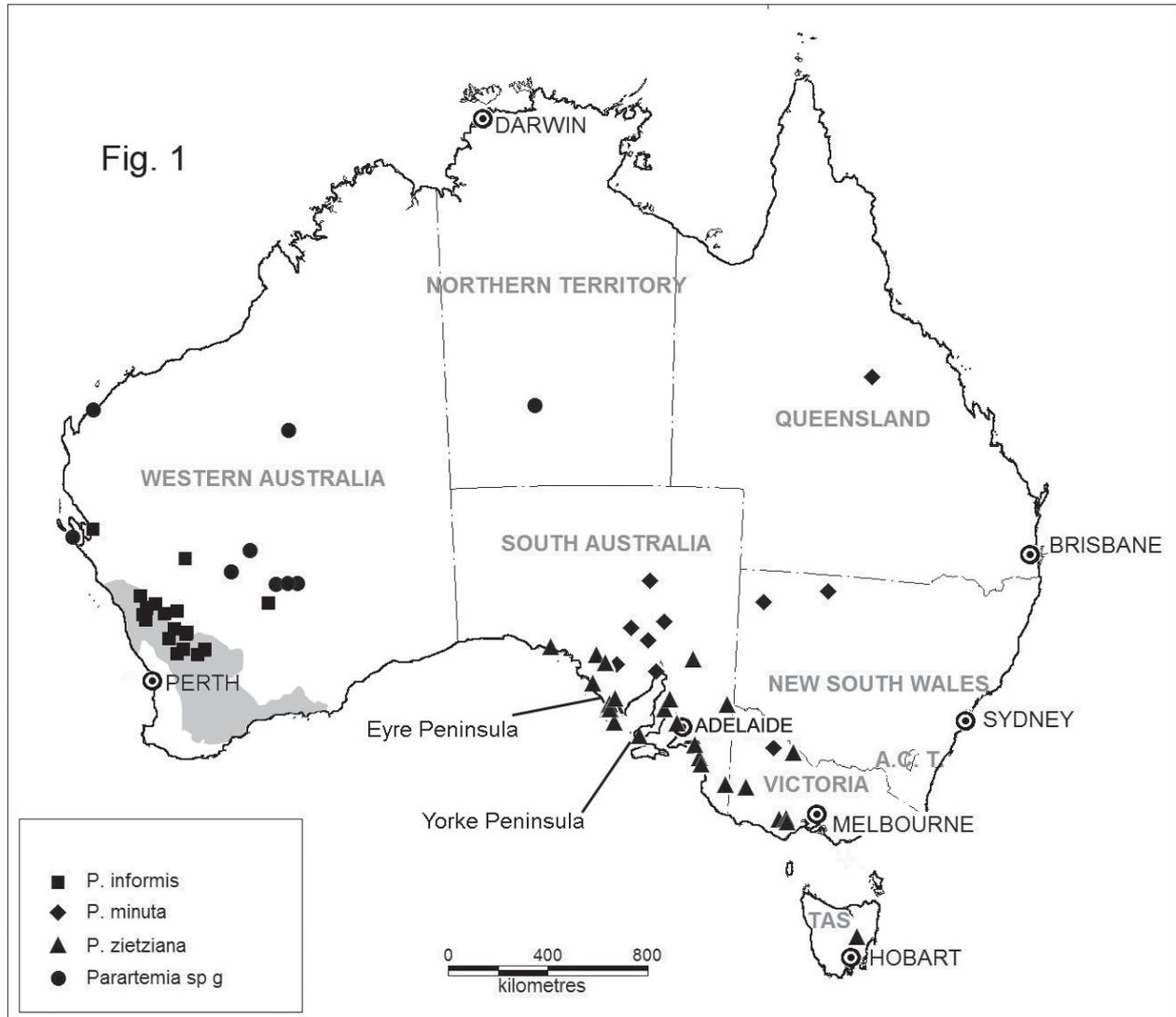


Figure 1. Map of Australia showing distribution of *Parartemia informis*, *P. minuta*, *P. zietziana* and species ‘g’. The shaded area is the approximate boundary of the Western Australian Wheatbelt – defined by the 600 mm rainfall isohyet to the west and the extent of land clearing to the east. Closely spaced multiple records are not shown, and many others are so close that they overlap at the scale of the map.

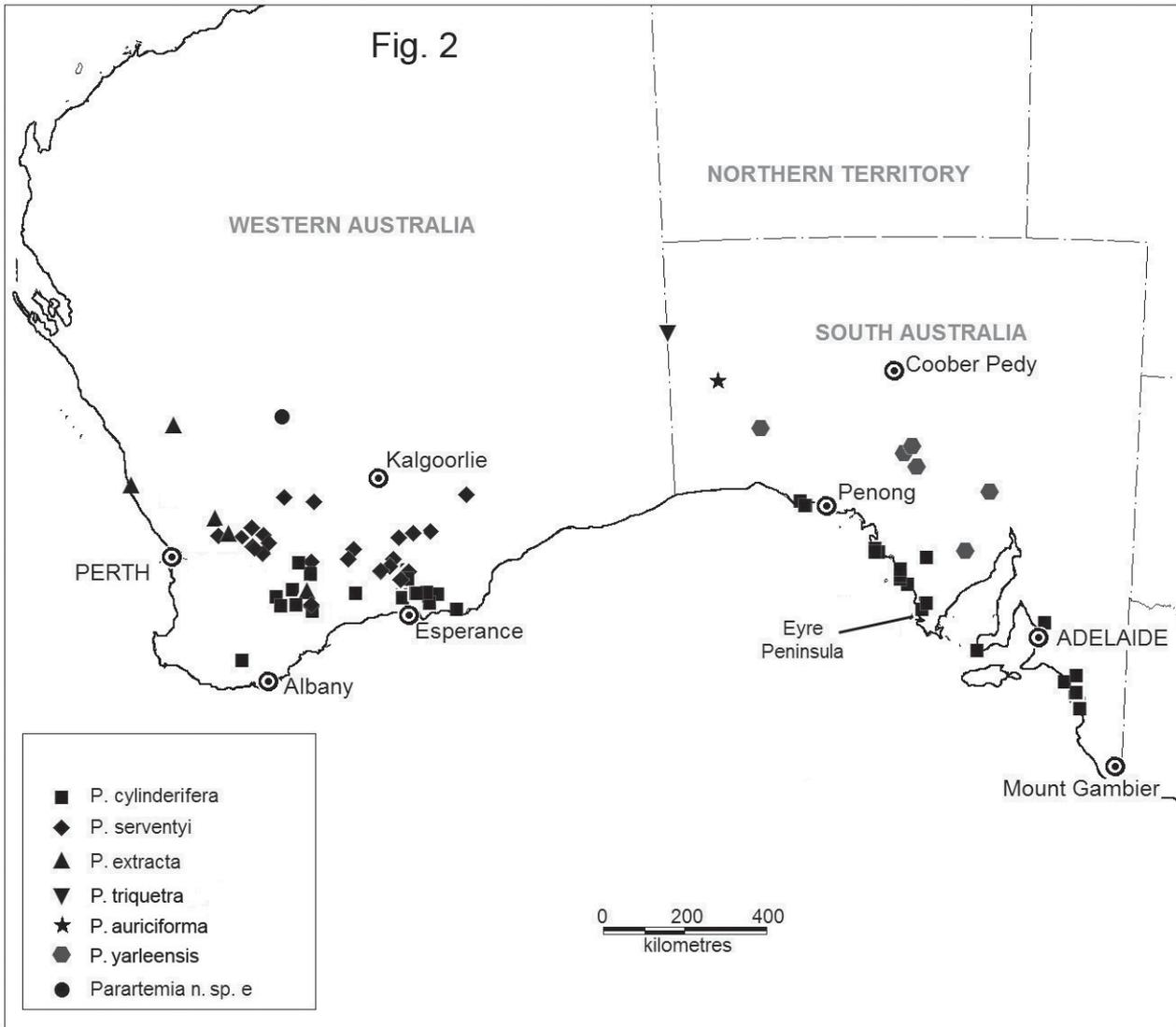


Figure 2. Map of southern and western Australia showing distribution of *Parartemia cylinderifera*, *P. serventyi*, *P. extracta*, *P. triquetra*, *P. auriciforma*, *P. yarleensis* and species 'e'. Closely spaced multiple records are not shown, and many others are so close that they overlap at the scale of the map.

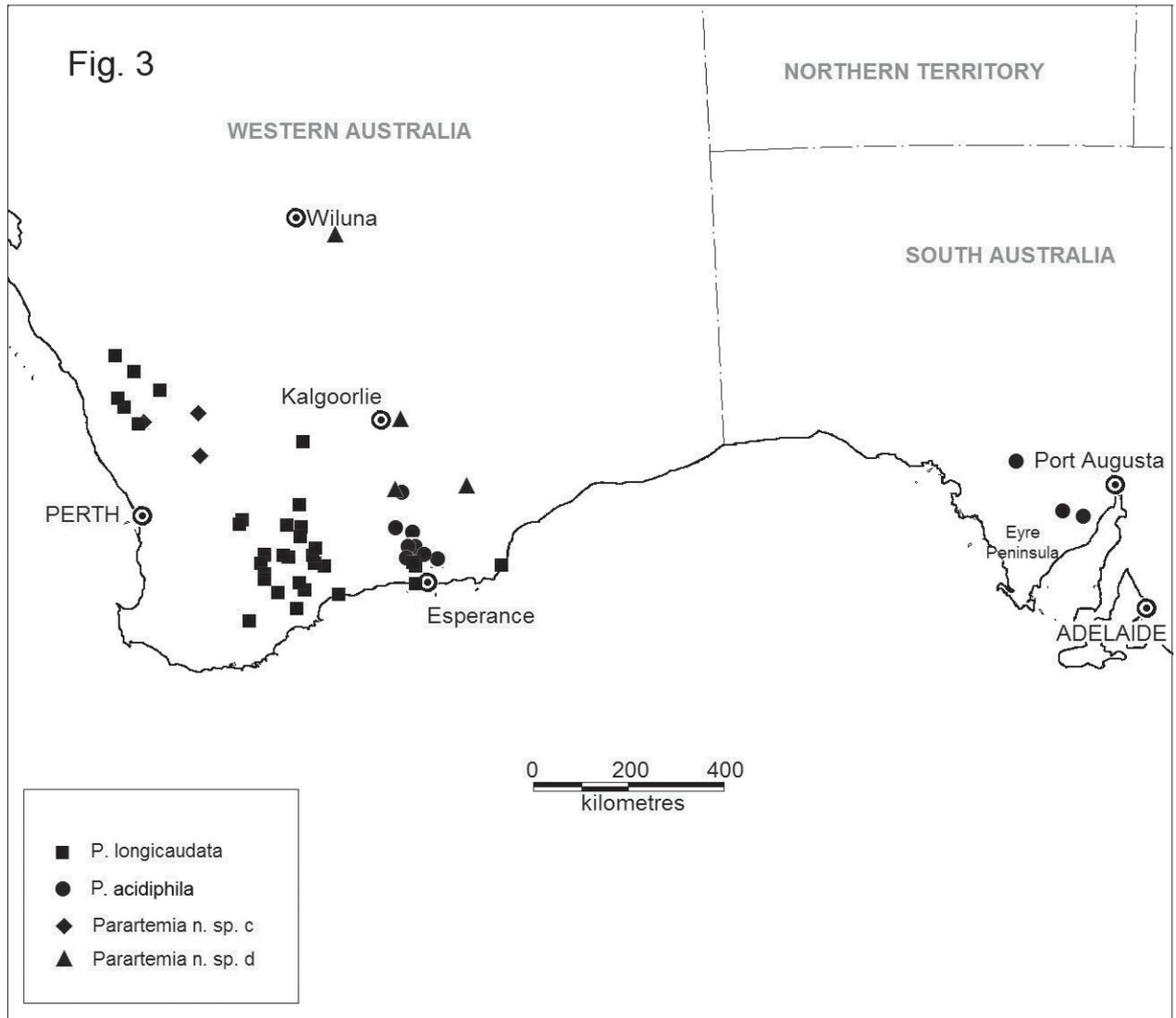


Figure 3. Map of southwestern Australia showing distribution of *Parartemia longicaudata*, *P. acidiphila* and species 'c' and 'd'. Closely spaced multiple records are not shown, and many others are so close that they overlap at the scale of the map.

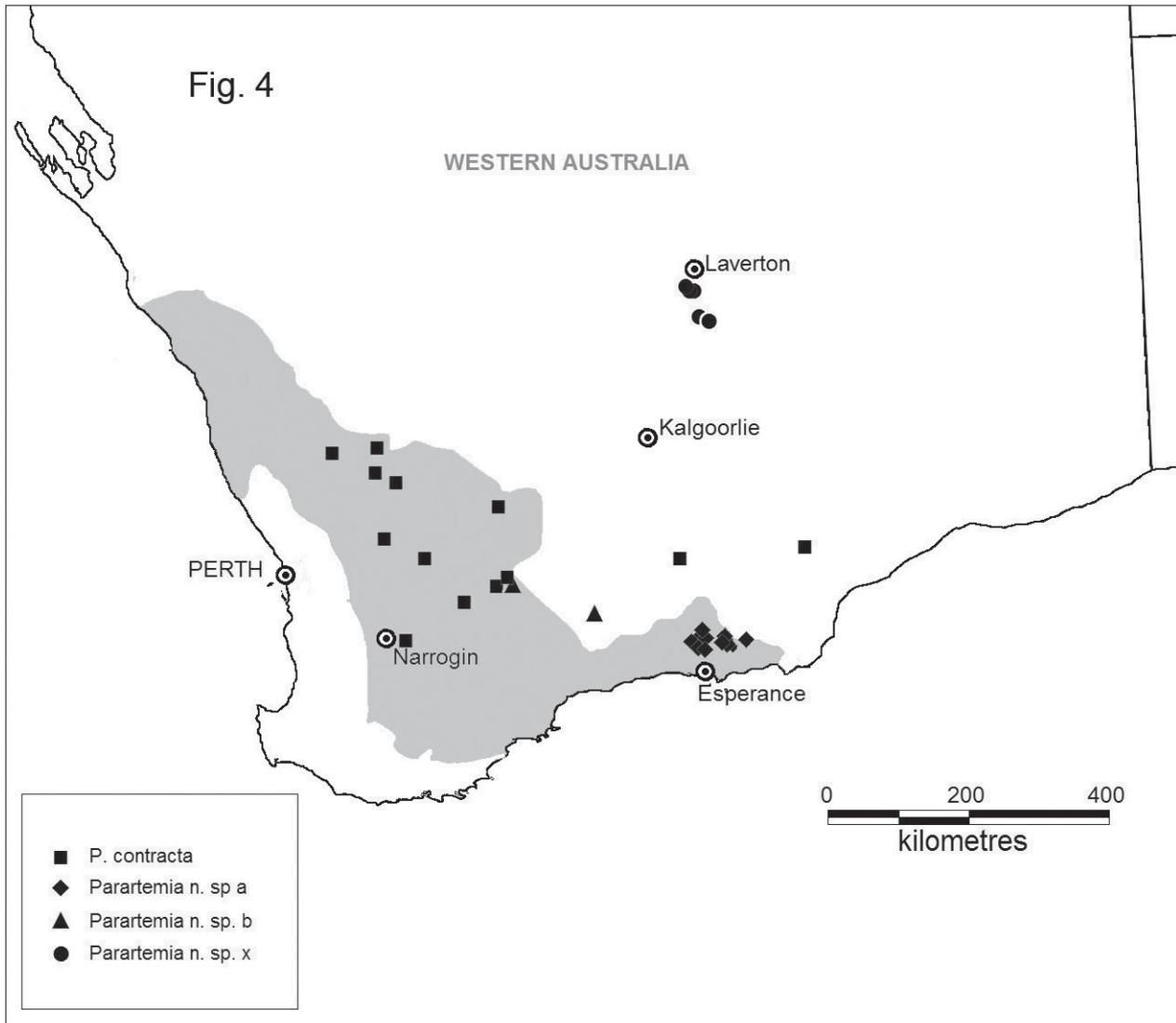


Figure 4. Map of southwest Western Australia showing distribution of *Parartemia contracta* and species 'a', 'b', and 'x'. The shaded area is the approximate boundary of the Wheatbelt – defined by the 600 mm rainfall isohyet to the west and the extent of land clearing to the east. Closely spaced multiple records are not shown, and many others are so close that they overlap at the scale of the map.

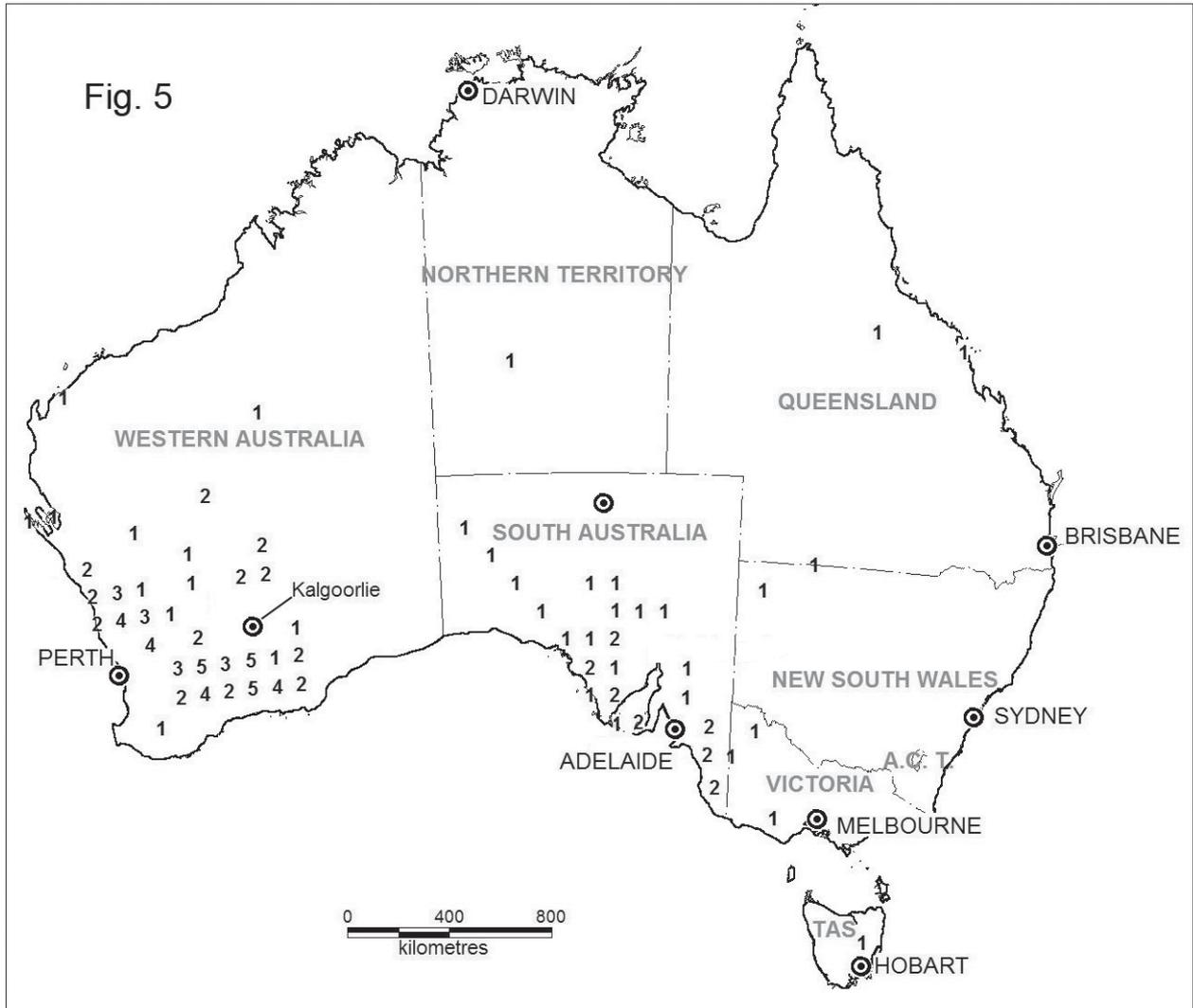


Figure 5. Map of Australia showing numbers of *Parartemia* species in rectangles of one degree latitude and one degree longitude. Many rectangles in the inland areas of Western Australia and to a lesser extent also in South Australia, western Northern Territory, far western NSW, and western Victoria probably also contain at least one species but they have not been sampled.