Caridina thermophila, an Enigmatic and Endangered Freshwater Shrimp (Crustacea: Decapoda: Atyidae) in the Great Artesian Basin, Australia

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Abstract

Only one species of freshwater shrimp, *Caridina thermophila*, has been recorded from the Great Artesian Basin (GAB) springs and associated wetlands in central Queensland. The species seems to be endemic to Queensland, has a restricted distribution and, whilst it is listed as Endangered in the IUCN Red List of Threatened Species, is not specifically protected under any Australian state or federal legislation. Although *C. thermophila* was first described from hot-water springs, it is now known to also inhabit much cooler waters, and hence its temperature tolerance range is quite broad. Apart from its general ecology and associated spring communities (many of which include rare and endangered endemic species), very little is known about the population dynamics and resilience of this species, particularly in relation to anthropogenic pressures and climate change. It is recommended that this species be specifically protected under national legislation, and a conservation plan be developed and implemented to ensure its long-term survival.

Keywords: Great Artesian Basin, springs, wetland, shrimp, *Caridina thermophila*, endemic, endangered

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Introduction

Caridina thermophila (Figure 1) was first described by Riek (1953) along with several other freshwater atyid shrimps from Australia. All his *C. thermophila* specimens, including the types, were collected on 27 May 1945 from an artificial bore drain in Muttaburra, western Queensland. He mentioned that the habitat was quite "remarkable" and the shrimps were "simply swarming". He also mentioned that "the water emerging from the ground was too hot for normal life (and unpleasant to stand in for any considerable time) but after flowing for some distance it had cooled sufficiently to support life". The shrimps were most abundant where the water was still "too hot for comfortable wading", hence the species descriptor "*thermophila*". Riek (1953) also mentioned that "only two of the many specimens collected were ovigerous" but thought that although May was rather too early to expect eggs, it seemed most likely that the species bred in this hot-water habitat.

Caridina thermophila is one of the many endemic species that occur in the springs of the Great Artesian Basin (Fensham et al., 2010). Its status has, however, been somewhat questionable and the species has not been treated as uniquely as other endemic species (e.g. Fensham & Fairfax, 2005; Rossini et al., 2018). This may be due partly to its being rather abundant whenever it occurs, and partly because of its dubious taxonomic status and perceived widespread distribution. Other species that often co-occur with *C. thermophila* include the endangered endemic fishes, the red-finned blue-eye (*Scaturiginichthys vermeilipinnis*) and the Edgbaston goby (*Chlamydogobius squamigenus*). Invertebrates that co-occur include annelids, molluscs, amphipods, isopods, and a variety of insect nymphs and larvae such as caddisflies, mayflies,

damselflies and beetles (Ponder et al., 2010; Rossini et al., 2018). The exotic eastern gambusia or mosquito fish (*Gambusia holbrooki*) is also known to infest these artesian springs (Fairfax et al., 2007). However, its impact on *C. thermophila* is not known.

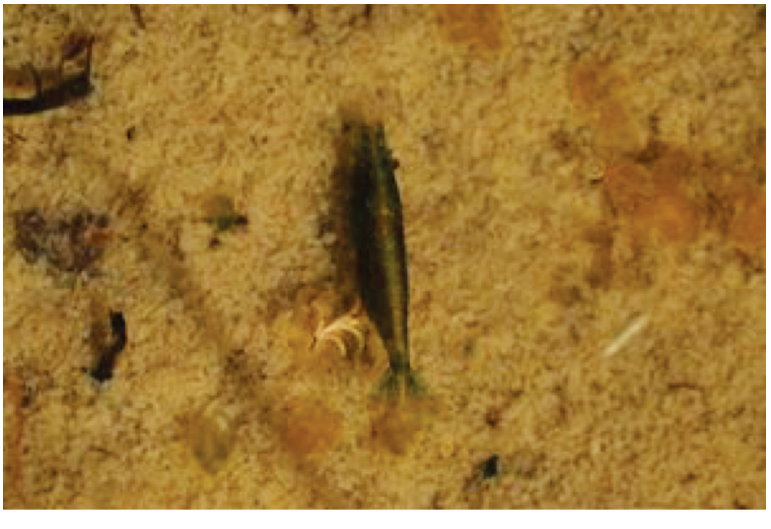
Taxonomy

Based on its morphology, *Caridina thermophila* clearly belongs to the genus *Caridina* and is a valid species (Riek, 1953). Recent genetic studies have confirmed its validity as a species (Page et al., 2007a) and being epigean (Page et al., 2007b). Whilst there is another undescribed species of *Caridina* in the Lake Eyre Basin (*C.* sp. LE, from Algebuckina Waterhole, Neales River, in the Lake Frome area, South Australia), it does not belong to the same genetic clade as *C. thermophila* (Page et al., 2007a; Short et al., 2019). Interestingly though, there is a newly described species, *C. biyiga*, from Leichhardt Springs, Kakadu National Park, Northern Territory (Short et al., 2019), and two undescribed species (*C.* sp. NT1 from Melville Island, Northern Territory, and *C.* sp. WA3 from the Pilbara, Western Australia) that belong to the same genetic clade as *C. thermophila* (Page et al., 2007a; Cook et al., 2011; Short et al., 2019).

Riek (1953) provided a detailed morphological description of *Caridina thermophila*. It is a relatively small but robust animal with a short rostrum and stout appendages. Younger animals, particularly the males, are a bit more slender. Based on specimens in the Queensland Museum (Reg. No. QM W17177) collected from another locality (Edgbaston Station Springs at Homestead, coll. 15/5/91), some of the morphological features are much more variable than those described by Riek (1953). For example, the rostrum can be variable in length and shape, its dorsal teeth can range from 19 to 25, and its ventral teeth can range from 2 to 6. Additional features not described by Riek (1953) include: no appendix interna on the first pleopod of males; carapace depth 0.80–0.83 times the post orbital carapace length (CL); rostral length 0.61–0.72 CL; antennular peduncle length 0.68–0.72 CL; sixth abdominal segment length 0.44–0.58 CL; and telsonic length 0.56–0.7 CL.

An interesting feature that Riek (1953) reported was that one of his specimens had an exopodite on the first left pereiopod. However, it was absent on the right periopod. Riek (1953) mentioned that this condition approached that which was "normal" for the genus *Caridinides* Calman, 1926, where both first pereiopods have exopodites. It has now been demonstrated that, whilst *Caridinides* was somewhat unique in having these exopodites, it is genetically no different from the genus *Caridina* H. Milne Edwards, 1837 (Page et al., 2007a; De Grave & Page, 2014).

Figure 1. *Caridina thermophila*, photographed from Edgbaston Reserve (Photo: Renee Rossini (www.bushheritage.org.au/blog/edgbastons-hidden-charms)).

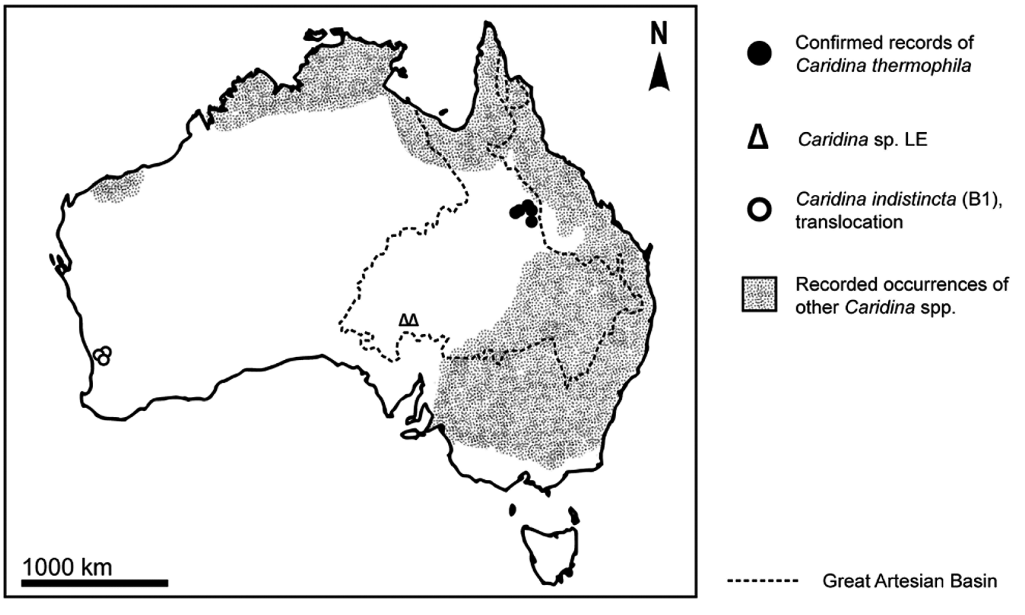


Caridina species are notoriously difficult to identify based just on their morphological features. This is because they exhibit great morphological plasticity based on the environment in which they live, and many of the features used to separate species taxonomically can be highly variable (Page et al., 2005; De Mazencourt et al., 2017; Choy et al., 2019). A combination of morphology, molecular techniques and ecology seems to be the best way to resolve many of the taxonomic uncertainties, and this is now becoming a standard approach (De Mazencourt et al., 2018; Choy et al., 2019). Molecular techniques are also allowing evolutionary and biogeographic elucidations (Page et al., 2008). Based on such techniques, it seems that *C. thermophila* has evolved and adapted to living in aquatic habitats created by artesian springs, along with many other rare and endangered endemic species of flora and fauna in artesian springs (Fensham et al., 2010).

Distribution

According to the *Atlas of Living Australia* (www.ala.org.au), there are 59 records of *Caridina thermophila* from 4 collection datasets. These are Australian Museum (4 records), Queensland Museum (3 records), Museums Victoria (43 records) and South Australian Museum (9 records). Based on these and other confirmed collections, the current known distribution of *C. thermophila* includes artesian springs around Edgbaston Station, about 15 km south-west of Muttaburra (22.733°S, 144.427°E) and Muttaburra (22.600°S, 144.550°E), as well as artesian springs about 30 km north-east of Barcaldine (23.280°S, 145.24°E) and artesian springs about 30 km north-east of Aramac (22.730°S, 145.417°E). All these sites are about 100 km from Aramac, about 100 km north to east of Longreach, and cover an area of only about 70 km^2. All of these springs are in the Great Artesian Basin and the Cooper Creek catchment of the Lake Eyre Basin (Figure 2). A detailed distributional map of the 59 museum records can be found at https://spatial.ala.org.au. There are also unconfirmed records from Yowah Springs in the Eulo complex, Elizabeth Springs and the Einasleigh Upland springs (Rossini, pers. comm.). Even if these and possibly other distribution records were to be confirmed, it is clear that *C. thermophila* is endemic to Australia, occupies a rather unusual niche, and needs to be recognised as such. The current knowledge of the exact distribution of *C. thermophila* is still very unclear, and concerted effort is required to study its taxonomic status, genetic clades, distribution, ecology and conservation status.

Figure 2. Distribution of *Caridina thermophila* in relation to other *Caridina* species in Australia.



Riek (1953) commented that "a study of the distribution of this species would be most interesting for bores are artificial and of recent origin and not a high percentage are so hot". He also commented that "given that the eyes of *Caridina thermopila* were well developed, the species was unlikely to be subterranean". Studies since then suggest that *C. thermophila* is found in natural artesian springs, in cooler waters, and it is not subterranean (Fensham & Fairfax, 2005; Page et al., 2007b). Riek (1953) also reported that there was a decrease in the concentration of specimens as one proceeded downstream, from hotter to colder water. Rossini et al. (2015) found that Atyidae (= *C. thermophila*) were more abundant in the deeper "pool" areas than in the shallower "tail" areas of the springs they studied.

Ecology

As discussed above, *Caridina thermophila* has been reported from several localities in central Queensland. The artesian springs and associated wetlands in which it occurs are also home to many other endemic species of plants and animals (Fensham & Fairfax, 2005), some of which are listed under Endangered Species legislation and the subject of recovery plans (Fensham et al., 2010). Despite this, the basic taxonomic and ecological information of many artesian spring invertebrates is lacking (Rossini, 2018). It has been reported that *C. thermophila* has been excluded from most studies because the taxonomy of *Caridina* within Australia has generally been poorly resolved (Rossini et al., 2018), and that there was currently not enough evidence to suggest it is endemic (Ponder et al., 2010; Rossini et al., 2018). A compilation of studies, however, indicates that *C. thermophila* is not only endemic to central Queensland, it is confirmed only in the Barcaldine spring supergroup (Choy, pers. ob., Choy & Howitz, 1995; Fensham & Fairfax, 2005; Page et al., 2007b).

The aquatic habits in which all artesian spring species occur have been described as isolated aquatic "islands" in a semi-arid landscape (Kerezsy, 2013). Most habitats are less than 50 m wide, with depths of about 0.1 m. Water quality is highly variable, from fresh to somewhat saline, near zero to saturated dissolved oxygen, near freezing water temperatures in winter to about 40°C in summer. In these habitats, *Caridina thermophila* lives as an opportunistic omnivore, making use of whatever resources are available for its survival. Reik (1953) noted different distributional patterns of *C. thermophila* even within a single spring. This pattern appears to be driven by the interaction between different environmental conditions in different microhabitats and the environmental tolerances of the species. However, the interactions are not likely to be simple (Rossini et al., 2017).

An interesting feature of *Caridina thermophila* is that the eggs are relatively large (about 0.5 mm wide and 0.8 mm long) and few (<30) per brood. This suggests that larval development occurs mainly within the eggs, which then hatch as advanced larvae, and so the planktonic stage is short or non-existent (Hancock, 2008; Lai & Shy, 2009). Such abbreviated or direct larval development is a feature of many inland and endemic species of aquatic invertebrates (Morton & Britton, 2000; Darragh, 2002). In contrast, coastal and more widespread species tend to have a prolonged larval stage (Pechenik, 1999). The former strategy results not only in less predation mortality but also in restricted distributions (Obrebski, 1979; Choy, 1991). It is therefore likely that *C. thermophila* may not be as widespread as some unconfirmed records suggest.

Conservation and Management

Caridina thermophila is endemic to Queensland and seems to have a very restricted distribution. It is currently confirmed only from Spring Complex Numbers 49 (Cares), 65 (North), 80 (Umbridge) and 81 (Caring), all of which are in the Barcaldine North Great Artesian Basin Water Resource Plan Management Area (GABWRPMA) and are listed under the EPBC (Australian *Environment Protection and Biodiversity Conservation Act 1999*) (Fensham & Fairfax, 2005). These spring complex and supergroup names are somewhat different from those listed in Appendix S2 in Rossini et al. (2018). *C. thermophila*'s listing in Spring Complex Number 156 (Yowah Creek) in the Warrego East GABWRPMA is likely to be erroneous. No specimens have been sampled from here recently (Peter Negus, pers. comm.), and even if they were, they would most likely be another species of *Caridina*.

Caridina thermophila is listed as Endangered in the IUCN Red List of Threatened Species (De

Grave et al., 2013), yet it does not have an EPBC status or a NCA status (under the *Queensland Nature Conservation Act 1992*). Even under the Great Artesian Basin Water Resource Plan (GAB WRP) the species is listed just as "other species of interest" (Fensham & Fairfax, 2005). However, the communities within which this species occurs are listed as Endangered under Commonwealth and Queensland legislation (Table 1).

Whilst the species itself has no direct protection through its own state or national listing, it is somewhat protected through the status of the communities within which it occurs. However, most complexes of high conservation value remain outside of conservation reserves, and the endangered species status of many taxa, particularly the invertebrates, remains unassessed (Rossini et al., 2018). There is also a national recovery plan for these communities (Fensham et al., 2010), and *Caridina thermophila* also has a "high" Back on Track status, meaning that it has a high priority amongst Queensland's native species to guide conservation management and recovery. Many species that co-exist with *C. thermophila* are also rare and endangered (e.g. red-finned blue-eye (*Scaturiginichthys vermeilipinnis*) and the Edgbaston goby (*Chlamydogobius squamigenus*). Some protection is therefore offered through the protection of these fish species. However, the GAB springs and wetlands in which these species occur are subject to climate change, competing human interests (e.g. aquifer drawdown, agriculture and mining) and introduced fauna (e.g. eastern gambusia (*Gambusia holbrooki*), cane toad (*Rhinella marina*) and redclaw crayfish (*Cherax quadicarinatus*)), all of which pose great danger to this and other species, as well as their communities (Clifford et al., 2013; Green, 2013).

It has been suggested that the most appropriate level for the management of endemic species are the spring complexes (Green, 2013). Whilst this may be the best overall management approach, it is imperative that *Caridina thermophila* is locally and nationally recognised, listed as an endangered species, and that a specific conservation plan be implemented. It has been suggested that *C. thermophila* specimens be subject to relocations, be made available to private breeders and even introduced to the aquarium trade. Whilst these may be viable options, such strategies would risk genetic contamination and hybridisation (von Rintelen et al., 2007).

Since very little is known of the exact taxonomic status, distribution, demography (population size, structure, natality and mortality rates) and ecology of this species, it is recommended that further research into these aspects be implemented to support its management and conservation. However, all field collections of this enigmatic species should be minimised during specific research projects, as well as from broader-scale artesian spring studies, and all sampling strategies should consider returning all specimens alive and well to the localities where they are collected.

Emerging Issues

The Great Artesian Basin is one of the world's largest underground water reservoirs, but despite its size, age and persistence to date, it is facing many threats, both natural and anthropogenic. Its water utilisation since European colonisation has led to unsustainable practices in many areas, hence the desire of stakeholders and governments to commence appropriate forms of conservation and management. Whilst management strategies are working in some parts of the GAB, upcoming threats make them very challenging. The flora and fauna that are reliant on the GAB water and habitats are facing even greater threats and, whilst conservation efforts are being implemented, it is the larger and more iconic species that are getting the most attention. Smaller and less-conspicuous species are being neglected, and some may be disappearing even before being discovered and formally named by science. Species such as *Caridina thermophila* have largely been ignored, mainly because of their uncertain taxonomy, distribution, ecology and conservation status. Whilst broad management strategies to conserve spring complexes and iconic species will no doubt benefit non-target co-inhabitants, specific conservation status and management strategies should be implemented for all endemic species, including *C. thermophila*; and more nature reserves, such as those of Bush Heritage Australia, should be set up to protect such species. Unless these steps to protect endemic spring species are taken now, for many species it will be "death by a thousand cuts" and many of them will disappear while we watch and wait.

Table 1. Communities in which *Caridina thermophila* occurs, and their conservation status.

Community	Conservation status	Legislation
The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin	Endangered	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
Springs in discharge areas of the Great Artesian Basin, and not located in Tertiary aquifers	Endangered	*Vegetation Management Act 1999* (Queensland)
Regional Ecosystem 2.3.39, spring wetlands on recent alluvium	Endangered	*Vegetation Management Act 1999* (Queensland)
Regional Ecosystem 4.3.22, springs on recent alluvia and fine-grained sedimentary rock/shales	Endangered	*Vegetation Management Act 1999* (Queensland)
Regional Ecosystem 6.3.23, springs on recent alluvia, ancient alluvia and fine-grained sedimentary rock/shales	Endangered	*Vegetation Management Act 1999* (Queensland)

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