Current State and Reassessment of Threatened Species Status of Invertebrates Endemic to Great Artesian Basin Springs

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Abstract

Springs are unusual freshwater ecosystems of high cultural and conservation significance, yet they are often overlooked in discussions of global freshwater biodiversity, ecology and conservation. Springs that emerge from the Great Artesian Basin (GAB) in Australia support a high diversity of endemic aquatic species. The majority of these species are at high risk of extinction due to their small geographic ranges, severe habitat loss and ongoing threats. However, the ecological requirements of most spring biota are poorly understood and the majority are unprotected, particularly invertebrates, for which basic taxonomic and ecological information is lacking for numerous species. This assessment of threat status determined that 98% of molluscs and 80% of crustaceans endemic to GAB springs meet the criteria for designation of 'critically endangered' under the Australian *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (the EPBC Act). However, none of these species is currently listed. The analyses in this paper provide support for individual EPBC listing of all species of gastropods and crustaceans.

Keywords: springs, invertebrates, endemic species, threats to springs, conservation status, Great Artesian Basin

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Introduction

Freshwater environments are amongst the most altered and under-conserved global ecosystems, despite being 'hotspots' of cultural significance and endemic diversity (Geist, 2011; Strayer & Dudgeon, 2010). Freshwater environments that depend on groundwater, such as springs, are particularly vulnerable because increasing water demands are leading to significant anthropogenic alteration of the groundwater sources that sustain them (Cantonati et al., 2012; El-Saied et al., 2015; Fairfax & Fensham, 2002; Famiglietti, 2014; Kreamer & Springer, 2008; Nevill et al., 2010; Powell et al., 2015; Stevens & Meretsky, 2008; Unmack & Minckley, 2008). Despite the pertinent threats springs face, they are rarely included in global assessments of freshwater biodiversity, ecology or conservation (Cantonati et al., 2012). Springs are unique and diverse freshwater ecosystems that emerge in a range of landscapes, but those in arid regions are particularly important because they provide a reliable source of water in areas characterised by water scarcity and impermanence (Davis et al., 2013, 2017). They act as 'islands' of hospitable wetlands in a 'sea' of aridity (Ponder, 1995) that are used as watering points for broadly distributed species, as well as providing critical wetland environments for suites of organisms endemic to springs (Fensham et al., 2011; Myers & Resh, 1999). Extensive spring systems are present in the arid and semi-arid regions of most continents, with each region sharing parallel stories of unique features, fragility, threat and destruction (Powell & Fensham, 2016; Unmack & Minckley, 2008).

Arid zone springs fed by the Australian Great Artesian Basin (GAB) have been a focus of both Indigenous and colonial use because they provide a reliable source of water in prevailingly dry portions of the continent. The chain of GAB springs that extends from Kati Thanda–Lake Eyre to north-east Queensland forms vital points in the lore and song-lines of numerous First Peoples (Harris, 2002; Potezny, 1989), and springs remain important sources of material and spiritual inspiration for traditional custodians (Ah Chee, 1995; Moggridge, 2020). Springs facilitated the occupancy and stocking of the arid interior during the early colonial period, and by 1895, water inspectors documented the use and alteration of many Queensland springs (Fairfax & Fensham, 2002; Powell et al., 2015). Physical alteration of springs and extraction of water from the GAB using bores drastically increased with agricultural intensification, leading to increased extraction volumes and decreased water pressure within the GAB. This caused a large proportion of springs to become dormant (Fairfax & Fensham, 2002; Powell et al., 2015). The loss of GAB springs is of concern because of their extremely high biological and cultural values, and because their demise is a sign of the broader issue of diminished pressure in the aquifer at large. Nation-wide schemes to regain GAB pressure by capping bores have been enacted (e.g. the GAB Sustainability Initiative (GABSI); Brake, 2020).

Discharge springs that survived the initial broad-scale habitat loss post-1890 remain exposed to a range of threatening processes (Davis et al., 2017). Continued extraction of water from the GAB creates further pressure loss, leading to the extinction of springs and populations of endemic species that occupy them (Mudd, 2000), or the permanent alteration of spring chemistry (Shand et al., 2013). Industries with high water demands (e.g. mining and intensive agriculture) magnify this threat, and models of how these threats will affect springs and their biodiversity provide limited predictions at best (Mudd, 2000). Springs that survive drawdown remain exposed to introduced species. Introduced plants and nutrient-led changes to the dynamics of native species mean that some species grow to dominate springs (e.g. Holmquist et al., 2011) and can diminish the spring pools vital to the persistence of aquatic animals (Kodric-Brown & Brown, 2007; Lewis & Packer, 2020). Ungulates trample springs, with pigs being particularly destructive as they actively uproot vegetation (Kovac & Mackay, 2009). Invasive aquatic fauna living within the springs (including invertebrates, amphibians and fish) consume or compete with species endemic to springs, in some cases to the point of near extinction (Kerezsy & Fensham, 2013). Although the excessive drawdown associated with unchecked water extraction from the GAB has been ameliorated by programs such as GABSI, risky extraction licenses are still being granted (Currell, 2016; Currell et al., 2017) and these additional threatening processes continue to affect the unique biodiversity that exists in GAB springs.

Relative few of the species currently described as endemic to GAB springs have been the subject of detailed published accounts regarding their distribution, population numbers and ecology. For those species for which detailed population and distribution data are available, it appears common for species to be restricted to a single spring complex, or numerous complexes in the same locality (Fensham et al., 2011). Populations of species endemic to the GAB spring wetlands are rarely found in all springs within an occupied complex, and the particular springs occupied tend to change through time (Fensham & Fairfax 2002; Kerezsy & Fensham, 2013; Ponder et al., 1989; Worthington-Wilmer et al., 2008). Extirpations in a single spring seem relatively common over decadal time scales, but species can persist within their broader geographic range due to the presence of an ever-shifting set of viable populations (Worthington-Wilmer et al., 2011). These patterns of spring occupancy appear to vary across species, with different species occupying different sets of springs and displaying different patterns of population connectivity (Murphy et al., 2010). Consequently, some springs are more diverse (Kodric-Brown & Brown, 1993; Ponder et al., 1989) or maintain populations over longer periods, whilst others host only one particular species for a short time (Worthington-Wilmer et al., 2011). As small geographic range appears to be the norm, it is probable that severe biodiversity losses accompanied the broad-scale loss of springs that occurred post-1890 (Fensham et al., 2010). Habitat loss that has not led to extinction is still associated with the loss of genetic diversity (Faulks et al., 2017) and the potential loss of cryptic species or clades before they are discovered or described (Mudd, 2000).

Despite the unique nature of GAB springs, and the severity of the threats they face, these wetlands have only recently attracted state and

Commonwealth conservation attention, although they were cared for previously under customary systems (Moggridge, 2020). The flora and fauna associated with springs came under Commonwealth protection in 2001, via a blanket listing of "the community of native species dependent on natural discharge of groundwater from the GAB" as 'endangered' under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act, 1999). The effectiveness of this legislation is contingent on a range of factors, but of relevance is the need for up-to-date and accurate information regarding patterns of endemic diversity, distribution and threat (Pointon & Rossini, 2020). However, appraisals of the species that compose the endangered community, their distribution, and the information available about them, generally remain focused on particular broad taxonomic groups, such as plants (Fensham & Price, 2004; Silccock, 2017) and snails (Ponder, 1995), or are locality-specific, e.g. Edgbaston Springs (Ponder et al., 2010). The extensive review that accompanied the original Recovery Plan (Fensham et al., 2010) remained the only system-wide analysis until the publication of a review of the biogeographical patterns of endemic biodiversity in GAB springs (Rossini et al., 2018), with both assessments excluding whole classes of taxa due to data deficiency.

In some cases, species identified as being at particularly high risk of extinction are afforded additional protection through individual EPBC listing (e.g. the red-finned blue-eye, *Scaturiginichthys vermeilipinnis*; Wager & Unmack, 2004). This listing has resulted in far more intensive conservation attention and effort for the red-finned blue eye and is likely the reason it has dodged extinction to date. Whether all species that require this level of additional protection should or can be listed is an important consideration. Some invertebrates with small geographic ranges that have experienced significant population declines are classified as 'critically endangered' under the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2001). However, the effort required to review and submit an application to list the hundreds of species endemic to GAB springs is a major barrier to equivalent assessment of all taxa. Despite this barrier, it is surprising that none of the species listed by the IUCN is listed individually as threatened species under EPBC legislation.

Lack of attention to invertebrates that are at risk of extinction in springs is representative of a global trend that hinders conservation efforts in freshwater systems (Bland et al., 2012; Cardoso et al., 2011; Strayer, 2006). In Australia, populations of some of the most restricted and threatened invertebrate taxa remain un-monitored and un-managed on private grazing properties. For example, resurveying in 2020 of the freshwater snail *Jardinella colmani* (Ponder, 1996) revealed all populations being directly exposed to grazing, very few springs with the species remaining, and severe disturbance to >80% of the springs sampled (Rossini, unpublished data). Data concerning the patterns of distribution and abundance of invertebrate species, and ongoing monitoring programs concerning species within the threatened community in general, are rare. Existing monitoring programs often employ different sampling methodologies that may render data inaccurate due to methodological biases (Cantonati et al., 2007; Cheal et al., 1993; Rosati et al., 2016). Current conservation practices generally focus on local scales, and rest heavily on stock exclusion and attempts to eradicate invasive flora and fauna (Kodric-Brown & Brown, 2007; Lewis & Packer, 2020; Peck, 2020). In systems where long-term monitoring is occurring, such interventions can be evaluated; however, a lack of published baseline data for most spring complexes means the effectiveness of management practices is rarely assessed quantitatively (for exceptions, see Kerezsy & Fensham, 2013; Kovac & Mackay, 2009; Peck, 2020). Calls are being made for managed relocation and captive breeding programs to protect species from extinction (Lawler & Olden, 2011), and levels of 'acceptable' drawdown of spring waters are being set (Lewis et al., 2018). However, the potential success of these initiatives is constrained by a lack of data regarding the true diversity, population numbers, patterns of occupancy, and the environmental requirements of most endemic invertebrate species (Ponder & Walker, 2003).

In an attempt to collate the information that is available, and translate it into an up-to-date assessment of the threatened species status of invertebrates endemic to the GAB springs system, this paper aims to:

1. Present a case study of fundamental challenges associated with the estimation of metrics that are essential to assessments of conservation status under EPBC criteria. These are the geographic range (EoO – extent of occurrence) and the habitable or inhabited area (AoO – area of occupancy) for each species. The case study uses data on gastropods endemic to the Pelican Creek Springs complex to illustrate issues around accurate estimation of EoO and AoO peculiar to springs.
2. Summarise the availability of data needed to assess threat status for all known invertebrate species, or evolutionarily significant units, in GAB springs (using data listed in Rossini et al., 2018).
3. Assess the current conservation status of invertebrate taxa from the same list under IUCN and EPBC criteria.

Methods

Case Study: Endemic Gastropods of the Pelican Creek Springs

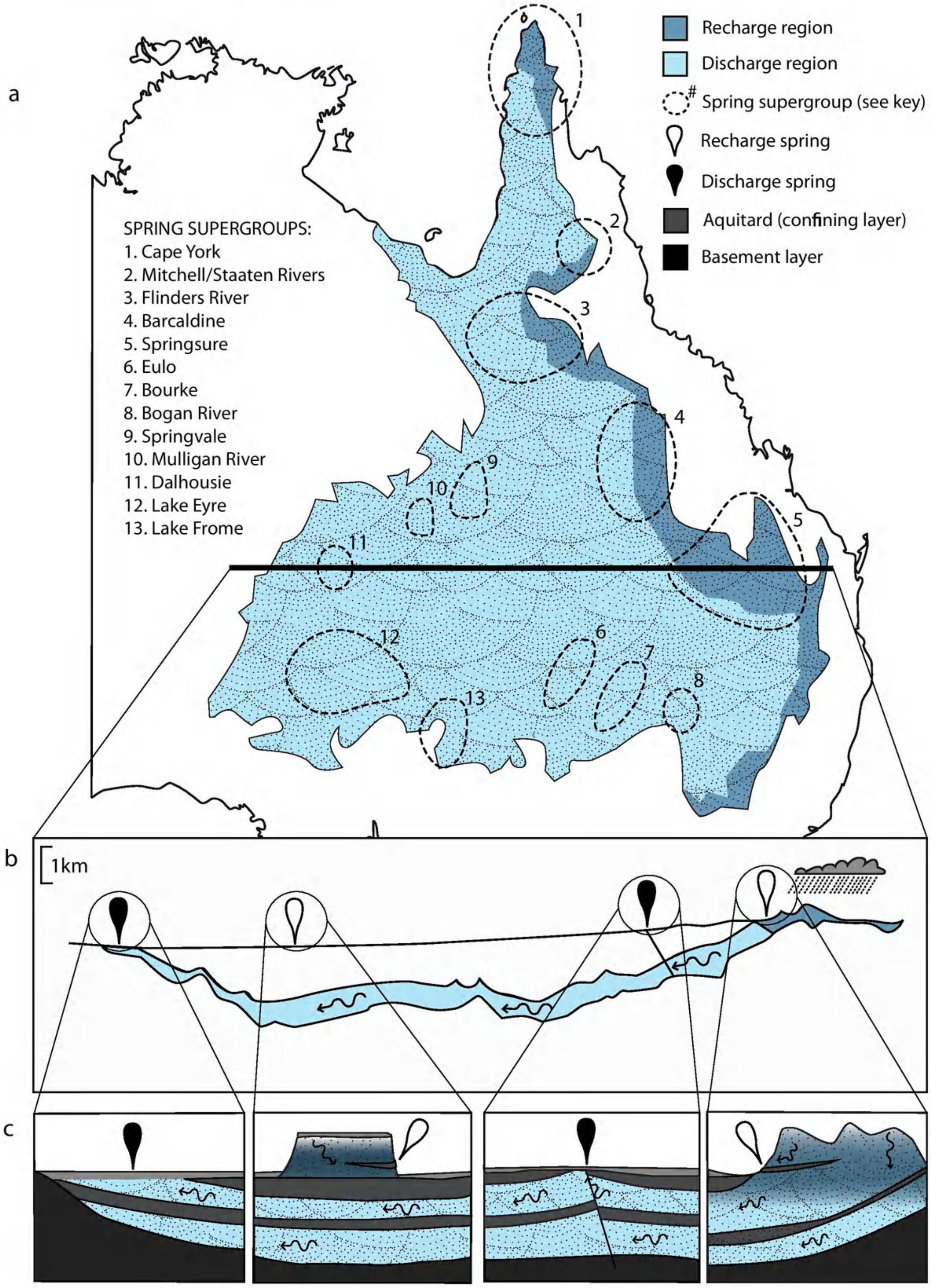
The northern portion of the Pelican Creek Springs complex is enclosed within the Edgbaston Reserve (managed by Bush Heritage Australia), within the Barcaldine supergroup located in central Queensland (Figure 1). Springs of the Pelican Creek complex are spread across a north-to-south axis, with the northern springs at the base of a rocky escarpment (latitude –22.725° to –22.721°), the central springs mostly within a large clay pan and scald (latitude –22.725° to –22.74°) and the southern springs within, or in the proximity of, a large ephemeral waterbody, Lake Mueller (which drains into the nearby Aramac Creek) (latitude –22.74° to –22.76°). The complex continues to the south of Lake Mueller, into an adjoining property outside of Edgbaston Reserve that contains additional endemic species. These springs all have shallow open-water pools of a limnocrenic morphology (Springer & Stevens, 2008). The Pelican Creek Springs complex, as a whole, comprises ~145 springs, with 113 of those within the Edgbaston Reserve. This complex was chosen for the case study as within-complex distribution studies have been conducted for most invertebrate species, and ecological information regarding within-spring restrictions on distribution are available for most endemic gastropod species.

Assessments of wetland area, species distributions and summations for assessments of the threatened species status of endemic gastropod species at the Pelican Creek complex were conducted in 2015 as part of the annual invertebrate surveys of the Bush Heritage Australia portion of the complex.

Spring wetland area was estimated as a rhombus of the maximum length and width (a polygon) of the vegetated area of each spring. Size of distribution was calculated at three scales: spring supergroup; across springs of the Pelican Creek complex; and within springs of the Pelican Creek complex. At the supergroup scale, frequency of occurrence (how many complexes are occupied, FoO) and extent of occurrence (the area within a polygon around the springs, EoO) and the total potential area of occupancy (AoO) were measured as the total wetland area within the supergroup.

Springs species operate as meta-populations, and in theory individuals are free to move about the complex and occupy a subset of springs at any one time. However, empirical data suggest that considering all springs to be occupied by any particular species at any one time is likely to generate an overestimate of AoO. Therefore, at a within-complex scale, the number of springs occupied by each species as a total and percentage of all springs in the complex, and the minimum limit of environmental variables of significance, were calculated to determine the accuracy of the AoO as a measure of the true inhabited area for each species. At a within-spring scale, species were allocated to a distribution category (P = pool only; T = tail only; P(T) = higher abundance in pool but also occupies tail) using data from the literature (Rossini et al., 2017a). The pool areas of GAB springs at the Edgbaston complex have consistently different environmental conditions (Rossini et al., 2017a) and represent a subset of the total spring area. Therefore, estimating the area of wetland available to a pool-restricted species (the AoO) using the total spring area will significantly overestimate their available useable habitat. For any species with sufficient evidence to suggest it is restricted to spring pool areas, area of occupied wetland (AoO) was calculated using the total pool area of all occupied springs in the Pelican complex instead of the total spring area.

Figure 1. Conceptualisation of the Great Artesian Basin showing: (a) the location of spring supergroups, location of aquifer discharge and recharge zones; (b) & (c) hydrogeological cross-section depicting water sources and flow paths to discharge and recharge springs.



Meta-analysis of Data Availability and Threat

The taxa list used for this part of the study is that presented in a review by Rossini et al. (2018). Logic used for differentiating spring complexes, defining endemic taxa and surveying the literature can be found in this publication. The state of data deficiency regarding each taxon included in the 2018 review was assessed. The amount of published information regarding each taxon was categorised (Table 1) in each of the key areas of data deficiency identified as hindering the conservation of invertebrates (Cardoso et al., 2011); these include taxonomy, distribution, abundance, ecology and threat, as well as patterns of population connectivity or divergence as recommended by Murphy et al. (2015a, 2015b). For each taxon, the amount of information available from the peer-reviewed literature was scored on an ordinal scale using the criteria detailed in Table 1 and added to give a final score. Whilst interactions between data deficiencies are likely (e.g. it is difficult to understand the impact of a threatening process without ecological or distribution data), this analysis applied an additive model for simplicity. Using this system, a taxon for which data that could be considered sufficient to make an assessment of conservation status scores high (maximum score of 24), whereas a taxon for which minimal information is available regarding any of these categories of data scores low (minimum score 4).

Table 1. The parameters used to score literature information on data availability for each endemic taxon included in this review of conservation status.

Data category	Score	Conditions
Taxonomy	4	Full morphological description supported by genetic assessment of relationship to other taxa and the potential of cryptic species complex if it occupies >1 complex or supergroup.
	3	In-depth morphological description with brief genetic analysis at species level; if range >1 complex, no in-depth enquiry into cryptic species.
	2	Morphological description but no genetic data.
	1	Remains undescribed.
Distribution	4	Full survey of range, regular (>1) and/or ongoing temporally replicated surveys of patch occupancy in at least one part of the range.
	3	Rudimentary knowledge regarding patch occupancy within the range from 1 or few disparate surveys, with no regular temporal element.
	2	No data regarding full range as yet; no ongoing monitoring.
	1	Few specimens from one or few visits.
Abundance	4	Temporally replicated (>1 time) systematically collected abundance assessments across >5 springs within the range.
	3	Robust anecdotal observations regarding relative abundance within most springs in the range.
	2	One-off or limited anecdotal observations within some parts of the range.
	1	No information.
Connectivity	4	Patch level data regarding population connectivity across at least 50% of the range.
	3	Spatially limited but detailed patch level data for part of the range (e.g. one group of springs within one complex).
	2	Anecdotal observations regarding potential connectivity in the system or patterns inferred from data in other similar species.
	1	No information.

Data category	Score	Conditions
Ecology	4	Extensive spatially and temporally replicated information regarding environmental correlates of occupancy and abundance, seasonal variance, trophic ecology, reproductive ecology, physiological limits or behaviour.
	3	Robust but not systematic observations regarding microhabitat associations, environmental limits, and responses to environmental variance from part of the range.
	2	Anecdotal observations regarding potential associations with some element of the environment (e.g. only in pools; found in billabongs and springs) or physiological limits.
	1	No information.
Threat	4	Experimental and/or temporally replicated observations regarding species' response to possible threats.
	3	Robust knowledge regarding some threats but not the full range or their potential to interact.
	2	Anecdotal and/or expert opinion regarding the potential response to threats but no explicit testing.
	1	No information.

Threat assessments were conducted using the criteria given by both the IUCN Red List and the EPBC Threatened Species assessment (IUCN, 2001; TSSC, 2018). The core criteria are listed as column headings in Table 2 below, and details of the criteria needed to meet each category of threat are available in each assessment guide, respectively. Species extent of occurrence (EoO) was calculated using a minimum bounding polygon in Google Earth Pro^{TM} (Version 7.3.2). The author has incorporated additional caveats specific to springs regarding the number of springs occupied (EoO) or the number of springs offering suitable habitat within a springs complex (AoO). These caveats were incorporated to account for spring complexes where the polygon containing all springs is large but the available habitat (i.e. number and area of springs likely to be inhabited) is small. The importance of this caveat is explored in the case study presented above for endemic gastropods in Pelican Creek Springs.

Estimating evidence of decline was critical for differentiating species threat levels. The Lake Eyre Basin Springs Assessment (LEBSA) database was used to assess, for each species, what portion of its range has disappeared (South Australian springs data reported in DEWNR, 2015; Queensland springs data held by the Queensland Herbarium). Unfortunately, this estimate only considers habitat decline at a spring complex scale and cannot incorporate habitat loss within the complex (i.e. reduction of the area of individual spring wetlands) or extirpations caused by severe disturbance to individual springs.

The proportion of the complex experiencing habitat quality reduction due to invasive species or pollutants was inferred from the LEBSA database (disturbance) and from the GAB springs risk assessment conducted by Kennard et al. (2018). Threats from groundwater drawdown were attributed using the calculated threats given in Kennard et al. (2018). Threatened species distributions and taxa vulnerability scores were also derived from this source. The percentage of springs with damage was extracted from the LEBSA database.

Results

Case Study: Endemic Gastropods of the Pelican Creek Springs

Nine species were included in this analysis: *Gyraulus (Gy.) edgbastonensis* (Brown, 2001), an undescribed species of *Glyptophysa* sp. considered to be endemic to the Pelican Creek Springs complex (Ponder et al., 2016), *Gabbia (Ga.) fontana* (Ponder, 2003), *Jardinella acuminata*, *J. corrugata*, *J. edgbastonensis*, *J. jesswiseae*, *J. pallida* and *Edgbastonia alanwillsi* (Ponder et al., 2008; Ponder & Clark, 1990).

These species have a small global distribution warranting listing as critically endangered under the IUCN criteria. The extent of occurrence (EoO) of any species endemic to the Pelican Creek complex is 29.7 km^2 and all species are considered to have the same EoO. However, within that 29.7 km^2, the area of occupancy (AoO) – the inhabited or theoretically habitable amount of spring wetland – is only 0.3% (~0.028 km^2). No species at this complex occupies all springs or all areas within them. At most, the eight species occupy 36% of springs, and at the least one species occupies only 6% (Table 2). Therefore, in the most extreme case the EoO overestimates the actual occupied wetland area by >99%, as a species that occupies only a few springs and is restricted to only the pool areas of those springs has an AoO of ~3212 m^2 of wetland (e.g. *Glyptophysa* sp., Table 2).

Basin-wide Analysis: Data Availability

Across all taxa, there are differences in how much information is currently available to inform an assessment of extinction risk (Figure 2). For 30% of taxa, a formal taxonomic description is yet to be published. Good to extensive data are available regarding the presence or absence of taxa among spring complexes, but knowledge concerning taxon distributions at finer spatial scales (i.e. among individual springs within complexes) is available for only ~70% of taxa. For >75% of organisms there are no published estimates of abundance anywhere within their range, nor information concerning the connectivity between populations. There is no literature at all regarding the basic ecology of >50% of taxa, and for the vast majority of species there is little quantitative information regarding how they respond to threatening processes (Figure 2).

The relative quantity and nature of the available data differ considerably across taxonomic groups. Of all groups, the fishes have the highest scores (Figure 3), but some taxa still score low (e.g. the Dalhousie catfish, *Neosiluris gloveri*). The molluscs have the broadest range of data availability scores (Figure 3), with equal numbers scoring the highest (e.g. *Fonscochlea* and *Trochidrobia*) and the lowest (e.g. *Glyptophysa* and *Gabbia*) (Figure 3). The low-scoring taxa tend to be within the less diverse families (e.g. the only species of bivalve scored lowest). Both groups of crustaceans considered here scored moderately (Figure 3), and low-scoring taxa are from radiations outside of the Kati Thanda system (i.e. both species of *Ponderiella* and an undescribed *Austrochiltonia* from Queensland). Most plant taxa fall within the moderate range of scores, although three species have low scores for data availability (*Isotoma*, *Chloris* and *Peplidium*) (Figure 3).

Basin-wide Analysis: Threatened Species Status of Endemic Invertebrates

The current level of listing under the IUCN and EPBC criteria does not reflect the present assessed threat status of invertebrate species endemic to discharge springs of the GAB (Figure 4). At the time of publication, no invertebrate taxa were listed individually as a threatened species under EPBC legislation, whereas 14 taxa have been assessed under the IUCN criteria, all of them molluscs. The assessment presented here recommends that 20 endemic species should be listed under the IUCN as critically endangered (5 crustaceans, 15 molluscs), 19 be listed as endangered (4 crustaceans, 15 molluscs) and 15 be listed as vulnerable (6 crustaceans, 9 molluscs). When assessed using the EPBC criteria, 50 species are recommended for critically endangered listing. This is an extreme estimate, so a revised EPBC listing has also been presented based on the relative threats currently faced by each species.

Figure 2. The varying levels of data deficiency for different information types (taxonomy, distribution, abundance, connectivity, ecology, threats) identified across all taxa (red = data deficient; orange = basic data; yellow = good data; and green = extensive data) (Source: Renee Rossini).

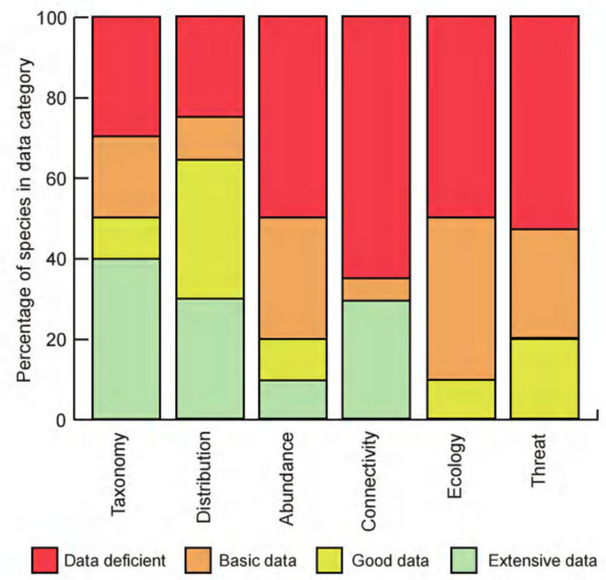


Table 2. Summary of estimates of distribution under different calculation methods for six species of GAB spring gastropod endemic to the Pelican Creek Springs complex. Calculations at a supergroup scale include frequency of occurrence (FoO) representing how many complexes the species occupies; extent of occurrence (EoO) is the area of a minimum bounding polygon around all springs in the complex; and area of occupancy (AoO) is the total available wetland area within the EoO. Considering detailed distribution data for each species at a spring complex scale allows refined estimates of AoO (occupiable spring wetland) to be calculated. With the addition of within-spring distribution data, these estimates can be refined further to reflect the true wetland area occupied by the species (corrected AoO).

	Supergroup scale			Complex scale Environmental limits					Within-spring scale Environmental limits				
	FoO	EoO (km^2)	AoO (km^2)	No. of springs (% total)	Spring size (m^2)	Pool size (m^2) Pool depth (cm)	Area of wetland that meets limits (km^2)	Area of wetland occupied	Conductivity (μS)	pH	Depth (mm)	Habitat Category	Corrected AoO (km^2) (as % of AoO)
Tateidae													
Jardinella acuminata	1	29.7	0.09	11 (13%)	>1000	>5 m^2 >5 cm	0.07	0.04	<1500	<8.5	>8	P	0.004 (4%)
Jardinella jesswiseae	1	29.7	0.09	25 (29%)	>100	>0 m^2 >1 cm	0.08	0.04	<1500	<8.5	>8	P(T)	0.07 (78%)
Jardinella edgbastonensis	1	29.7	0.09	31 (36%)	>1	>0 m^2 ≥0 cm	0.09	0.05	<1500	<9.0	>1	T	0.05 (56%)
Planorbidae													
Glytophysa sp.	1	29.7	0.09	5 (6%)	>1000	>10 m^2 >5 cm	0.05	0.03	<1500	<8.5	>10	P	0.003 (4%)
Gyraulus edgbastonensis	1	29.7	0.09	10 (13%)	>100	>5 m^2 >5 cm	0.08	0.03	<1500	<8.5	>10	P	0.003 (4%)
Bythiniidae													
Gabbia fontana	1	29.7	0.09	12 (13%)	>100	>5 m^2 >5 cm	0.05	0.03	<2000	<9.0	>5	P(T)	0.03 (33%)

Figure 3. Total data availability score out of 20 (4 points for each of 5 data categories) for each species identified in Rossini et al. (2018) as being endemic to discharge springs fed by waters of the Great Artesian Basin (Source: Renee Rossini).

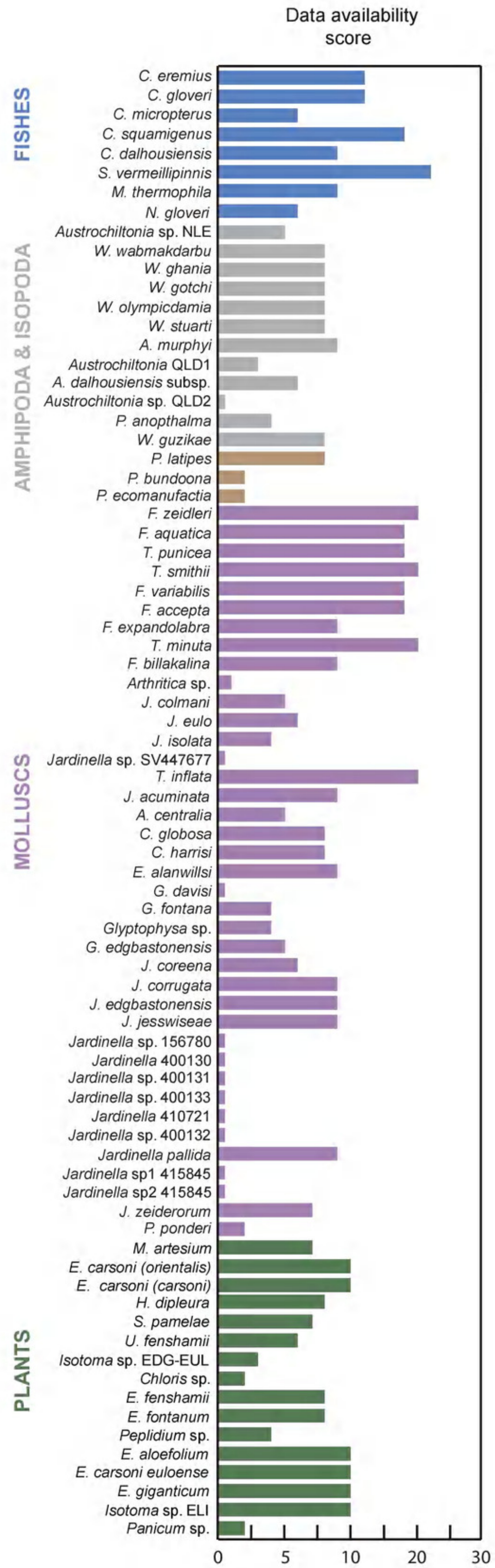
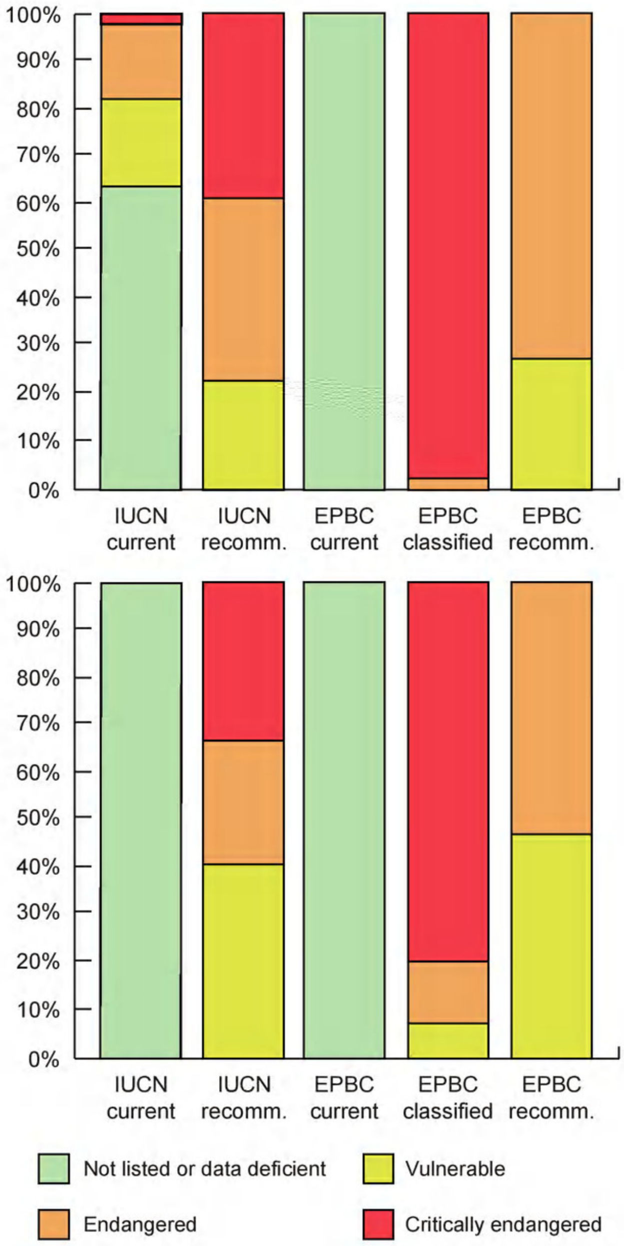


Figure 4. Summary of current listings, classified listings and recommended listings for molluscs (top) and crustaceans (bottom) endemic to discharge springs of the Great Artesian Basin. Taxa not yet described at species level have been excluded here but are classified in Appendix 1.



All taxa are at the critically endangered level for the extent of occurrence (EoO) criteria, which demonstrates how the further restriction placed by the EPBC assessment framework for two or more additional elements can be applied logically in cases where the spring wetland system creates naturally small distributions and the habitat is innately fragmented. In addition, by qualifying the risks associated with restricted ranges by the number of supergroups occupied and the number of springs available, some differentiation emerges between species. More than 50% of taxa satisfy the 'severely low number of locations' criteria, and 29 species have <50 springs available within their overall distribution (83% with <20 springs). If both of these elements are considered necessary to satisfy the low number of locations criteria, taxa from a single complex with very few springs are likely to have a higher level of extinction risk (primarily those from small complexes in the basins to the north of the GAB) than those widely distributed over multiple complexes in the basins to the south (Figure 1).

Exposure to threatening processes is generally ubiquitous across taxa and helps to differentiate those with narrow distributions and more pertinent threats from those that may be relatively stable. Drawdown as a process has affected some areas of the basin more than others. Across species that have seen drawdown within their range, few have experienced above-average losses. Unfortunately, complexes where the strongest losses of springs due to drawdown have been recorded are likely to have seen extinction of fauna before a full census had been completed (e.g. Flinders River supergroup, all supergroups in New South Wales). Most taxa are exposed to introduced alien species for which there is ample evidence that they can be considered vulnerable. For example, snail species endemic to Edgbaston Springs have been found in high frequency in the stomachs of both the cane toad, *Rhinella marina* (Clifford et al., 2020) and the alien fish, *Gambusia holbrooki* (Unmack, pers. comms). Populations of *G. holbrooki* often far exceed those of endemic fishes. For example, estimates of *G. holbrooki* populations in a subset of springs at the Edgbaston Springs complex in 2016 suggested that up to 30,000 individuals are present in a single spring (Alexander Burton, unpublished data), whilst naturally occurring *S. vermeillipinnis* populations average 2000 individuals (Fairfax et al., 2007). This hyperabundance of predators undoubtedly influences invertebrate prey populations; however, no time-series data are currently available to test the effect of *G. holbrooki* colonisation and proliferation on populations of endemic invertebrates.

Most species have part or all of their distribution outside of conservation areas, where they are exposed to uninhibited ungulate disturbance (Table 3). There is very little published information on the effects of ungulate disturbance on threatened invertebrate persistence (for exceptions, see Kovac & Mackay, 2009; Peck, 2020). There is reason to believe pugging by pigs and cows and rooting by pigs will have a detrimental effect on endemic invertebrates. The initial disturbance event can be severe, uprooting plants, mixing sediments, elevating salinity and increasing eutrophication through defecation and decay. In mound-forming springs, ungulate disturbance can expose or damage travertine deposits, changing spring mound shape. Many invertebrate taxa included in this assessment are bacterial film feeders or sediment grazers (e.g. crustaceans, Choy, 2020; gastropods, Ponder, 1995). These films attach to sediment grains or the surfaces of plants and presumably require clear water and time to establish. Post-disturbance recovery will most likely disrupt these food resources. The gastropods at least require hard surfaces to attach egg capsules, again disrupted by physical disturbance. The physical change in bathymetry caused by vertebrate pugging changes flow patterns, where water once flowing continuously over the wetland area forms numerous small, isolated pools within pugged sediments. Due to the low flow of many springs, they can take years to return to the pre-disturbance state (e.g. one spring at Edgbaston disturbed in mid-2000 is still noticeably pugged over a decade later; Peck, pers. obs, 2020).

Discussion and Recommendations

In recent years, threats to groundwater systems (Famiglietti, 2014) and the diverse array of species that rely on them (Boulton, 2005; Danielopol et al., 2003) have been highlighted as issues of global concern. The GAB is a unique groundwater system that, at present, has largely avoided the broad-scale disturbance and loss that has occurred in other extensive aquifer systems in other arid landscapes (El-Saied et al., 2015; Famiglietti, 2014; Powell & Fensham, 2016). Nevertheless, acknowledgement of severe declines in discharge and loss of spring wetlands over the past 200 years (Fairfax & Fensham, 2002), and the pertinent threats that remained in the system, culminated in 2001 with the protection of species reliant on GAB springs as an endangered community (Fensham et al., 2010). However, this blanket listing of the GAB spring community is not necessarily sufficiently robust to protect endemic spring species from further declines (Pointon & Rossini, 2020), and the present analysis suggests there is justification for listing most endemic spring invertebrates as threatened species in their own right.

Based on the available evidence, >50% of endemic GAB spring taxa should be listed as threatened species under both the IUCN and EPBC criteria. These taxa are spread across the basin with species ascribed critically endangered status under the standard EPBC criteria occurring in all major spring supergroups that contain endemic species. The nature of springs as an environment is to be spatially clustered and provide small patches of specialised habitat – i.e. they are inherently fragmented and restricted to small areas of wetland habitat. Due to these characteristics, all species assessed herein satisfy the critically endangered criteria for limited spatial distribution under the EPBC Act. Whilst retaining the standard EPBC method of threat status aligns GAB spring species with assessments of threatened species outside of springs, it does not accurately capture the different risks for endemic taxa within GAB spring wetlands. By further quantifying the 'small geographic distribution' criteria to include spring-specific criteria (e.g. number of springs within the complex, pool vs. tail habitat), the present assessment under the EPBC Act more accurately reflects the different levels of risk for spring invertebrates, and potentially taxa other than invertebrates. Under this revised EPBC listing, it is not suggested that any species should be listed as critically endangered; however, this assessment is highly conservative and is primarily an effort to align these suggested listings with the only existing listings within the GAB for fauna. At present the only species listed as critically endangered under IUCN criteria is the red-finned blue-eye (*Scaturiginichthys vermeilipinnis*) and the snail *Jardinella colmani*. Under EPBC Act criteria, the highest level of listing is endangered and only applied to *Scaturiginichthys vermeilipinnis*. The IUCN conservation status of fishes has been revised herein (Kerezsy, 2020) and the listing of plants was revised recently (Silcock et al., 2015; Silcock & Fensham, 2019). An accurate assessment of risk of extinction will need to involve a discussion of all lifeforms, and ensure the same methods and criteria are applied to all taxa. The present assessment is a first step towards that end. However, some hurdles remain for accurately assessing extinction risk of GAB springs taxa, especially invertebrates and other under-researched groups.

First, data availability and present understanding of extinction risk strongly interact. The way to estimate spatial distribution, and the information available concerning the habitat associations of each species, affect perceptions of susceptibility to extinction. As demonstrated in the case study from Pelican Creek Springs, without information on the number of springs in a complex, their total wetland area and pool area, the total number of springs occupied and the environmental limits of each species, we cannot accurately estimate the area of occupancy (AoO) and must rely on a severe overestimate of EoO (i.e. the total spring wetland area within the complex). In lieu of accurate spring wetland extent and limitations of ecological information, this assessment has attempted to qualify the EoO and differentiate species based on whether 'all their eggs are in one basket' at two spatial scales. At the supergroup scale this has involved scoring the number of locations supporting each species; this criterion is important because species endemic to a single spring complex are more at risk than those occupying numerous complexes. Within the occupied complexes, scores are based on the total number of springs potentially available to inhabit. These are still likely to be overestimates of spatial restriction, given no species in the Pelican springs case study occupied more than 30% of springs in the complex. Collecting the data needed to remedy this data deficiency is relatively simple (Rossini et al., 2016), rapid, and robust to the use of different methods if estimates of presence/absence are all that is required. However, it is time consuming and costly to survey each species' distribution in detail, and finding the resources needed to access remote GAB sites is difficult. In other taxa, prioritisations like the Red List have helped focus survey efforts. A systematic and strategic program to target surveys towards filling knowledge gaps which prioritise species at greatest risk would greatly improve understanding of threat and extinction risks to GAB springs taxa.

No analyses of cryptic species complexes or population structure have been completed for species outside of Kati Thanda–Lake Eyre. Given that most species subjected to such enquiries have been split into species or subspecies complexes, calculations of available spring habitat for species as they are currently defined could be overestimates. For example, when the amphipod lineages endemic to Kati Thanda were considered as a single species (as they were prior to Murphy et al., 2009) their EoO encompassed the majority of Kati Thanda and was >1000 km^2, which is beyond the limits of a species whose distribution is considered as vulnerable to extinction according to the IUCN criteria. However, after identification of cryptic species, all are ranked as critically endangered (Table 4). To work within this limitation, all classifications have been conducted for each species and for each clade or subunit based on evidence from the literature. Listing currently undescribed cryptic species, or clades of a single species, can be difficult (Pointon & Rossini, 2020) but worthwhile; including such information in the threatened community listing will help to quantify the level at which a loss of a spring population will significantly impact genetic diversity within the species. Clarity regarding both the extent of available habitat for these organisms and accurate estimates of species richness and genetic structure are vital for accurately assessing a species' extinction risk (Ponder et al., 1995), as is information on quantifiable limits of 'significant impacts' that jeopardise persistence (Pointon & Rossini, 2020).

For species where information is available, such as the gastropods from the Pelican Creek Springs, understanding the extreme limits on their distributions helps to clarify and conceptualise their susceptibility to threatening processes. Basin-wide threats such as artesian drawdown caused the loss of up to 50% of springs within some endemic species distributions (e.g. the undescribed member of the Tateidae – *Jardinella* AMS C.156780), and 24% of taxa have lost >10% of springs within their distribution range. These losses continue as drawdown causes the dormancy of springs. When a species has a global distribution of 10 shallow ponds with a total area smaller than an AFL football oval (e.g. *Gyraulus edgbastonensis*), the loss of a single spring is significant. As springs become reduced in area, any localised threats (e.g. trampling by cattle) will have more and more concentrated effects. With such a limited distribution comes an exacerbated risk;

the incursion of a small herd of cattle for a week, or the concentrated efforts of a few pigs in a single spring, can represent a disturbance to >20% of a species' global distribution. Furthermore, threats to springs are likely to interact synergistically (Côté et al., 2016); for example, in all species of gastropod tested from Pelican Creek, environmental extremes caused mortalities sooner in warmer months and in populations already persisting under elevated salinity or pH (Rossini et al., 2017a). Assessing these conservation risks via conceptualisations of threats and their interactions is the first step. Connecting the conceptualisations with a quantifiable understanding of how they affect populations is important for predicting population trends and designing management interventions. This can be done relatively easily (Ponder et al., 1989; Rossini et al., 2017b). For threats pertinent to much of the GAB (e.g. drawdown and ungulate disturbance) or for taxa whose range is severely limited, targeted quantifiable ecological assessments of how threat exposure influences population levels or dynamics would improve understanding of the potential for extinction.

The second obstacle to overcome in GAB springs conservation concerns scale. The GAB is one of the world's largest active groundwater systems, and GAB-dependant springs exist in remote or pastoral contexts. Knowledge and management are currently focused on particular complexes, but management is generally lacking in isolated spring complexes. By way of example, within the Barcaldine supergroup, the Pelican Creek complex has full distribution lists, relatively sound ecological information for target organisms (primarily fishes and snails) that include time-series needed to document decline, and threat-reducing interventions. This is thanks to extensive collaborative data collection since the 1990s. All other complexes within the Barcaldine supergroup are little known or studied, despite the fact that they also provide habitat for known endemic species, one of which is the only species of invertebrate endemic to the springs listed as critically endangered under IUCN criteria (*J. colmani*). Likewise, the Kati Thanda springs have been the focus of numerous dedicated taxonomic and ecological studies, but the nearby Lake Frome supergroup is lesser known and likely contains endemic species yet to be described. Given the sheer number of species and vastness of the area to be covered, basin-wide initiatives that guide a strategic approach to spring surveys, management interventions and conservation works will aid in avoiding species loss outside of well-known complexes (see Brake, 2020). Such prioritisation and planning create nothing but 'fantasy documents' if they are not supported financially (Cox, 2018). As most springs exist on private property, it is also essential for any such efforts to engage with and support relevant stakeholders. Conservation covenants, landholder support and education were all suggested in the Recovery Plan of 2010 and should be fostered in any basin-wide initiatives (Fensham et al., 2010).

The third and overarching conclusion of this paper is that invertebrate taxa are, according to current knowledge, the most diverse component of the threatened community of native species, but they are the most vulnerable. This statement stands until the biodiversity and threat within other crustacean groups, microinvertebrates and algae are better known. The invertebrates included in this assessment generally have narrow distributions, and strong dispersal and environmental limitations combine for many species to restrict them to tiny areas of habitat. They represent a diverse range of unique evolutionary narratives documenting the quaternary changes in the Australian continent. They present numerous examples of theory in action by epitomising the evolutionary consequences of restrictions on gene flow and environmental factors driving diversification as a process (Gotch et al., 2008; Murphy et al., 2015; Ponder, 1995). Yet invertebrates are the least represented in threatened species legislation, and evidently have the highest data deficiency of all taxa in the GAB system. Even though many are exposed to the same threatening processes as more charismatic fauna such as fishes, no species of endemic GAB invertebrate has been assessed or listed under the EPBC legislation. In many systems including springs (Hershler et al., 2014; Ponder & Walker, 2003), rates of extinction in the molluscs are highlighted as particularly concerning (Kay, 1995). This is a global problem for conservation (Cardoso et al., 2011), and particularly for freshwater systems where endemic invertebrates with restricted distributions make up most of the assemblage (Strayer, 2006). We owe it to *kwatye* (Arranda name for groundwater) species to do better, and hope this is a first step towards doing so.

Appendix 1

A reassessment of all invertebrate taxa under the criteria provided by the Environmental Protection and Biodiversity Conservation (EPBC) Act in Australia for the listing of threatened species. Recommended listing levels under the EPBC Act are provided, as well as under the IUCN Red List (as the categories in this assessment framework are similar). In many cases, the level of threatened species listing recommended using the assessment is different from that which is recommended. Recommended listings are based on current patterns of listing within the EPBC Act (i.e. highly threatened taxa such as the red-finned blue-eye are still only listed as Endangered).

	1. It has undergone, is suspected to have undergone, or is likely to undergo in the immediate future:				2. Its geographic distribution is precarious.									
	Reduction in area of occupancy or extent of occurrence		Reduction in quality of habitat due to effects of introduced taxa or pollutants		Small geographic distribution	Plus 2 or 3 of:								
	Extinction of springs at the designated % as evidence of decline in area of occupancy	Human modification to springs at the given % (if it is in multiple complexes, the % of complexes that score over 0.5)	Introduced aquatic flora or fauna present in X% of species range AND focal species deemed 'vulnerable' to them	% of complex in which threat exposure for 'animal disturbance' at occupied complex is >0.5 AND is outside of conservation management	Extent of occurrence measured as the area within the minimum bounding polygon is X	Severely low number of locations	AND/OR very few springs available	Scored more than 0.3 for groundwater drawn down (i.e. above average) in more than 50% of occupied complexes	Introduced taxa present in species range and focal species deemed 'vulnerable' to them	Anywhere where animal disturbance scored more than 0.5 in >50% of occurrences are outside of conservation = Y	Current IUCN listing	Rec. IUCN	Classified EPBC	Rec. EPBC
	CE >80	CE >80	CE >80	CE >80	CE <100 km^2	CE 1	CE <10							
	E >70	E >70	E >70	E >70	E <5000 km^2	E <=5	E <20							
	V >50	V >50	V >50	V >50	V <20,000 km^2	V <=10	V <50							
Arabunnachiltonia murphyi	–	–	–	CE	CE	E	–	Y	–	Y	NE	E (A1c, B1, B2bc)	E	V
Arthritica sp. AMS C.449156	–	V	–	CE	CE	E	–	Y	Y	Y	NE	E (A1ce, B1, B2bc)	CE	E
Austrochiltonia dalhousiensis sub.sp. *dalhousiensis*	–	–	V	–	CE	CE	–	Y	Y	–	NE	V (B1, B2b, D2)	CE	V
Austrochiltonia n.sp. (North Eyre)	–	–	–	CE	CE	V	–	–	–	Y	NE	V (B1, B2b, D2)	V	V
Austrochiltonia n.sp. AMSP68165	–	V	V	V	CE	E	–	–	Y	Y	NE	E (A1ce, B1, B2bc)	E	V
Austrochiltonia sp. AMS P68160	–	–	CE	CE	CE	CE	E	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Austropyrgus centralia	–	–	V	–	CE	CE	–	Y	Y	–	LC	V (B1, B2b, D2)	CE	V
Caldicochlea globosa	–	–	V	–	CE	CE	–	Y	Y	–	LC	V (B1, B2b, D2)	CE	V
Caldicochlea harrisi	–	–	V	–	CE	CE	–	Y	Y	–	LC	V (B1, B2b, D2)	CE	V
Edgbastonia allanwilsi	–	–	CE	CE	CE	CE	–	–	Y	Y	NE	EN (A1ce, B1abc)	CE	E
Fonscochlea accepta	–	–	–	CE	CE	–	–	Y	–	Y	V	V (D2)	CE	V
Fonscochlea aquatica	–	–	–	V	CE	–	–	Y	–	Y	EN	EN (B2ab)	CE	V

	1. It has undergone, is suspected to have undergone, or is likely to undergo in the immediate future:				2. Its geographic distribution is precarious.									
	Reduction in area of occupancy or extent of occurrence		Reduction in quality of habitat due to effects of introduced taxa or pollutants		Small geographic distribution	Plus 2 or 3 of:								
	Extinction of springs at the designated % as evidence of decline in area of occupancy	Human modification to springs at the given % (if it is in multiple complexes, the % of complexes that score over 0.5)	Introduced aquatic flora or fauna present in X% of species range AND focal species deemed 'vulnerable' to them	% of complex in which threat exposure for 'animal disturbance' at occupied complex is >0.5 AND is outside of conservation management	Extent of occurrence measured as the area within the minimum bounding polygon is X	Severely low number of locations	AND/OR very few springs available	Scored more than 0.3 for groundwater drawn down (i.e. above average) in more than 50% of occupied complexes	Introduced taxa present in species range and focal species deemed 'vulnerable' to them	Anywhere where animal disturbance scored more than 0.5 in >50% of occurrences are outside of conservation = Y	Current IUCN listing	Rec. IUCN	Classified EPBC	Rec. EPBC
	CE >80	CE >80	CE >80	CE >80	CE <100 km^2	CE 1	CE <10							
	E >70	E >70	E >70	E >70	E <5000 km^2	E <=5	E <20							
	V >50	V >50	V >50	V >50	V <20,000 km^2	V <=10	V <50							
Fonscochlea aquatica Clade A	–	–	CE	CE	CE	E	–	Y	Y	Y	NE	–	CE	E
Fonscochlea aquatica Clade B	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Fonscochlea aquatica Clade C	–	–	–	CE	CE	E	–	Y	Y	Y	NE	–	CE	E
Fonscochlea aquatica Clade D	–	–	–	–	CE	–	–	–	–	–	NE	–	CE	–
Fonscochlea billakalina	–	–	–	CE	CE	E	–	Y	–	Y	EN	EN (A1ce, B1abc)	CE	E
Fonscochlea expandolabra	–	–	V	CE	CE	V	–	Y	Y	Y	NE	V (A1ce, B1, B2abc)	CE	V
Fonscochlea expandolabra Clade A	–	–	CE	CE	CE	E	–	Y	Y	Y	NE	–	CE	E
Fonscochlea expandolabra Clade B	–	–	–	CE	CE	V	–	Y	Y	Y	NE	–	CE	V
Fonscochlea variabilis	–	–	–	–	CE	–	–	–	Y	Y	NE	V (D2)	CE	–
Fonscochlea variabilis Clade A	–	–	–	–	CE	CE	E	–	–	–	NE	–	–	–
Fonscochlea variabilis Clade B	–	–	–	–	CE	–	–	–	–	–	NE	–	–	–
Fonscochlea zeidleri	–	–	–	V	CE	–	–	Y	Y	Y	NT	EN (B2ab)	CE	V
Fonscochlea zeidleri form A Clade A	V	–	–	CE	CE	CE	–	Y	Y	Y	NE	–	CE	E
Fonscochlea zeidleri form B Clade B	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Fonscochlea zeidleri form A Clade C	–	–	–	CE	CE	–	–	Y	Y	Y	NE	–	CE	E
Fonscochlea zeidleri form A Clade D	–	–	–	–	CE	–	–	–	Y	–	NE	–	–	–
Fonscochlea zeidleri form A Clade E	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Gabbia davisi	–	–	CE	CE	CE	CE	CE	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Gabbia fontana	–	–	CE	–	CE	CE	CE	–	Y	–	NE	EN (A1ce, B1abc)	CE	E
Glyptophysa n.sp.	–	–	CE	–	CE	CE	CE	–	Y	–	NE	EN (A1ce, B1abc)	CE	E
Gyraulus edgbastonensis	–	–	CE	–	CE	CE	CE	–	Y	–	DD	EN (A1ce, B1abc)	CE	E

	1. It has undergone, is suspected to have undergone, or is likely to undergo in the immediate future:				2. Its geographic distribution is precarious.									
	Reduction in area of occupancy or extent of occurrence		Reduction in quality of habitat due to effects of introduced taxa or pollutants		Small geographic distribution	Plus 2 or 3 of:								
	Extinction of springs at the designated % as evidence of decline in area of occupancy	Human modification to springs at the given % (if it is in multiple complexes, the % of complexes that score over 0.5)	Introduced aquatic flora or fauna present in X% of species range AND focal species deemed 'vulnerable' to them	% of complex in which threat exposure for 'animal disturbance' at occupied complex is >0.5 AND is outside of conservation management	Extent of occurrence measured as the area within the minimum bounding polygon is X	Severely low number of locations	AND/OR very few springs available	Scored more than 0.3 for groundwater drawn down (i.e. above average) in more than 50% of occupied complexes	Introduced taxa present in species range and focal species deemed 'vulnerable' to them	Anywhere where animal disturbance scored more than 0.5 in >50% of occurrences are outside of conservation = Y	Current IUCN listing	Rec. IUCN	Classified EPBC	Rec. EPBC
	CE >80	CE >80	CE >80	CE >80	CE <100 km²	CE 1	CE <10							
	E >70	E >70	E >70	E >70	E <5000 km²	E <=5	E <20							
	V >50	V >50	V >50	V >50	V <20,000 km²	V <=10	V <50							
Jardinella acuminata	–	–	CE	–	CE	CE	CE	–	Y	–	E	EN (A1ce, B1abc)	CE	E
Jardinella colmani	–	–	CE	CE	CE	E	V	–	Y	Y	CE	CE (A1ce, B1, B2bc)	CE	E
Jardinella coreena	–	–	CE	CE	CE	CE	V	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella corrugata	–	–	CE	–	CE	CE	CE	–	Y	–	V	EN (A1ce, B1abc)	CE	E
Jardinella edgbastonensis	–	–	CE	–	CE	CE	–	–	Y	–	V	EN (A1ce, B1abc)	CE	E
Jardinella eulo	–	–	–	CE	CE	E	CE	–	–	Y	V	CE (A1ce, B1, B2bc)	CE	E
Jardinella isolata	–	–	–	–	CE	CE	–	Y	–	–	V	EN (A1ce, B1abc)	CE	E
Jardinella jesswiseae	–	–	CE	–	CE	CE	–	–	Y	–	E	EN (A1ce, B1abc)	CE	E
Jardinella n.sp. AMS C.156780 (sp1)	V	CE	CE	–	CE	CE	CE	–	Y	–	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella n.sp. AMS C.400130/ QMS05 (sp2)	–	–	–	CE	CE	CE	CE	–	–	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella n.sp. AMS C.400131/ QMS04 uncoil (sp3)	–	–	CE	CE	CE	CE	E	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella n.sp. AMS C.400133/ QMS04 (sp4)	–	–	CE	CE	CE	CE	E	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella n.sp. AMS C.410721 (sp5)	–	–	CE	CE	CE	CE	E	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella n.sp. AMS C.400132/ QMS04 keel (sp6)	–	–	CE	CE	CE	CE	E	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella pallida	–	–	CE	–	CE	CE	CE	–	Y	–	E	EN (A1ce, B1abc)	CE	E

	1. It has undergone, is suspected to have undergone, or is likely to undergo in the immediate future:				2. Its geographic distribution is precarious.									
	Reduction in area of occupancy or extent of occurrence		Reduction in quality of habitat due to effects of introduced taxa or pollutants		Small geographic distribution	Plus 2 or 3 of:								
	Extinction of springs at the designated % as evidence of decline in area of occupancy	Human modification to springs at the given % (if it is in multiple complexes, the % of complexes that score over 0.5)	Introduced aquatic flora or fauna present in X% of species range AND focal species deemed 'vulnerable' to them	% of complex in which threat exposure for 'animal disturbance' at occupied complex is >0.5 AND is outside of conservation management	Extent of occurrence measured as the area within the minimum bounding polygon is X	Severely low number of locations	AND/OR very few springs available	Scored more than 0.3 for groundwater drawn down (i.e. above average) in more than 50% of occupied complexes	Introduced taxa present in species range and focal species deemed 'vulnerable' to them	Anywhere where animal disturbance scored more than 0.5 in >50% of occurrences are outside of conservation = Y	Current IUCN listing	Rec. IUCN	Classified EPBC	Rec. EPBC
	CE >80	CE >80	CE >80	CE >80	CE <100 km^2	CE 1	CE <10							
	E >70	E >70	E >70	E >70	E <5000 km^2	E <=5	E <20							
	V >50	V >50	V >50	V >50	V <20,000 km^2	V <=10	V <50							
Jardinella sp. AMS C.415845 (Myross) (sp1)	–	–	CE	CE	CE	CE	V	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella sp. AMS C.415845 (Myross) (sp2)	–	–	CE	CE	CE	CE	V	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella sp. AMS C.447677	–	–	–	CE	CE	E	E	–	–	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Jardinella zeiderorum	–	–	CE	CE	CE	CE	V	–	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Phraetochiltonia anopthalma	–	–	V	–	CE	CE	–	Y	Y	–	LC	V (A1ce, B1, B2abc)	CE	V
Phraetomerus latipes	–	–	–	CE	CE	–	–	Y	–	Y	NE	EN (A1ce, B1abc)	CE	E
Phraetomerus latipes Clade C1	–	–	–	–	CE	–	–	–	–	–	NE	–	–	–
Phraetomerus latipes Clade C2	–	–	–	CE	CE	CE	–	Y	–	Y	NE	–	CE	E
Phraetomerus latipes Clade C3	–	–	CE	CE	CE	E	–	Y	Y	Y	NE	–	CE	V
Phraetomerus latipes Clade C4	–	–	–	CE	CE	CE	–	Y	–	Y	NE	–	CE	E
Phraetomerus latipes Clade S5	–	–	–	CE	CE	E	–	Y	Y	Y	NE	–	CE	E
Phraetomerus latipes Clade S6	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Phraetomerus latipes Clade N7	–	–	V	CE	CE	E	E	Y	Y	Y	NE	–	CE	E
Phraetomerus latipes Clade N8	–	–	–	CE	CE	E	E	Y	–	Y	NE	–	CE	E
Phraetomerus latipes Clade N9	–	–	–	CE	CE	E	–	Y	–	Y	NE	–	CE	V
Ponderiella bundoona	–	V	CE	V	CE	E	E	Y	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Ponderiella ecomanufactia	–	V	CE	V	CE	E	E	Y	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Posticobia ponderi	–	–	–	–	CE	CE	CE	Y	–	–	NE	CE (A1ce, B1, B2bc)	CE	E

	1. It has undergone, is suspected to have undergone, or is likely to undergo in the immediate future:				2. Its geographic distribution is precarious.									
	Reduction in area of occupancy or extent of occurrence		Reduction in quality of habitat due to effects of introduced taxa or pollutants		Small geographic distribution	Plus 2 or 3 of:								
	Extinction of springs at the designated % as evidence of decline in area of occupancy	Human modification to springs at the given % (if it is in multiple complexes, the % of complexes that score over 0.5)	Introduced aquatic flora or fauna present in X% of species range AND focal species deemed 'vulnerable' to them	% of complex in which threat exposure for 'animal disturbance' at occupied complex is >0.5 AND is outside of conservation management	Extent of occurrence measured as the area within the minimum bounding polygon is X	Severely low number of locations	AND/OR very few springs available	Scored more than 0.3 for groundwater drawn down (i.e. above average) in more than 50% of occupied complexes	Introduced taxa present in species range and focal species deemed 'vulnerable' to them	Anywhere where animal disturbance scored more than 0.5 in >50% of occurrences are outside of conservation = Y	Current IUCN listing	Rec. IUCN	Classified EPBC	Rec. EPBC
	CE >80	CE >80	CE >80	CE >80	CE <100 km²	CE 1	CE <10							
	E >70	E >70	E >70	E >70	E <5000 km²	E <=5	E <20							
	V >50	V >50	V >50	V >50	V <20,000 km²	V <=10	V <50							
Trochidrobia inflata	–	–	CE	CE	CE	E	–	Y	Y	Y	E	EN (A1ce, B1abc)	CE	E
Trochidrobia minuta	–	–	V	CE	CE	V	–	Y	Y	Y	V	V (A1ce, B1, B2abc)	CE	V
Trochidrobia punicea	–	–	–	–	CE	–	–	Y	–	Y	LC	V (A1ce, B1, B2abc)	CE	V
Trochidrobia punicea Clade A	–	–	–	–	CE	V	–	–	Y	–	NE	–	CE	–
Trochidrobia punicea Clade B	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Trochidrobia smithii	–	–	–	E	CE	–	–	Y	–	Y	VU	V (A1ce, B1, B2abc)	CE	V
Trochidrobia smithii Clade A	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Trochidrobia smithii Clade B	–	–	–	CE	CE	V	–	Y	–	Y	NE	–	CE	V
Trochidrobia smithii Clade C	–	–	–	–	CE	E	–	–	–	–	NE	–	–	–
Wangiannachiltonia ghania	–	–	–	CE	CE	E	–	Y	–	Y	NE	EN (A1ce, B1abc)	CE	E
Wangiannachiltonia gotchi	V	–	–	CE	CE	E	–	Y	–	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Wangiannachiltonia guzikae	–	–	CE	CE	CE	CE	–	Y	Y	Y	NE	CE (A1ce, B1, B2bc)	CE	E
Wangiannachiltonia olympicdamia	–	–	–	CE	CE	E	–	Y	–	Y	NE	V (A1ce, B1, B2abc)	CE	V
Wangiannachiltonia stuarti	–	–	–	–	CE	E	–	–	–	–	NE	V (D2)	–	–
Wangiannachiltonia wabmakdarbu	–	–	–	–	CE	V	V	–	–	–	NE	V (D2)	–	–

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Author Profile

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