Received: 29 June 2023 | Accepted: 18 July 2023

DOI: 10.1111/aec.13403

EDITORIAL

Opportunities for research and conservation of freshwater turtles in Australia

Abstract

Australia's freshwater turtles have high endemicity and many are threatened by extinction. Following a symposium held at the 2022 conference of the Australian Society of Herpetologists, we summarized the current status of research and conservation for Australian freshwater turtles and identified opportunities for future research. Eight species (32%) of Australia's 25 native freshwater turtles are listed as threatened by Australia's Federal Government. Symposium discussions on the primary gaps in research identified the lack of baseline data to inform population modelling as a key deficiency. Knowledge of the most effective conservation actions, the effectiveness of attempts to aid population recovery, and whether these actions are required at all, remains lacking for many species. A heavy bias exists between some well-studied species compared with others for which little or no information is published. Community science, engagement with First Nations people, advances in technology, and recognition of the importance of turtles are contributing to better knowledge.

INTRODUCTION

Globally, over half of our ~360 turtle species are threatened or endangered (Lovich et al., 2018; Stanford et al., 2020) resulting in a significant loss of ecosystem services. Turtles can reach high biomasses and influence the environment (Glorioso et al., 2010; Iverson, 1982) through their roles in food webs as both consumers (Blamires & Spencer, 2013; Petrov et al., 2018) and prey (Lettoof et al., 2021). Turtles influence water quality (Santori et al., 2020), soil bioturbation (Kaczor & Hartnett, 1990), seed dispersal (Falcón et al. 2020), and nutrient cycling (Wenger et al., 2019). Thus, ecosystem health is affected by declines in turtle populations. Socially, turtles were part of cosmic symbolism of ancient cultures (Rappengliick & Gilching, 2006) and remain important in many communities and traditional cultures (Cann & Sadlier, 2017; Fordham et al., 2006). They also play a role in storytelling as popular characters in books and movies, often as the underdog or hero (Hicks & Kanevsky, 1992). Thus, conservation of turtles is valuable environmentally and socially.

Freshwater turtle conservation in Australia is crucial, because the majority of species are endemic (88%), which places an imperative on Australian society to preserve their existence. Australian freshwater turtles, with the exception of *Carettochelys*, represent the distinct sub-family Chelodininae within the side-necked turtles (Pleurodira). Chelodininae is restricted to Australasia, where they are adapted to the dynamic freshwater environment. Australia is also a largely arid island continent with highly irregular rainfall in many places, which makes its freshwater systems more susceptible to climate change. Australian freshwater turtles are currently threatened by a suite of factors affecting the environment. Proximate causes for their declines include viruses (Chessman et al., 2020), habitat loss and degradation (Chessman, 2011), and invasive species (Fordham et al., 2006; Spencer & Thompson, 2005).

To address declines in Australian freshwater turtles and ensure their persistence for future generations, research (Chessman, Dillon, et al., 2023; Chessman, Fielder, et al., 2023; Coleman, 2023; Kidman et al., 2023; McKnight, 2023; McKnight et al., This issue; Nordberg & McKnight, 2023; Van Dyke et al., This issue) and conservation actions (Campbell et al., 2023; Streeting et al., 2023; Terry et al., 2023) are ongoing. However, compared to many other taxa, freshwater turtles have received less focus and funding in Australia (Gawne et al., 2020). Recognition of turtle declines, their potential to garner community support, and the role they play in facilitating ecosystem functioning, has led to increased interest from community groups and government in recent years (Santori et al., 2021).

Our special issue follows a symposium held to discuss the key priorities for the conservation and research of Australia's freshwater turtles at the conference of the Australian Society of Herpetologists at Mylor in South Australia 11th–14th July 2022. The symposium resulted in a series of ecological papers (this special issue) to increase our knowledge of Australian freshwater turtles and aid in their conservation management. Here, we summarize the current status of research and conservation for Australian freshwater turtles, identify opportunities for future research, and discuss important

factors for prioritizing future research, drawing on both new research published in this special issue and the literature more broadly.

STATUS AND DISTRIBUTION OF AUSTRALIAN TURTLES

Currently, 25 native species of freshwater turtles inhabit Australia, comprising 24 chelid species and *Carettochelys insculpta*. The geographic distributions of Australian freshwater turtle species vary considerably, from exceptionally narrow ranges that may be as small as a single catchment (e.g., *Myuchelys georgesi*), to widespread species occupying multiple catchments and states (e.g., *Emydura macquarii*, *Chelodina longicollis*, and *C. expansa*) (Figure 1). *Carettochelys insculpta*, *Emydura subglobosa*, and *Chelodina rugosa* also occur in New Guinea, while the remaining species are endemic to Australia. All of Australia's endemic turtles are aquatic, and thus they are largely absent from the arid centre (Figure 1). Centres of diversity occur in the Northern Territory and mid-eastern Australia where up to nine species are broadly sympatric.

Eight species (32%) of Australian freshwater turtles are listed as threatened by the Federal Government (EPBC Act, 1999; EPBC Act List of Threatened Fauna (environment.gov.au) accessed 10 May 2022). Three species are listed nationally as Critically Endangered. Two of these three species (*Elseya albagula* and *Pseudemydura umbrina*) are from monotypic genera, while the third (*Myuchelys georgesi*) is from a genus with three other species (two of which are listed as Endangered). Four species are listed as Endangered (*Elseya lavarackorum*, *Elusor macrurus*, *Myuchelys bellii*, and *M. purvisi*) and a further species is listed as Vulnerable (*Rheodytes leukops*). These species are all range-restricted (Figure 2; Table 1).

RESEARCH KNOWLEDGE AND GAPS

Australian freshwater turtles are unique in their habits and exhibit many remarkable adaptations to the Australian environment. For example, bizarre habits in reproduction include the underwater nesting of *Chelodina rugosa* (Kennett et al., 1993), the extensive embryonic diapause of *Chelodina expansa* (Booth, 2000), and the explosive hatching of *Carettochelys insculpta* (Webb et al., 1986). In oxygen-rich environments we see cloacal breathing as the primary form of respiration (FitzGibbon & Franklin, 2010), allowing extensive dive times in species adapted to

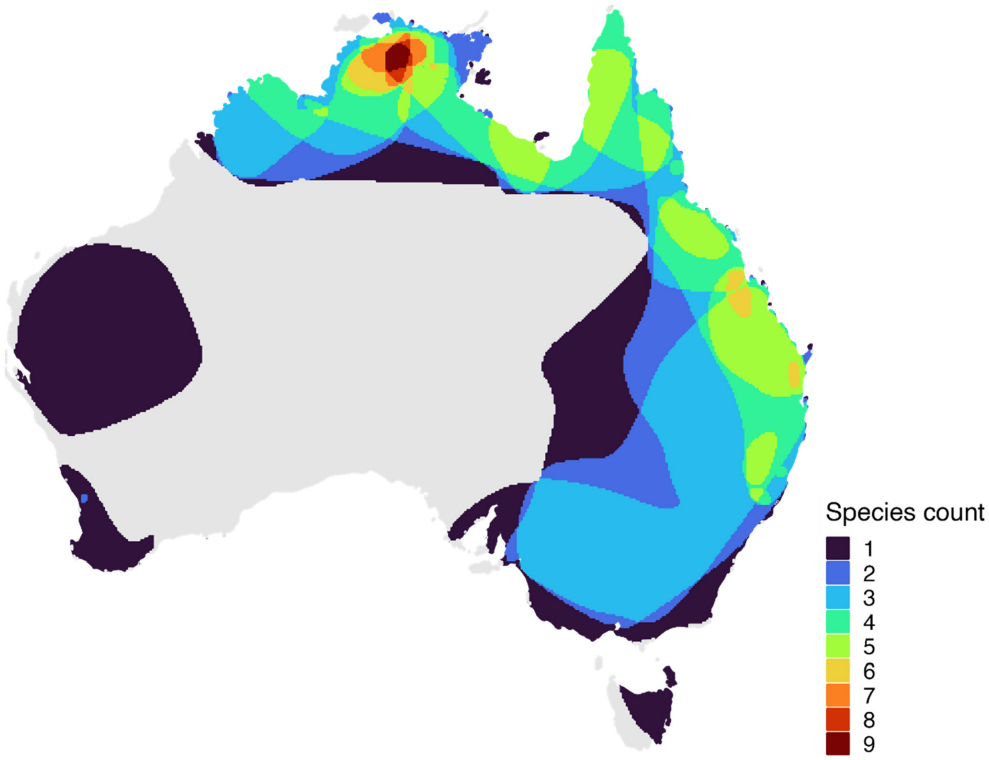

FIGURE 1 Map of turtle species distributions in Australia showing hotspots of richness in northern and eastern Australia and an absence of turtles in the arid centre. Notes: the one species found in Tasmania (*Chelodina longicollis*) has been introduced there; *Emydura macquarii* has also spread beyond its native range.

lotic environments with clean water (Clark et al., 2008; Gordos et al., 2004). In other species (e.g., *Chelodina longicollis*), a long coevolution with salt has driven the evolution of salt tolerance which approaches that of estuarine turtle species in other countries (Bower et al., 2016). Australian freshwater turtles were also among the first to be documented vocalizing, with an extensive repertoire of underwater vocalizations in *Chelodina oblonga* (Giles, 2005). It was also only recently discovered that some turtles in northern Australia bask nocturnally (Kidman et al., 2023; McKnight et al., 2023; Nordberg & McKnight, 2020, 2023). Some species have complex patterns of habitat use that include permanent, semi-permanent, and ephemeral wetlands (Santoro et al., 2020) and extensive terrestrial activity (Kennett et al., 2009). Additionally, life in large riverine environments enables long-distance movements by male turtles, the extent of which we are only just beginning to understand (Bower et al., 2012; Van Dyke et al., This issue). Future research will almost certainly continue to document many more weird and wonderful habits of Australian freshwater turtles.

While ecology is the primary research discipline in publications on Australian freshwater turtles, we still lack basic knowledge of home range sizes, movement cues, social structures, cognitive abilities, and environmental factors influencing growth and reproductive output. These knowledge gaps are true even for species for which there are substantial publication outputs (e.g., *Emydura macquarii*). With the advent of new technologies, such as camera trapping (McKnight et al., 2023), tissue stable isotope

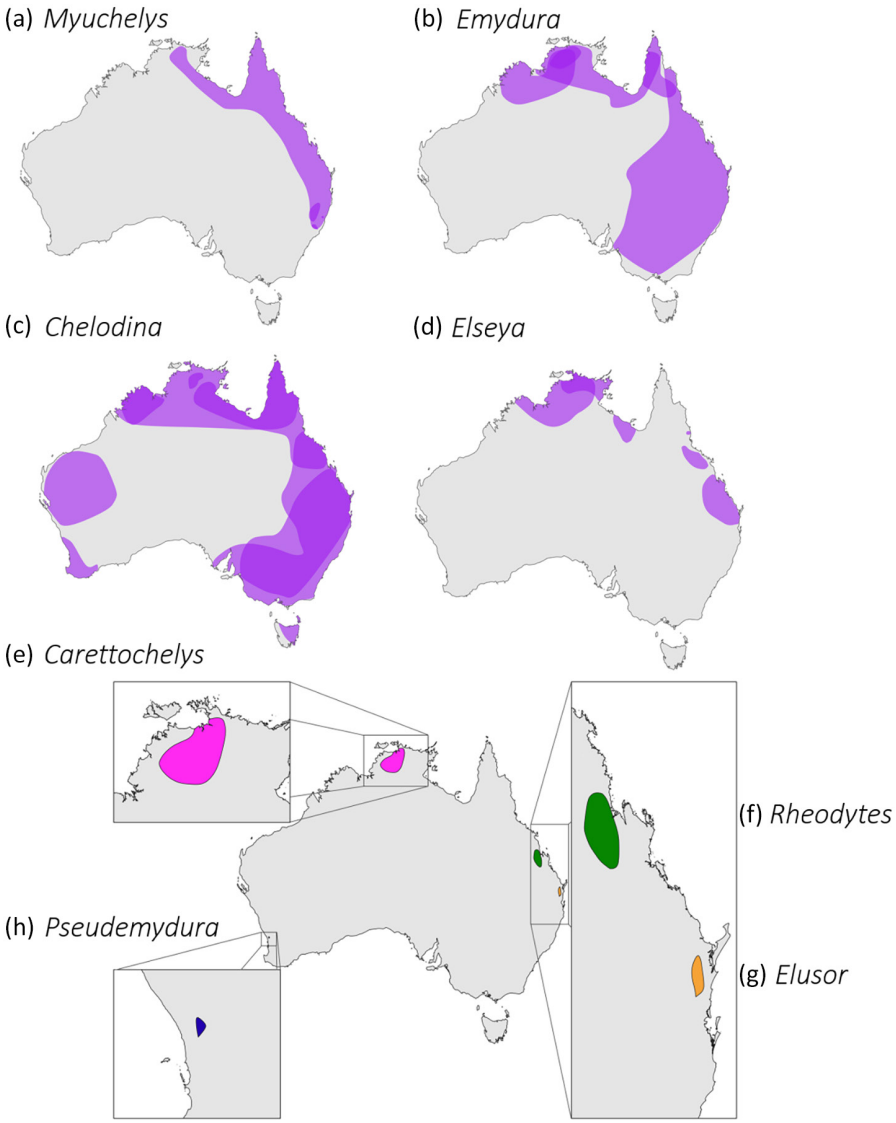

FIGURE 2 Species ranges overlaid to show variation in the Australian freshwater turtle genera distribution for (a) *Myuchelys* (b) *Emydura* (c) *Chelodina* (d) *Elseya* and monotypic (e) *Carettochelys insculpta* (f) *Rheodytes leukops* (g) *Elusor macrurus* (h) *Pseudemydura umbrina*.

TABLE 1 Current and interim proposed listing of Australian freshwater turtles under the *Environment Protection and Biodiversity Act 1999* (subject to change as the consultation process proceeds).

Species	Current Commonwealth listing	2022 SEAP proposed Commonwealth listing
Carettochelys insculpta	Not listed	Endangered
Chelodina burrungandjii	Not listed	
Chelodina canni	Not listed	Insufficient data
Chelodina expansa	Not listed	
Chelodina kuchlingi	Not listed	
Chelodina longicollis	Not listed	Vulnerable
Chelodina oblonga	Not listed	Insufficient data
Chelodina rugosa	Not listed	
Chelodina steindachneri	Not listed	
Elseya albagula	Critically endangered	Critically endangered
Elseya dentata	Not listed	
Elseya flaviventralis	Not listed	
Elseya irwini	Not listed	Endangered
Elseya lavarackorum	Endangered	Endangered
Elusor macrurus	Endangered	Critically endangered
Emydura macquarii gunabarra	Not listed	Endangered
Emydura macquarii	Not listed	Vulnerable
Emydura subglobosa subglobosa	Not listed	Critically endangered
Emydura tanybaraga	Not listed	
Emydura victoriae	Not listed	
Myuchelys bellii	Endangered	Endangered
Myuchelys georgesi	Critically endangered	Critically endangered
Myuchelys latisternum	Not listed	
Myuchelys purvisi	Endangered	Endangered
Pseudemydura umbrina	Critically endangered	
Rheodytes leukops	Vulnerable	Endangered

analysis (Micheli-Campbell et al., 2017), passive acoustic tracking (Micheli-Campbell et al., 2017; Van Dyke et al., This issue), environmental DNA (Villacorta-Rath et al., 2022), and underwater baited video cameras (Coleman, This issue), we are beginning to unravel the mysteries of turtle behaviour. In addition, the reduction in cost and increase in the capability of genetic techniques have enabled better resolution of phylogenetic relationships among and within turtle species, providing clarity around systematics and nomenclature (Georges et al., 1999, 2018; Thomson et al., 2021).

Symposium discussions on the primary gaps in research identified the lack of baseline data to inform population modelling as a key deficiency (Petrov et al., This issue). This lack of data includes relationships for fertility, hatching rates, sex ratios, age of maturity, maximum age, and age-dependent survival rates. Repeated population estimates are not available for most species, which limits our ability to track population changes through time (Howell et al., 2019). This sort of information is doubly important for long-lived species such as turtles because it is harder to detect population declines initially, and because they can take longer to respond to conservation efforts since they have delayed sexual maturity and high rates of juvenile mortality. For many northern species, there is little published information on basic ecology, such as nesting location and timing, reproductive output, or habitat use. Excluding subspecies, six of the seven species excluded from the Special Expert Assessment Panel owing to data deficiency were species from northern Australia (Petrov et al., This issue). Many species live in remote parts of northern Australia (e.g., *Elseya flaviventralis*, *Emydura tanybaraga*), are recently described (*Myuchelys purvisi*), or are rare or sympatric with crocodiles, and therefore difficult to study (e.g., *Emydura subglobosa subglobosa*). This lack of fundamental information may be an opportunity for reptile breeders to contribute collectively to aid in establishing baseline information for little-known species and their demographics.

PRIORITIES AND CHALLENGES FOR THE CONSERVATION OF AUSTRALIAN TURTLES

Conservation biologists continue to refine the best approaches to counteract population declines and causes of mortality in Australian freshwater turtles. Actions include attempts to mitigate threats of feral species such as pigs and foxes through predator-proof fencing (Cochrane, 2006; Streeting et al., 2023), nest protection measures (Campbell et al., 2020; Connell, 2018;Streeting et al., 2023; Terry et al., 2023), and artificial incubation of eggs and release of hatchlings (Streeting et al., 2022). Likewise, conservation translocations of Critically Endangered species such as reintroductions (*Myuchelys georgesi*) and assisted colonization (*Pseudemydura umbrina*) have attempted to mitigate critically low population sizes due to disease (Chessman et al., 2020) and habitat loss and degradation (Bouma et al., 2020; Kuchling et al., 2018). Improved river management, such as managed flow delivery in regulated systems, has attempted to improve wetland habitats and the condition of rivers (Espinoza et al., 2022; Francis et al., 2022). More broadly, technological advances such as biobanking gametes, controlling diseases, and advances in genetic and bioinformatic tools should assist future conservation measures (Clulow et al., 2022). However, knowledge of the most effective conservation actions, the effectiveness of attempts to aid population recovery, and whether these actions are required at all, remains lacking for many species.

Community Science is leading the way in the broad-scale reporting and mitigation of major threats to freshwater turtles, such as road mortality and nest predation (e.g., TurtleSAT.org.au – (Santori et al., 2021). The 1 Million Turtles (1MT) Community Conservation Program (1MillionTurtles.com) is engaging the public in turtle conservation and connects them with nature through a hands-on approach to conservation. Individuals and community groups can participate in activities such as nest monitoring, turtle rescues, and habitat restoration/modification (e.g., turtle islands). Similarly, community science programs to counteract road mortality and predation of nesting females and their nests have been established for *Chelodina oblonga* in Western Australia (Santoro, 2022).

Discussions on the priorities required in freshwater turtle conservation noted that science is hindered by a lack of baseline information. While research has been completed to counteract feral species as a source of mortality (Streeting et al., 2023; Terry et al., 2023), we still do not know how this mortality compares to the predation pressures that were evident prior to the decline of many medium-sized mammals (e.g., bandicoots, quolls) which were likely nest predators (Chessman, 2022). Although Australian turtles can withstand relatively high levels of nest predation, when coupled with unnaturally high levels of adult mortality, their populations will inevitably decrease (Spencer, 2018). Additionally, the decreased productivity created by regulating rivers and the associated habitat loss has likely reduced the density of freshwater turtles in areas they still occupy. This suggests that turtles were much more abundant previously (Thompson, 1993), but historical densities are difficult to accurately quantify. The lack of baseline information has placed an increasing importance on the need to determine current trends in turtle population growth over time, so that action can be taken where population trajectories suggest ongoing declines. In addition, the lack of any ecological information for some species of Australian freshwater turtle (e.g., *Elseya flaviventralis*, *Emydura tanybaraga*) highlights the need to better understand those species to inform conservation.

An ongoing challenge for Australian freshwater turtle conservation has been the lack of awareness of their importance to freshwater systems. Consequently, they have received less attention than sea turtles, many high-profile mammals (e.g. koalas), and economically or recreationally important taxa (e.g., fish). Despite being historically undervalued, the increasing understanding of the importance of turtles to river health (Santori et al., 2020) is helping garner support for increased protection. In addition, turtles are popular among Australians, which as previously noted, has led to successful community science campaigns, including individual participation, community group conservation, school participation (Santori et al., 2021), and the production of conservation guidelines for practitioners and land managers. The significance of turtles to First Nations Australians has also facilitated conservation efforts by Indigenous ranger groups (Cochrane, 2006), and the Working on Country program provides an ongoing opportunity for conservation and land and river management led by First Nations People. The increasing recognition of the value of engaging First Nations People when setting priorities around conservation and the benefit of collaboration on country (Ward-Fear et al., 2019) is leading to improved conservation outcomes.

CONCLUSION

While research has unravelled much of the biology and conservation needs of Australian freshwater turtles, there remains much to be learned. With many species recommended for an upgrade to more severe listings in the Special Assessment Expert Panel process in 2022 (Petrov et al., This issue), the trend in declines for Australian freshwater turtles highlights the need for increasing

conservation efforts. A heavy bias exists between some well-studied species compared with others for which no information is published. Our management for almost all species suffers from a lack of long-term population level data to assess trends in population size and demography, critical to inform conservation measures. Technological advances, alongside the increased participation of community members and investment in freshwater turtle conservation by governments, will likely catalyse our capacity to respond with appropriate long-term conservation action for these remarkable long-lived creatures. Our special issue is dedicated to further unravelling the mystery of Australian freshwater turtles, and improving access to our knowledge of these unique animals.

AUTHOR CONTRIBUTIONS

Deborah Bower: Conceptualization (equal); project administration (equal); writing – original draft (equal). **Donald McKnight:** Conceptualization (equal); methodology (equal); writing – original draft (equal). **Kyra Sullivan:** Data curation (equal); project administration (equal); writing – review and editing (equal). **Stewart Macdonald:** Data curation (equal); formal analysis (equal); investigation (equal); visualization (lead). **Arthur Georges:** Conceptualization (supporting); writing – review and editing (supporting). **Simon Clulow:** Conceptualization (supporting); writing – review and editing (supporting). **Rupert Mathwin:** Conceptualization (supporting); writing – review and editing (supporting). **Marilyn Joy Connell:** Conceptualization (supporting); writing – review and editing (supporting). **Holly Nelson:** Conceptualization (supporting); writing – review and editing (supporting). **Anthony Santoro:** Conceptualization (supporting); writing – review and editing (supporting). **Bethany Nordstrom:** Conceptualization (supporting); writing – review and editing (supporting). **James U Van Dyke:** Conceptualization (supporting); writing – review and editing (supporting). **Rosie Kidman:** Conceptualization (supporting); writing – review and editing (supporting). **Louise Streeting:** Conceptualization (supporting); writing – review and editing (supporting). **Martin Dillon:** Conceptualization (supporting); writing – review and editing (supporting). **Ricky-John Spencer:** Conceptualization (supporting); writing – review and editing (supporting). **Michael Thompson:** Conceptualization (equal); writing – review and editing (supporting). **Eric Nordberg:** Conceptualization (equal); methodology (equal); writing – original draft (equal).

KEYWORDS

chelonian, freshwater turtle, tortoise

ACKNOWLEDGEMENTS

We acknowledge the Peramangk people as the traditional custodians of the land on which we held the 55th Annual General Meeting of the Australian Society of Herpetologists at Mylor in South Australia.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Deborah S. Bower[1]
Donald T. McKnight[2]
Kyra Sullivan[1]
Stewart L. Macdonald[3]
Arthur Georges[4]
Simon Clulow[5]
Rupert Mathwin[6]
Marilyn J. Connell[7]
Holly V. Nelson[8]
Anthony Santoro[9]
Bethany Nordstrom[10]
James U. Van Dyke[2]
Rosie A. Kidman[1]
Louise M. Streeting[1]
Martin L. Dillon[11]
Ricky-John Spencer[12]
Michael B. Thompson[8]
Eric J. Nordberg[1]

[1]*School of Environmental and Rural Science, University of New England, Armidale, New South Wales, Australia*
[2]*Centre for Freshwater Ecosystems, Department of Environment and Genetics, School of Agriculture, Biomedicine and Environment, La Trobe University Wodonga Campus, Wodonga, Victoria, Australia*
[3]*CSIRO Health & Biosecurity, Townsville, Queensland, Australia*
[4]*Institute for Applied Ecology, University of Canberra, Canberra, Australian Capital Territory, Australia*
[5]*Centre for Conservation Ecology and Genomics, Institute for Applied Ecology, University of Canberra, Bruce, Australian Capital Territory, Australia*
[6]*Global Ecology (Partuyarta Ngadluku Wardli Kuu), College of Science and Engineering, Flinders University, Adelaide, South Australia, Australia*
[7]*Tiaro & District Landcare Group Inc, Tiaro, Queensland, Australia*
[8]*School of Life and Environmental Sciences, The University of Sydney, Sydney, New South Wales, Australia*
[9]*Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University, Perth, Western Australia, Australia*
[10]*School of Biological Sciences, The University of Western Australia, Crawley, Western Australia, Australia*
[11]*Northern Tablelands Local Land Services, Armidale, New South Wales, Australia*

[12]*School of Science, Western Sydney University, Penrith, New South Wales, Australia*

Correspondence
Deborah S. Bower, School of Environmental and Rural Science, University of New England, Armidale, NSW 2351, Australia.
Email: dbower3@une.edu.au

ORCID

Deborah S. Bower https://orcid.org/0000-0003-0188-3290
Donald T. McKnight https://orcid.org/0000-0001-8543-098X
Arthur Georges https://orcid.org/0000-0003-2428-0361
Rupert Mathwin https://orcid.org/0000-0001-9316-9451
James U. Van Dyke https://orcid.org/0000-0002-3933-111X
Rosie A. Kidman https://orcid.org/0000-0001-7115-2691
Louise M. Streeting https://orcid.org/0000-0002-1663-0010
Eric J. Nordberg https://orcid.org/0000-0002-1333-622X

TWITTER

Deborah S. Bower @deborah_bower

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